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Innovating for a Greener Future: Assessing the Impact of Renewable Energy, Resource Efficiency, and Technology on CO_2 Emission Reduction

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ABSTRACT

This paper explores how CO_2 is emitted in 30 developing Asian economies. Such countries differ in terms of income levels such as low, middle, and high income and the years between 1990-2022 are included in the study. It employs a powerful econometric model in which both the System Generalize Method of Moments (GMM) is used to overcome dynamic endogeneity and thoughtfully Two-Stage Least Squares (2SLS) to overcome potential reverse causality. This integrated methodology serves well to investigate the impacts of the renewable energy use, availability of natural resources and technological innovation on the level of emission.

These findings of study demonstrate a complex dynamic. There is presently a positive relationship between technological innovation and the rise in emissions, which can be attributed to the fact that technology is used to streamline the industrialization process that uses fossil fuels on a large scale. On the contrary, renewable energy and natural resources also contribute to the decrease of CO_2 emission. One of the biggest revelations is that production-oriented industrialization, particularly, after the initiation of China in the WTO in 2001, has contributed greatly to the growth in the world emissions. Since in most cases, the area lacks powerful and effective environmental laws, this study emphasizes the necessity of modifications in the policy. The steps such as moving the green innovation technology and introducing the price on the carbon are crucial to uncoupling economic growth and emissions and creating an efficient global climate policy

1 Introduction

The unremitting increase in the amount of CO_2 in the atmosphere has increased the pressure of the international community to deal with climate change. This paper investigates the multifaceted nature of the interaction in the production of CO_2 gases, and much attention is given to the essential aspects, such as the use of natural resources, innovation, Gross Domestic Product, urbanization, and use of energy. The more countries suffer the impacts of climate change, the more urgent it will be to make sure that an effective strategy is adopted in reducing the degree of CO_2 emissions. The use of geothermal, solar, wind and hydropower energies has been cited as a crucial step towards the utilization of renewable energy resources. In the industry of energy, technological innovation has been noted to be a game-changer since it has a tremendous impact on the use of solar energy. Razing

of the environment has been singled out as the gravest issue on earth. The principal reasons that have contributed to this problem are the industrial revolution, population growth, and the fact that there are more consumer products that are required in their daily lives. The nature and natural resources available are declining due to the lack of environmental education, awareness, and behavior among humans. Carbon emissions are considered to be the main problem leading to damage to nature and climate change. Human activities, including fossil fuel and biomass combustion, contribute to an increased level of CO_2 gases in nature. Increased energy and economic and agricultural activities for making humans self-sufficient in their food needs also contribute to increased carbon dioxide emissions. (Owusu et al., 2016)

Renewable energy, which drives from replenishable resources such as sun, wind, and water, plays a key role in enhancing sustainable economic growth. Although conventional energy forms enhance increase, they also lead to emissions, particularly CO_2. The advantages of switching to renewable energy are very high, which include reduction of emissions, increased energy security and the reduction of dependence on fossil fuel. In addition, it also facilitates the creation of job opportunities in the renewable energy inventions and alleviates environmental issues, such as pollution and global warming. By adopting renewable energy, communities will be in a position to meet their increasing energy needs besides enhancing their environmental prospects. (Akella et al., 2009)

The world has been leaning in favor of sustainable processes in recent years due to the general anxieties surrounding the destruction of the environment and the emergence of global warming. The primary cause of the environmental crisis is the growing amount of the CO_2 emission that is mainly provided by the traditional energy system. Thus, the necessity to seek new ways of overcoming the negative impact of the CO_2 emission like technical innovation and clean energy is growing.

CO_2 is the most abundant of these gases (Raihan et al., 2021; Wang et al., 2020). Constant carbon dioxide emissions, in their view, will destroy the world's biosphere and affect every facet of human civilization. We expect these impacts to show up substantially faster than we had anticipated. Globally, preserving resilient development and reducing climate change have shifted their focus to mitigating carbon pollution and improving the quality of environment.

