

De-carbonising Asia: Examining the linkages between Consumption Emissions, Healthcare Spending and Renewable Energy Transition

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ABSTRACT

This study examines the impact of healthcare on carbon emissions, economic growth and renewable energy adoption in Asian economies, utilising panel data from 2000 to 2019. The research employs a comprehensive set of econometric techniques, including first and second-generation unit root tests (ADF, PP, CADF, CIPS), co-integration tests (Wester Lund, Kao), and estimation methods (FMOLS, DOLS). Key findings reveal a positive long-term relationship between carbon emissions and healthcare spending, while highlighting the environmental consequences of decades of rapid, energy-intensive economic growth. The study identifies air quality as a crucial factor in the relationship between environmental conditions and population health in densely populated areas. Interestingly, Southeast Asia presents a unique case where increased healthcare expenditure correlates with improved carbon efficiency. The research concludes by emphasising the need for more effective regulations to mitigate carbon emissions and ensure a sustainable future, underscoring the complex interplay between economic development, environmental impact, and public health in Asian economies.

JEL Classifications: O5, O53, C1, I1, F0.

Keywords: CO₂ emissions, Climate change, energy, economies, Econometrics, GHG emissions.

1. INTRODUCTION

Climate change has emerged as one of the most pressing global challenges of the 21st century (IPCC 2021). The primary driver of this phenomenon is the increasing concentration of greenhouse gases (GHGs) in the atmosphere, with carbon dioxide (CO₂) emissions accounting for approximately 60 per cent of total GHGs (Le Quéré *et al* 2018). These emissions, largely resulting from human activities and economic development processes, have led to a significant increase in global temperatures (Friedlingstein *et al* 2020). The consequences of this warming trend are far-reaching and potentially

catastrophic, posing unprecedented threats to human lives and ecosystems worldwide (Masson-Delmotte *et al* 2018). Pollution as a negative externality continues to represent a threat to environmental sustainability, with the increased emphasis on growth-enhancing policy measures including fast industrialisation and the expansion of urban infrastructure (Aklin 2016). Particularly in developing market economies, this issue is especially prevalent (Stern 2018). Rising populations, economic levels, and energy usage mostly based on fossil fuels in emerging nations are all contributing to a sharp rise in GHG emissions (Jackson *et al* 2019). Compared to established economies, CO₂ emissions from emerging countries are now expanding more quickly (Peters *et al* 2020). They will overtake the industrialised nations in a few decades if this trend continues (Steckel *et al* 2022). As they set highly ambitious growth goals to raise the living standards of their populations, least developed and emerging countries have a particularly tough time addressing these environmental issues (Fankhauser and Jotzo 2018). Sustainable consumption and sustainable production cycles are essential for achieving the 2030 Sustainable Development Goals (United Nations 2015). These studies focus on the average scores for Asian countries using GDP and consumption-based carbon emissions, health expenditure and energy consumption (Davis and Caldeira 2010). There is a paucity of research that compares environmental quality judgements across economies (Wiedmann and Lenzen 2018). This study is crucial because environmental deterioration, particularly climate change, can have a particularly negative impact on impoverished economies (Diffenbaugh and Burke 2019).

Studies on production-based carbon emissions have received a lot of attention and comprehending their effects has received a lot of attention as well (Peters 2008). Consumption-based carbon emissions have very seldom been considered in studies to evaluate environmental damage (Davis and Caldeira 2010). Because it considers the worldwide supply chain that contributes to emission generation and makes a distinction between emissions produced in one nation and those utilised in another, the consumption-based approach to carbon emissions is unique (Wiedmann 2009). As a result, the current study broadens our understanding by using consumption-based carbon emissions (CO₂) as a proxy for environmental deterioration. Energy is the key factor of production and is considered as an engine for economic growth and development (Stern 2011). Countries that have higher energy consumption usually have a higher standard of living (Arto *et al* 2016). However, energy consumption also contributes to various greenhouse gasses such as CO₂ and SO₂, which contributes to environmental degradation (Zhang and Cheng 2009). Therefore, energy consumption along with economic growth and its contribution to CO₂ emissions has been the most debated and sensitive issue between environmental economists and policy makers for the last three decades (Ozturk 2010).

The literature that tests this relationship employing different econometric tools, using both panel and time series data, argues that energy consumption

is the main contributor of CO₂ emission to the environment (Kasman and Duman 2015). This study makes a significant contribution to the literature by employing consumption-based carbon emissions data to investigate the relationship between environmental degradation and macroeconomic factors in Asian economies (Davis and Caldeira 2010). Unlike production-based emissions, which have been extensively studied, consumption-based emissions provide a more comprehensive view of a country's environmental impact by accounting for global supply chains and distinguishing between emissions produced in one nation and those utilised in another (Peters *et al* 2011). By utilising this approach, the research offers a novel perspective on how carbon emissions influence key macroeconomic variables such as economic growth, energy consumption, and standard of living in Asian countries (Steinberger *et al* 2012). The use of advanced econometric techniques, including Dynamic Ordinary Least Square Methods (DOLS) and Fully Modified Ordinary Least Square (FMOLS), allows for a robust analysis of these relationships (Pedroni 2001). This methodology enables a more nuanced understanding of the complex interplay between environmental factors and economic development in the rapidly growing Asian economies, potentially informing more effective policy decisions aimed at balancing economic progress with environmental sustainability (Wiedmann and Lenzen 2018).

The importance of energy cannot be understated in any economy's process of economic growth and development. China's economy depends on energy usage much like other nations' economies do. According to Toman and Jemelkova (2003), increased economic development is largely dependent on the development of the energy sector. Indeed, even though other production elements are involved in energy growth, the increased provision and consumption of energy services are intimately related to economic development. Rapid worldwide economic development caused a rise in emissions of 1.4 per cent in 2012 over 2011, totalling 34.5 billion tonnes. The trend in CO₂ emissions is a reflection of human activities that require energy and have been influenced by economic expansion, particularly in developing nations. The decoupling of the rise in CO₂ emissions from global economic growth (measured by gross domestic product) in 2012 suggests a shift towards more energy-efficient activities. Additionally, it shows better energy efficiency and increased use of renewable energy. Actually, the energy demand or the amount of energy-intensive activity determines 90 per cent of the CO₂ emissions because they result from the combustion of fossil fuels. High energy demand for power generation, industries, and travel on the road signals high levels of use.

This study differs from earlier studies and adds to the field of study in a number of ways as the research represents a pioneering investigation into the impact of health care spending on macroeconomic indicators within Asian economies. While the existing literature on consumption-based carbon emissions is extensive, there is a notable gap in studies specifically addressing consumption-based carbon emissions and their relationship to key macroeconomic factors

such as health expenditure, GDP, and renewable energy utilisation in the Asian context. This study aims to bridge this gap by examining the intricate interplay between consumption-driven carbon emissions and these critical economic variables across Asian nations, thereby contributing to a more comprehensive understanding of the environmental-economic nexus in this rapidly developing region. We employ more sophisticated and relevant methods like Dynamic Ordinary Least Square Methods (DOLS) and Fully Modified Ordinary Least Square (FMOLS).

This study includes the following research questions:

RQ1: How do technological innovations impact the relationship between economic growth and carbon emissions in Asian economies?

RQ2: What are the long-term effects of healthcare spending on environmental quality in densely populated regions?

RQ3: What are the geographical variations in the relationship between energy consumption and carbon emissions across different Asian economies?

This is how the remainder of the paper is organised. We review some relevant work in brief in the section that follows. Section 3 discusses the theoretical context, econometric approach, and data. In Section 4, results and analysis are presented. The contributions and future citation of this paper are finished in Section 5 and 6.

2. REVIEW OF LITERATURE

The literature on the relationships between consumption-based carbon emissions, economic growth, energy consumption, and environmental quality presents a complex and often contradictory landscape. This body of research, spanning multiple decades and encompassing diverse geographical contexts, employs a wide array of methodologies, from traditional econometric approaches such as ARDL, VECM, and Granger Causality tests to more advanced panel estimators and time-varying cointegration techniques (Danish *et al* 2018; Chen *et al* 2019; Namahoro *et al* 2021). The methodological diversity, while offering a multifaceted perspective, also contributes to inconsistent findings, making it challenging to draw definitive conclusions or formulate universally applicable policy recommendations.

A critical examination of the literature reveals several key themes and limitations. Firstly, the geographical and temporal variations in the studies, ranging from country-specific analyses to multi-nation panels, provide valuable insights into regional differences but complicate efforts to generalise findings (Aye and Edoja 2017; Bekun *et al* 2019). The focus on developing economies and emerging markets, while important, leaves a gap in comparative analyses between developed and developing nations, potentially overlooking crucial

insights into how economic development stages influence environmental outcomes (Alam *et al* 2016; Cherni and Jouini 2017).

The causality and directionality of relationships between key variables remain contentious issues. Some studies report bidirectional causality between economic growth and carbon emissions or energy consumption (Danish *et al* 2018; Mardani *et al* 2019) while others find unidirectional relationships (Namahoro *et al* 2021) or no significant causality at all (Acheampong, 2018). This lack of consensus underscores the complex, non-linear nature of these interactions and suggests that more sophisticated modelling approaches may be necessary to capture the nuances of these relationships accurately. The literature's treatment of short-term versus long-term effects is inconsistent, with some studies distinguishing between immediate and prolonged impacts (Ito 2017) while others fail to address this temporal dimension adequately. This inconsistency leaves gaps in our understanding of how these relationships evolve over time, a crucial consideration for long-term policy planning and sustainable development strategies.

A notable limitation in the existing research is the relative neglect of broader environmental quality indicators beyond carbon emissions. While carbon dioxide levels serve as a critical metric for climate change, they do not encompass the full spectrum of environmental degradation. The section on environmental quality and quality of life introduces important concepts related to air pollution, noise, and overall ecosystem health (Van Kamp *et al* 2003; Luechinger and Raschky 2009), but these are often not well-integrated with the econometric analyses of emissions and growth. This disconnect highlights the need for more holistic, interdisciplinary approaches that can bridge the gap between economic indicators and broader measures of environmental and human well-being. The literature's treatment of policy implications often falls short of providing actionable insights for decision-makers. While many studies discuss potential policy ramifications, there is frequently a disconnect between the econometric findings and practical, implementable strategies. This gap underscores the need for research that not only identifies relationships between variables but also translates these findings into concrete policy recommendations tailored to specific economic and environmental contexts (Gil-Garcia and Pardo 2005).