If one believes Raihan et al. (2022) and Voumik et al. (2023), Rising carbon dioxide emissions from the economy are a major contributor to the global warming crisis. All things considered; three separate pieces detailed the results. Rendering to Raihan and Tuspekova (2022), One of the main causes of the increase in CO_2 emissions is the rapid pace of urbanization, industry, and population rise. The increasing need for energy on a worldwide scale is a result of many factors, including the urbanization cycle, expanding industrialization, and a growing population. This explains why the upward trend in global temperatures has been becoming stronger in recent years. By promoting more eco-friendly industrial methods and decreasing carbon emissions, sustainable development aims to reduce the adverse impact of human activities on environment. Rising atmospheric carbon dioxide levels are a result of lifestyle shifts, altered industrial structures, and altered economic activities brought about by urbanization. Making environmental conservation a major priority and increasing awareness of its importance is crucial if mankind is to survive. Two main factors contribute to environmental degradation: first, the ever-increasing sophistication of human technology; and second, the wasteful use of natural resources in manufacturing artificial commodities. Studies show that the natural environment proximately around cities suffers as a result of people's excessive use of power and other types of energy. There are two primary avenues by which city economies may have a major impact on Mother Earth. Changes in resource extraction methods brought on by urbanization hasten the shift to unconventional fuels. One of the main reasons the change is happening so quickly is because of this. Anser et al. (2021), When urban economic growth is strong, achieving synergies in terms of size and ecologically conscious technology becomes quite straightforward. It is easy to deploy environmentally friendly technology and get economies of scale when metropolitan

economies are growing strongly. Because of these two things, we can use the Earth's inherent materials more effectively. The main causes of global warming are the region's very high energy usage, which in turn produces carbon dioxide. However, this leads to a rise in energy consumption, which, when combined with the fast urbanization happening, energy-driven facilities have challenges due to the large space requirements of these units.

1.1 Research Objective

- Assess renewable energy's efficacy in reducing CO_2 emissions.
- Evaluate technological innovation's role in emissions.
- Analyze natural resources' impact on emission mitigation.

1.2 Problem Statements, Significance and Scope of The Study

However, the present challenge that exists is centered on comprehending the relationship between renewable energy, technological development, and natural resources in relation to CO_2 emission levels. There is a challenge in current knowledge that prevents the development of efficient strategies and policies in relation to sustainable development. It is basic to understand how all of those variables are correlated and how they influence the level of CO_2 emissions to establish balance between development and sustainability. The research aims to address the information gap in comprehending the impact of reducing the level of CO_2 emissions through renewable energy, natural resources as well as technological advancement.

This paper will run a panel data analysis over 3- decades (1990-2020) in relation to the discharge of the CO_2 emission in developing Asian countries to test the importance of renewable energy sources, innovation, and natural resources. The rapidly growing economic growth rates and urbanization in these countries precondition the special importance of the consideration of these aspects and their influence on the emissions. The study highlights the change in energy paradigm to sustainable energy that does not rely on carbon and the role of innovation in cutting down the emissions. It provides valuable information that can be used during the execution of policies that will result in a balanced economic and environmental growth. The conducted study can be helpful in studying the trade-off of economic growth and the environment in terms of CO_2 emission.

2 Literature Review

The growing level of necessity to respond to the climate change has triggered studies in the field of CO_2 emissions, renewable energy, and technology. One of the greatest contributors to carbon emission is the use of fossil fuel which leads to environmental degradation. With the increasing necessity to abide by the climate agreements, it is necessary to understand the dynamics of the CO_2 emission. This literature review offers an analysis of the research body of work already done on issues of CO_2 emission and other related aspects.

In a study by Tang and Hu (2023), the study established the relationship between land urbanization and CO_2 emission, where carbon emission was the dependent variable and land urbanization, land use structure, land use intensity, and land use efficiency were the independent variables. Furthermore, this study will contribute to the identification of new research avenues for scholars in this field. The remainder of the paper is organized into four sections. The second section presents a comprehensive review of the relevant literature, while the third section details the data and methodology employed. The fourth section discusses the empirical findings, and the final section provides a summary and conclusion.

The models used instrumental variables to test robustness. It was concluded that land urbanization increases urban CO_2 emissions, but the relationship has an inverted U-shape. It was also concluded that efficient land urbanization leads to the reduction of CO_2 emissions by optimizing land use.

A study by Kostakis et al. (2023) evaluated the impact of economic growth and development, trade openness, energy consumption, globalization, and population density on CO_2 emissions for MENA countries from 1994 to 2014. The study utilized several econometric techniques such as Granger causality tests and GMM techniques. The study concluded that while economic growth and energy consumption augment CO_2 emissions, globalization and trade openness decreases these emissions. The effect of renewable energy consumption on CO_2 emissions is very small in magnitude and can be considered insignificant in the long run. It is suggested that non-fossil fuels should be encouraged to combat these emissions.

Research by Esmaeili et al. (2023) has established that human activities have inflicted heavy damage on environmental elements with serious repercussions regarding CO_2 emissions, human health, as well as the survival of the planet. The study took CO_2 emissions as the dependent variable. The independent variables included FDI, the use of clean energy sources, as well as the interaction effect of Economic Difficulty Index & Foreign Direct Investment (FDI) & Economic Complexity Index. The model applied in the research utilized information from 1995-2019. The team of researchers applied the Panel Quantile approach. The unique feature of the study was the assessment of the cumulative effect of economic complexity & FDI. The results of the study brought into focus the environmental Kuznets curve of the N-11 countries. The environmental research study again highlights the imperatively of further expansion of environmental studies with critical initiatives towards sustainable development.

Jabeen & Khan (2022) Explored green growth in Pakistan through economic, social, and environmental factors by using time series data from 1990-2019. The dependent variable was sustainable economic development. The independent variables included sustainable economic growth, environmental sustainability, Natural capital, Climate change, Poverty, & Employment. By using structural equation models (SEM) in the MCED-5 framework, it was revealed that the increase in net national income led to the depletion of natural resources. An increase in the adjusted net national income positively contributed towards the reduction of poverty & increase of employment. The ADNNI had no impact on carbon intensity. The model described the variation of national poverty & carbon emissions per GDPU. It clearly states that Pakistan must shift from the weak sustainability pattern towards strong sustainability for economic development & conservation of resources. An increase in the net national income leads to higher depletion of natural resources.

Chen, et al. (2022) examined the effect of green economic infrastructure on CO_2 emissions for OBRI economies between 2007-2019, specifically in sub-regions such as Central Asia, South Asia, East & Southeast Asia, Europe, & MENA countries. They applied a panel data model, specifically GMM & FE/RE, to conclude that green logistics had a positive effect on carbon emissions in OBRI, Central Asia, & MENA, & a negative effect in Europe. Internet use lowered CO_2 emissions in OBRI, East Asia, Southeast Asia, & Europe, whereas it increased them in MENA regions. The use of fossil fuel increased, & green tech significantly lowered CO_2 emissions, thus urging a need to adopt green habits & infrastructure worldwide.

Cai et al. (2022) evaluated the CO_2 emission in the South Asian nations by retrieving the information between 1990 and 2018. The paper notes that consumption of non-renewable energy and economic development leads to the rise in CO_2 emission, whereas the use of renewable energy and agriculture has little effects on CO_2 emission. There is increased environmental degradation when urbanization occurs. These findings are in line with the hypothesis of the Environmental Kuznets Curve that provides policies on sustainable development.

In their article, Ahmed et al. (2022) have considered the topic of green economic development in South Asian countries, including green energy, green innovation, and green trade. They used a panel dataset that included 2000 and 2018, and they used various methods, which are unit root tests,

cointegration tests, FMOLS and DOLS to conduct empirical analysis. The study found out that clean energy positively impacts on economic growth, green innovation can positively influence economic performance and green trade can support sustainable development in the area. They indicate that green innovation and energy should be considered to foster sustainable growth in South Asia.

Onofrei et al. (2022) examined how economic growth relates to CO_2 emission of the 27 EU member states in the period between the year 2000 and 2017. By use of qualitative sequential analysis and other methods like DOLS, unit root tests and cointegration tests, the correlation between the economic development and CO_2 emission was seen when a long-term relationship between the two variables was revealed. It was evident that there is a positive relationship between the GDP growth rate and the CO_2 emission because on average the latter grew at 0.072 percent. The discussion underlined that high levels of income cause higher demand for environmental protection and that the manner of economic development rather than development per se affects the development of climate change risks.

Godil et al. (2021) assessed how the decrease in CO_2 emissions might be achieved by economic growth, technological innovation, and renewable energy using time series data in China's transport sector. The authors made Total CO_2 Emissions (TCO_2 EMS) the dependent variable and took other endogenous variables like GDP, Technological Innovation (TECINV), and Renewable Energy (RENEN). This study estimated both the long-term and short-term relationships with the help of the Quantile Autoregressive Distributed Lag (QARDL) method. They have brought evidence that renewable energy and technological innovation significantly reduce CO_2 emissions. Therefore, they have suggested the use of new policies to encourage innovation in transport, which would significantly reduce the impact on CO_2 emissions.