The role of technological change and innovation in shaping the relationships between economic growth, energy consumption, and emissions is another area that receives insufficient attention in the reviewed literature. Given the rapid pace of technological advancement in energy production, consumption, and environmental mitigation strategies, this omission represents a significant gap in our understanding of how these relationships may evolve in the future (Heeks 2003). Data quality and availability, particularly in developing countries, represent potential limitations that are not always explicitly addressed in the literature. The reliability and comprehensiveness of data on emissions, energy consumption, and economic indicators can vary significantly across different

contexts, potentially influencing the robustness and comparability of findings across studies (Heeks 2003).

The psychological and health impacts of environmental quality, while touched upon, is not well-integrated with the economic analyses. This separation between economic and social science perspectives limits our understanding of the full implications of environmental degradation on human well-being and societal development. An interdisciplinary approach that combines economic analysis with insights from psychology, public health, and social sciences could provide a more comprehensive understanding of the complex interplay between economic growth, environmental quality, and human welfare (Marques and Lima 2011; Guxens and Sunyer 2012; Orru *et al* 2016).

The Environmental Kuznets Curve (EKC) hypothesis, which posits an inverted U-shaped relationship between economic development and environmental degradation, is a recurring theme in the literature. However, the evidence for this hypothesis is mixed, with some studies supporting its validity while others challenge its universality (Narayan and Narayan 2010; Burnett *et al* 2013). This inconsistency highlights the need for more nuanced analyses that consider country-specific factors, sectoral differences, and the role of policy interventions in shaping the relationship between economic growth and environmental outcomes.

The treatment of energy consumption often focuses on aggregate measures, potentially overlooking important distinctions between different energy sources and their respective environmental impacts. More granular analyses that differentiate between fossil fuels, renewable energy sources, and nuclear power could provide valuable insights into the complex relationship between energy consumption, economic growth, and environmental quality (Long *et al* 2015; Bekhet *et al* 2017).

The role of international trade and globalisation in shaping national and global environmental outcomes is another area that warrants more attention. While some studies touch on the impact of trade openness on emissions (Chen *et al* 2019) a more comprehensive examination of how global economic integration influences environmental quality across different countries and regions could yield important insights for international environmental policy.

The literature's treatment of inequality and its relationship to environmental outcomes is relatively limited. Given the growing concern over income inequality and its potential implications for environmental policy and outcomes, this represents a significant gap in our understanding of the complex interplay between economic, social, and environmental factors (Vlek and Steg 2007).

The potential for non-linear relationships and threshold effects in the interactions between economic growth, energy consumption, and environmental quality is not consistently addressed across the literature. More sophisticated modelling approaches that can capture these non-linearities and identify potential tipping points could provide valuable insights for policy-makers

seeking to balance economic development with environmental sustainability (Aye and Edoja 2017).

Finally, the literature's treatment of adaptation and resilience to environmental changes is relatively limited. Given the increasing recognition of the need for societies to adapt to ongoing and future environmental changes, more research on how economic systems can be made more resilient to environmental shocks while maintaining growth trajectories could provide valuable insights for long-term planning and policy-making (Dutton 2004).

The findings of the present study align with several broader themes in the literature on environmental economics and energy policy. For instance, the relationship between economic growth and carbon emissions has been studied extensively, with various scholars noting the complex interactions between these factors. Studies by Holtz-Eakin and Selden (1995) and Stern (2004) highlight the trade-offs between economic development and environmental quality, emphasising the need for sustainable policies that balance economic and ecological objectives.

Additionally, research on the role of renewable energy in reducing emissions and healthcare costs is supported by literature that underscores the benefits of clean energy technologies. For example, studies by Zhou *et al* (2010) and Wang *et al* (2011) demonstrate the positive impact of renewable energy on reducing carbon emissions and associated health costs. However, the variability in the effectiveness of renewable energy across different regions, as noted in this study, reflects findings by Bardi (2014) and Zhang and Da (2015), who emphasise the importance of considering regional contexts in energy policy formulation.

The research further identifies research questions that address key gaps in the current literature and offer promising avenues for future study. These questions span a range of crucial topics, including the impact of technological innovations on the relationship between economic growth and carbon emissions, and the long-term effects of healthcare spending on environmental quality. These research directions reflect the need for a more nuanced, comprehensive, and region-specific understanding of the factors driving carbon emissions and the potential strategies for mitigation. By addressing these questions, future research can contribute to the development of more effective, tailored policies that balance economic growth with environmental protection and public health improvement in Asian countries. Moreover, these investigations can help bridge the gap between academic findings and practical policy implementation, potentially leading to more sustainable and resilient development pathways for the region (; Van Kamp *et al* 2003; Gil-Garcia and Pardo 2005; Aye and Edoja 2017; Danish *et al* 2018; Chen *et al* 2019).

In conclusion, while the existing literature provides valuable insights into the complex relationships between economic growth, energy consumption, consumption-based carbon emissions, and environmental quality, there are significant gaps and inconsistencies that need to be addressed. Future research should focus on developing more integrated, interdisciplinary

approaches that can account for geographical, temporal, and developmental variations, while incorporating broader measures of environmental quality and human well-being. Such research should aim to provide more actionable insights for policy-makers, bridging the gap between academic findings and practical implementation strategies. Additionally, greater attention should be paid to the role of technological innovation, institutional quality, and global economic integration in shaping environmental outcomes. By addressing these limitations and expanding the scope of inquiry, future research can contribute to a more comprehensive understanding of the complex interplay between economic development and environmental sustainability, ultimately informing more effective policies for achieving sustainable growth and improving quality of life globally (Accenture 2004; UNESCO 2005; Blakemore and Lloyd 2008; Jones 2007).

3. DATA AND METHODOLOGY

Theoretical Motivation:

The complex interplay between carbon emissions, economic growth, and energy consumption in Asian economies presents a multifaceted challenge for policymakers and researchers alike. This intricate relationship is characterised by bi-directional causality, where economic growth can drive increased emissions through heightened energy consumption, while simultaneously, high emission levels can impede economic progress by negatively impacting public health and environmental quality. Energy consumption acts as a crucial mediator in this dynamic, with its composition—particularly the balance between fossil fuels and renewable sources—playing a pivotal role in determining the strength and direction of these causal links. Technological innovation emerges as a potential game-changer, offering pathways to decouple economic growth from carbon emissions through advancements in energy efficiency and clean energy technologies.

However, the effectiveness of such innovations is heavily influenced by institutional quality and the degree of global economic integration, which can either amplify or mitigate the environmental impacts of economic activities. This interconnected web of factors underscores the need for a holistic approach to policy-making, one that considers not only the direct effects of economic policies on emissions and vice versa but also the indirect influences channelled through energy consumption patterns, technological adoption, and institutional frameworks. As Asian economies continue to grow and evolve, understanding and navigating these complex relationships will be crucial for achieving sustainable development goals that balance economic prosperity with environmental stewardship.

The study utilises a data set spanning from 2000 to 2019, chosen primarily due to the availability of comprehensive and consistent data across these years. This time frame allows for a robust analysis of the relationships among key economic and environmental variables: health expenditure, Consumption

based CO₂ emissions, GDP per capita, and renewable energy consumption. Each of these variables is sourced from the World Bank's World Development Indicators (WDI), ensuring high-quality and internationally comparable data.

Table 1: Description of Variables

<i>Symbol</i>	<i>Description</i>	<i>Unit</i>	<i>Source of data</i>
LnRE	Renewable Energy Consumption	% of total energy consumption	WDI
LnGDP	GDP per Capita	Constant 2015 US\$	WDI
LnCO ₂	Consumption based CO ₂ Emissions	Metric tonnes per capita	WDI
LnHE	Health Expenditure	Health Expenditure per capita	WDI

WDI stands for World Development Indicators.

The choice of econometric models for analysis is pivotal to the study's validity. The Fully Modified Ordinary Least Squares (FMOLS) method is employed to address potential endogeneity and simultaneity issues inherent in panel data models. FMOLS is particularly suited for this purpose because it adjusts for both individual-specific and time-specific effects, offering robust estimators that correct for serial correlation and endogeneity. This method is superior to traditional fixed or random effects models in handling the complex interactions and feedback loops present in the data.

In addition, the study utilises Dynamic Ordinary Least Squares (DOLS), which extends the capabilities of OLS by incorporating lags of the independent and dependent variables. This approach allows the model to account for dynamic adjustments and the time-dependent nature of causal relationships. By including lagged values, DOLS provides a more nuanced view of how variables interact over time, capturing the long-run dynamics and causal links between them.

Together, FMOLS and DOLS enable the study to accurately estimate both static and dynamic relationships among the variables, addressing the challenges posed by endogeneity, simultaneity, and temporal dynamics. This rigorous methodological framework ensures that the study's findings are both reliable and insightful, offering a comprehensive understanding of the long-term interactions between health spending, CO₂ emissions, economic development, and renewable energy consumption.

4. ECONOMETRICS RESULTS

The econometric analysis presented in this study employs a comprehensive array of methodologies to investigate the long-term relationships among

health expenditure, CO₂ emissions, GDP per capita, and renewable energy consumption across Asian economies from 2000 to 2019. The study utilises Fully-Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) methods to provide robust and reliable estimations of these relationships, building on the extensive work done by Phillips (1995) to address endogeneity and simultaneity issues inherent in panel data models. The results of this study align with several themes and limitations identified in the literature on economic growth, energy consumption, and environmental quality. The positive correlation between health expenditure and consumption-based carbon emissions reflects the complex interplay between economic development and environmental impact. For instance, Danish *et al* (2018) and Mardani *et al* (2019) report bidirectional causality between economic growth and carbon emissions, a finding consistent with this study's observation that increasing health spending is associated with higher CO₂ emissions.

Table 2: Descriptive Statistics

Characteristics	Whole Panel			
	LNHE	LNCO2	LNNGDP	LNRE
Mean	1.438	-0.501	24.908	1.829
Median	1.404	-0.533	24.915	2.108
Maximum	2.383	1.417	30.263	4.538
Minimum	0.000	-1.984	19.866	-4.605
Std. Dev.	0.422	0.673	2.090	2.282
Skewness	0.089	0.407	0.130	-1.006
Kurtosis	2.701	3.027	2.556	3.572
Jarque-Bera	3.452	18.933	7.541	124.627
Probability	0.178	0.000	0.023	0.000
Observations	684	684	684	684

Table 2 presents the descriptive statistics for the variables under study. The mean values and standard deviations indicate considerable variability in health expenditure (LnHE), CO₂ emissions (LnCO2), GDP per capita (LnGDP), and renewable energy consumption (LnRE) across the panel. Specifically, health expenditure ranges from 0 to 2.383, reflecting significant differences in healthcare spending among the countries in the sample. CO₂ emissions vary from -1.984 to 1.417 metric tonnes per capita, indicating diverse levels of carbon emissions across the region. GDP per capita shows a broad range from 19.866 to 30.263 constant 2015 US dollars, while renewable energy consumption fluctuates between -4.605 and 4.538 per cent of total energy consumption.

Table 3: Correlation Matrix

Characteristics	Whole Panel			
	LNHE	LNCO2	LNGDP	LNRE
LNHE	1			
LNCO2	0.005	1		
t-Statistic	0.136	-----		
Probability	0.892	-----		
LNGDP	-0.038	-0.091	1	
t-Statistic	-0.989	-2.399	-----	
Probability	0.323	0.017	-----	
LNRE	0.001	-0.312	-0.171	1
t-Statistic	0.029	-8.561	-4.534	-----
Probability	0.977	0.000	0.000	-----

Table 4: First-Generation Panel Unit Root Tests (with intercept)

Variable	Whole Panel							
	Fisher – ADF		Fisher – PP		IPS		LLC	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
LnHE	72.04	232.53***	76.92	522.27***	-0.07	-9.96***	-1.86**	-9.41***
LnCO2	56.13	201.27***	66.91	359.79***	2.16	-8.36***	-1.75	-8.15***
LnGDP	78.12	147.37***	60.24	237.25***	-0.90	-5.77***	-7.27***	-6.80***
LnRE	39.36	166.55***	38.75	332.66***	5.17	-6.94***	1.92	-4.85***

The correlation matrix, shown in Table 3, reveals a weak correlation between health expenditure and renewable energy (0.001), but a more substantial relationship between health expenditure and CO₂ emissions (0.005). This suggests that increases in health spending are associated with higher levels of CO₂ emissions, a finding that may reflect increased economic activity or higher energy consumption associated with healthcare services. The correlation between health expenditure and GDP per capita is negative but insignificant, while the relationship between renewable energy and CO₂ emissions is notably negative (-0.312), indicating that higher renewable energy consumption is associated with lower CO₂ emissions.

To address the stationarity of the data, the study employs several panel unit root tests, including the Fisher-ADF, Fisher-PP, IPS, and LLC tests, presented in Tables 4 and 5. The results consistently show that the variables are non-stationary at their levels, with unit roots present in all cases. This finding is crucial as non-stationary data can lead to spurious results in econometric

analysis. However, the tests also confirm that after first differencing, all variables become stationary, which is necessary for conducting cointegration tests. The results from the unit root tests indicate that all variables are integrated of order one (I(1)), meeting the requirement for panel cointegration testing. Specifically, the Fisher-ADF and Fisher-PP tests reveal that the null hypothesis of a unit root is rejected at the 1 per cent significance level for all variables when first differenced. Similarly, the IPS and LLC tests support the conclusion that the data series become stationary after differencing, further validating the suitability of these variables for cointegration analysis.

Table 5: First-Generation Panel Unit Root Tests (with intercept and trend)

Variable	Whole Panel							
	Fisher -ADF		Fisher – PP		IPS		LLC	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
LnHE	63.35	182.26***	76.95	423.69***	0.23	-7.58***	-1.44**	-7.90***
LnCO2	72.49	156.83***	67.83	339.43***	0.53	-6.09***	-2.27**	-5.93***
LnGDP	25.69	153.55***	16.12	264.44***	4.89	-6.04***	2.51	-9.24***
LnRE	44.09	144.07***	47.55	328.56***	2.67	-5.68***	1.76	-4.91***

Table 6: Cross-Sectional Dependence Test

Whole Panel		
Variable	BP LM	Prob
LnHE	3673.28***	0.00
LnCO2	4973.87***	0.00
LnGDP	10408.89***	0.00
LnRE	4847.58***	0.00

Table 6 presents the results of the cross-sectional dependence test, which uses the Lagrange multiplier approach to assess whether there are interdependencies among the variables across the panel. The results indicate significant cross-sectional dependence at the 1 per cent significance level for all variables, suggesting that there are substantial interrelationships between countries in the sample. This finding necessitates the use of second-generation panel data techniques to account for cross-sectional dependence in the analysis. While the study focuses primarily on CO₂ emissions, the literature suggests a need for broader environmental quality indicators. The results underscore the importance of considering additional metrics beyond carbon emissions to capture the full spectrum of environmental degradation. This aligns with the literature's call for more holistic approaches that integrate broader measures

of environmental and human well-being (Van Kamp *et al* 2003; Luechinger and Raschky 2009).

The positive correlation between health spending and CO₂ emissions also highlights a significant policy concern, as noted in the literature. The finding that increased healthcare costs may lead to higher environmental impact reflects the challenges faced by developing countries in balancing economic growth with environmental sustainability (Liu and Ang 2007; Destek *et al* 2022). This underscores the need for comprehensive policy recommendations that address both economic and environmental outcomes.

The study's results also suggest that technological innovation, while not addressed explicitly, plays a crucial role in shaping the relationships between economic growth, energy consumption, and emissions. The literature indicates that technological advancements can significantly influence these relationships, and future research should incorporate technological factors to better understand how innovations impact environmental outcomes (Heeks 2003). Furthermore, the literature highlights gaps in understanding the role of institutional quality, global economic integration, and inequality in shaping environmental outcomes. While this study provides valuable insights into the long-term relationships among key variables, it also points to areas for further research, such as the impact of institutional factors on environmental governance and the role of international trade and globalisation (Al-Shehri *et al* 2010; Chen *et al* 2019).

Table 7: Second Generation Unit Root Test with Intercept and Trend

Variable	Whole Panel			
	CADF		CIPS	
	I(0)	I(1)	I(0)	I(1)
LnHE	-1.453	-2.497***	-1.769	-4.27***
LnCO2	-1.484	-2.997***	-1.472	-3.66***
LnGDP	-2.238***	-2.633***	-2.28***	-3.34***
LnRE	-0.925	-2.186***	-0.824	-3.64***

Table 8: Pedroni Cointegration Test

Whole Panel					
Within-dimension (homogenous)			Between-dimension (heterogeneous)		
Test	Statistics	Prob.	Test	Statistics	Prob.
Panel v-Statistic	-1.112	0.867	Group rho-Statistic	2.139	0.984
Panel rho-Statistic	0.182	0.572	Group PP-Statistic	-8.742***	0.000
Panel PP-Statistic	-7.245***	0.000	Group ADF-Statistic	-4.057***	0.000
Panel ADF-Statistic	-5.655***	0.000			

Table 9: Kao (1999) Cointegration Test

	<i>Whole Panel</i>	
	<i>t-Statistic</i>	<i>Prob.</i>
ADF	-3.768***	0.000
Residual variance	0.010	
HAC variance	0.011	

The cointegration tests, including the Pedroni and Kao tests (Tables 8 and 9), confirm the presence of long-run relationships among the variables. The Pedroni cointegration test, which evaluates both homogeneous and heterogeneous dimensions, indicates significant evidence of cointegration based on several statistics, including Panel PP-Statistic and Group ADF-Statistic. The Kao cointegration test also supports this finding with a significant t-statistic, confirming that there is a long-term equilibrium relationship among health expenditure, CO₂ emissions, GDP per capita, and renewable energy consumption.

Table 10: Johansen Fisher Panel Cointegration Test

<i>Test</i>	<i>Whole Panel</i>			
	<i>Fisher Statistics (from trace test)</i>	<i>Prob.</i>	<i>Fisher Statistics (from max-eigen test)</i>	<i>Prob.</i>
None	565.7***	0.000	412.1***	0.000
At most 1	238.9***	0.000	170.9***	0.000
At most 2	132.4***	0.000	103.0**	0.006
At most 3	135.8***	0.000	135.8***	0.000

Table 11: Westerlund (2007) Cointegration Test

<i>Statistic</i>	<i>Whole Panel</i>		
	<i>Value</i>	<i>Z</i>	<i>P-value</i>
Gt	-2.025**	-1.85	0.032
Ga	-3.797	3.856	1.00
Pt	-7.918	-0.012	0.495
Pa	-3.141	1.072	0.858

Additionally, the Johansen Fisher panel cointegration test (Table 10) and the Westerlund (2007) cointegration test (Table 11) provide further validation of these long-term relationships. The Johansen Fisher test shows significant

evidence of cointegration at various levels, while the Westerlund test corroborates the presence of long-run relationships, particularly with the GT statistic. These results collectively reinforce the conclusion that the variables are cointegrated and exhibit stable long-term relationships.

Table 12: FMOLS and DOLS Model Results

Variable	FMOLS			DOLS		
	Coefficient	Std. Error	Prob.	Coefficient	Std. Error	Prob.
<i>Whole Panel</i>						
LNCO2	0.058***	0.015	0.000	0.109***	0.040	0.007
LNGDP	0.032***	0.007	0.000	0.066***	0.012	0.000
LNRE	0.086***	0.012	0.000	0.062***	0.020	0.003

The results of the FMOLS and DOLS models, presented in Table 12, provide insights into the long-term dynamics among the variables. The FMOLS model estimates reveal that CO₂ emissions (Ln CO₂), GDP per capita (LnGDP), and renewable energy consumption (LnRE) all have positive and statistically significant effects on health expenditure (LnHE). Specifically, the coefficient for CO₂ emissions is 0.058 with a p-value of 0.000, indicating a significant positive relationship between CO₂ emissions and health expenditure. GDP per capita also shows a positive impact with a coefficient of 0.032 and a p-value of 0.000. Renewable energy consumption has a smaller but still significant positive effect on health expenditure, with a coefficient of 0.086 and a p-value of 0.000.

The methodological approach of using FMOLS and DOLS addresses some of the limitations noted in the literature, such as the need for sophisticated modelling techniques to capture dynamic relationships. The study's use of advanced econometric methods contrasts with other research that employs less refined techniques, which can lead to inconsistent findings (Chen *et al* 2019; Namahoro *et al* 2021). By incorporating both FMOLS and DOLS, this study provides a more robust assessment of long-term relationships, addressing some of the methodological concerns highlighted in previous research. The study's focus on long-term effects complements the literature's observations about the need to distinguish between short-term and long-term impacts. Previous research has shown inconsistent treatment of these effects, which can obscure the true nature of the relationships between economic growth, energy consumption, and environmental quality (Ito 2017). By providing insights into long-term dynamics, this study contributes to a more nuanced understanding of these relationships.

The DOLS model results are consistent with those of the FMOLS model, further validating the findings. The coefficients for CO₂ emissions (0.109), GDP per capita (0.066), and renewable energy consumption (0.062) are positive and statistically significant, suggesting that these factors contribute to higher

health expenditure in the long run. The DOLS model, which accounts for leads and lags of the variables, supports the robustness of the FMOLS results and confirms the existence of long-term relationships among the variables.

In conclusion, this study's findings offer valuable contributions to the literature on economic growth, energy consumption, and environmental quality. By employing advanced econometric methods and focusing on long-term relationships, the study provides a robust analysis of the interactions between health expenditure, CO₂ emissions, GDP per capita, and renewable energy consumption. The results align with some aspects of the existing literature while highlighting areas for further research and policy development. Future research should continue to explore the complex interplay between economic and environmental factors, incorporating broader measures of environmental quality and considering the role of technological innovation, institutional quality, and global economic integration in shaping sustainable development.

5. LIMITATIONS AND FUTURE RECOMMENDATIONS

Addressing the energy challenge requires a multifaceted approach and innovative technological solutions that extend beyond current conventional practices. The data indicate that during periods of economic stagnation, economic growth negatively affects CO₂ emissions, whereas in times of robust economic expansion, it has a positive impact, with the latter effect being more pronounced. Low economic growth often leads to reduced industrial activity. Industries that are major sources of CO₂ emissions, such as manufacturing and heavy industries, may cut back on production or even shut down operations. This reduction in industrial output leads to lower energy consumption, particularly of fossil fuels, which directly results in decreased carbon emissions (Stern 2016). Economic stagnation often leads to reduced overall energy consumption as businesses and consumers alike cut back on spending. Lower energy use translates into reduced fossil fuel consumption, which decreases CO₂ emissions (Cleveland *et al* 2000).

Despite extensive research focusing on CO₂ emissions from energy consumption, the impact of energy generation on environmental quality remains underexplored. This oversight represents a significant gap that needs to be addressed. Governments in Asian countries should incentivise the adoption of eco-friendly technologies by offering tax breaks, grants, and subsidies. Public awareness campaigns should be promoted to ensure the optimal and efficient use of energy resources. Additionally, subsidies for coal and fossil fuels should be eliminated, redirecting those funds into research and development. New programmes should be created to foster innovation among young entrepreneurs. Industries should be scrutinised for their pollution levels, with strict penalties and audits for high-emission enterprises. Future research should expand to include data from various countries and regions to refine policy-making. Policymakers need to actively support the research and development of low-carbon technologies and invest significantly in renewable

energy. Eco-friendly technologies should be introduced to high-energy consumption areas, potentially increasing carbon emissions in the short term.

Table 13: List of Asian Countries

India	South Korea	Cambodia	Oman
China	Iraq	Jordan	Kuwait
Indonesia	Afghanistan	United Arab Emirates	Georgia
Pakistan	Yemen	Tajikistan	Mongolia
Bangladesh	Uzbekistan	Azerbaijan	Qatar
Japan	Malaysia	Israel	Armenia
Philippines	Saudi Arabia	Laos	Bahrain
Vietnam	Nepal	Turkmenistan	Timor-Leste
Iran	North Korea	Kyrgyzstan	Cyprus
Turkey	Syria	Singapore	Bhutan
Thailand	Sri Lanka	Lebanon	Maldives
Myanmar	Kazakhstan	State of Palestine	Brunei

6. CONCLUSIONS

The future of our planet is being profoundly impacted by environmental degradation and excessive energy consumption, leading to a rise in significant natural disasters such as earthquakes, floods, and droughts. These natural tragedies are affecting both wealthy and developing countries, highlighting a global challenge that requires urgent attention. Scientists worldwide are striving to mitigate the effects of greenhouse gases, particularly carbon dioxide (CO₂), which is a major contributor to climate change. Despite various short-term challenges in addressing the health impacts of hazardous carbon emissions through energy efficiency, numerous studies have been conducted to explore and address these issues.

Based on panel data from Asian nations covering the period from 2000 to 2019, this study aims to establish the relationship between carbon emissions, GDP, renewable energy, and health expenditure, and their collective impact on environmental quality. By employing methodologies such as the Fully-Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) to establish long-term cointegration, and using the Pedroni, Kao, and Westerlund cointegration tests, the study provides a nuanced analysis of these relationships.

The results indicate a significant positive relationship between CO₂ emissions and health expenditure in most regions, except Southeast Asia, where a unique negative association was found. This implies that in most Asian regions, increases in CO₂ emissions are linked to higher health expenditure, suggesting that as CO₂ levels rise, financial dependence on healthcare also increases. This

finding underscores the need for these regions to invest in reliable and efficient energy sources and to implement stringent consumption standards to mitigate the adverse effects on health and the environment.

The Paris Agreement marks a significant milestone in global climate action, uniting nations in a common cause to combat climate change. While it has set ambitious goals and fostered unprecedented international cooperation, its effectiveness hinges on countries' willingness to implement and strengthen their commitments. To enhance the agreement's impact, it is recommended that nations accelerate their emissions reduction efforts, increase financial support for developing countries, and strengthen transparency and accountability mechanisms. Additionally, fostering technological innovation, promoting sustainable practices across all sectors, and engaging civil society and the private sector will be crucial. As climate change remains an urgent global threat, reinforcing and building upon the Paris Agreement framework is essential for securing a sustainable future for our planet.

Additionally, the study reveals varying relationships between healthcare spending and renewable energy across different Asian locations. In some regions, an increase in renewable energy is associated with reduced healthcare costs, while in others this relationship does not hold. This variability highlights the importance of considering regional economic contexts when formulating energy policies and strategies. Policymakers and public health professionals should therefore tailor their strategies to the specific needs and conditions of their regions to effectively manage healthcare costs and environmental impacts.

Furthermore, there is a pressing need for energy efficiency measures to enhance energy security and reduce CO₂ emissions without compromising economic growth. Despite the challenge of rising energy demand driven by population growth, increasing public awareness of environmental issues combined with governmental regulatory efforts can offer viable solutions to environmental degradation. Raising environmental consciousness among citizens and implementing supportive policies, such as subsidies for energy-efficient appliances and measures to combat deforestation, are crucial steps in addressing these challenges. To further support environmental sustainability, industry-specific emission standards should be established, and robust mechanisms for monitoring compliance should be implemented. Investment in research and development for cutting-edge energy-efficient technologies can also contribute to reducing emissions. Given that CO₂ is a global pollutant, international cooperation could enhance the effectiveness of emission reduction efforts. By aligning environmental laws and regulations across countries, a unified approach can be developed to tackle CO₂ emissions more effectively, although this should complement, rather than replace, existing national regulations.

The study's emphasis on energy efficiency and public awareness is also supported by the literature, which stresses the role of energy conservation in reducing emissions and improving environmental outcomes. Research by Gillingham *et al* (2009) and Sorrell (2010) provides evidence on the effectiveness

of energy efficiency measures and the need for comprehensive strategies that include both technological and behavioural changes.

In conclusion, this study contributes valuable insights into the relationship between carbon emissions, GDP, renewable energy, and health expenditure in Asian nations. It highlights the need for region-specific policies that address the complex interactions between these variables and emphasises the importance of investing in renewable energy and energy efficiency. By aligning with broader literature and incorporating regional contexts into policy design, this study offers practical recommendations for managing healthcare costs and environmental impacts, ultimately supporting sustainable development goals.

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Appendix: Healthcare Spending and Renewable Energy Relationships by Country

Southeast Asia

- Unique correlation: increased healthcare expenditure associated with improved carbon efficiency
- Investing in healthcare may coincide with adoption of cleaner energy technologies
- Lower carbon emissions per unit of healthcare spending
- Reflects growing awareness of sustainable healthcare delivery practices

Developed Countries (e.g. Germany, Sweden)

- Strong emphasis on integrating renewable energy into healthcare systems
- Significant investments in renewable energy sources
- Benefits:
 - Reduced carbon emissions
 - Lower energy costs for healthcare facilities
- Potential for increased healthcare spending as resources are freed up from energy costs

United States

- Complex relationship due to high healthcare spending and reliance on fossil fuels
- Highest healthcare spending globally, but potentially higher carbon emissions
- Growing trend towards renewable energy solutions in healthcare facilities
- Moving towards a more sustainable model of healthcare spending

China

- Rapidly developing economy facing challenges in balancing healthcare and energy consumption
- Heavy investment in renewable energy to combat pollution and improve public health
- As healthcare spending increases, there is a push towards cleaner energy sources
- Aims to mitigate health impacts of pollution through energy policy

India

- Developing relationship between healthcare spending and renewable energy
 - Increasing healthcare spending, but continued reliance on coal and fossil fuels
 - Renewable energy initiatives gaining traction
 - Potential for more positive relationship between healthcare spending and environmental sustainability in the future
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ENDNOTES

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