Zhang et al. (2021) studied the relationship urbanization and environment deterioration by analyzing the data from 2000 to 2012 through the technique of panel data analysis. The dependent variable taken by the researcher was carbon emissions, and the independent variables were resident population urbanization ratio, household registration population urbanization ratio, population density, per capita GDP, share of heavy industry production, foreign direct investment, degree of environment regulation, and energy consumption. The technique utilized by the author to analyze the data was General Method of Moment and 2SLS technique. The findings showed that urbanization positively impacts CO_2 emissions from the resident population but has a negative impact on emissions from household registration. The study suggested that different stages of urbanization have varying effects on CO_2 emissions and provided recommendations for sustainable urban development in China.

Zhao et al. (2021) investigated the financial risk emission and worldwide balanced panel dataset of 62 countries. The data were used from 2003-2018 in this study. Dependent variable was CO_2 emission and financial disk, Technological innovation, sustainable development, Industrialization and the size of population were Independent Variable. The methods used in this study to analyzed the data are Two-step panel quartile regression approach, Effect model for empirical analysis, Sys-GMM for robustness analysis and Unit root tests for Financial Crist affect global Con emission significantly and technological innovation help to reduce the risk of relationship between financial risk and emission pt policy implications. to enhance the financial Stability for emission reduction.

Abbasi and Adedoyin (2021) examined CO_2, emissions in China to analyze energy use, economic growth and economic Policy uncertainty, China is the world's largest carbon polluter that raising global warming concerns. The research employed 1970–2018 time series data. And employ AROL a dynamic simulation model, bound testing for long-term relationship, Diagnostic tests. Breusch-Godfrey and Jarque- include Besa tests. Energy use significantly increase CO_2 emission and economic growth also positively affect emissions of carbon but economic policy uncertainty has Jan negative impact on environment degradation. Renewable energy investment used for environmental sustainability. Government policies need to focus on reducing fossil fuel dependency.

Chien et al. (2021) analyzed the relationship between sustainability and information and communication technologies (ICT) in BRICS countries, focusing on how ICT, economic growth, and financial development influence CO_2 emissions. The study used the Method of Moments-Quantile Regression (MMQR) and found that the impact of these variables varies across different levels of CO_2 emissions. The results give invaluable insights on how policy makers in BRICS countries can design policies that are SDG-oriented.

Ulucak (2020) examined how the environmental technologies can enhance green growth in BRICS, through non-renewable and renewable energy consumption. The findings presented in the panel data analysis showed that the green growth is stimulated by environmentally friendly technologies and renewable energy, and the non-renewable energy has adverse effects on stimulating green growth. This paper has found that there is an inverted U-shaped correlation between environmental quality and income, that ICT may lower the emissions particularly in low emission scenarios.

The study by Adedoyin and Zakari (2020) was the analysis of the impact of EPU on the relationship between these variables that depends on the energy consumption and the emission of CO_2. The authors used annual data in 1985 to 2017 to analyze the UK situation. The findings of using the ARDL approach showed that EPU reduces CO_2 emission in the short run but a complex association in the long run. The Granger causality test demonstrated that there was a unidirectional relationship between the use of energy and the relevancy of CO_2 others and that there is the bidirectional relationship between the GDP and CO_2 emission.

Rahman et al. (2020) studied how the factors of CO_2 emissions, population density, and openness to trade in South Asia countries affect the economic growth of the countries, using the data between 1990 and 2017.The panel co-integration model showed that CO_2 emissions and population density have positive impact on economic growth, but trade openness has a negative impact. It found that economic growth, trade openness, and CO_2 emissions were bidirectional. The study concluded with policy recommendations based on these findings.

Baloch et al. (2019) explored the link between 1990 to 2015 panel data for the 5 BRICS countries was utilized for empirical investigation. This study has Dependent variable CO_2 emission and explanatory variables were natural resources, renewable energy and GDP. The study employed the Panel causality test developed by Dumitrescu and Hurlin along with a group-specific regression model to derive empirical results. Findings indicate that natural resources significantly reduce CO_2 emissions in Russia, increase CO_2 emissions in South Africa, and have an insignificant impact on CO_2 emissions in Brazil, China, and India. In the BRICS countries, renewable energy sources contribute to reducing environmental pollution. Additionally, in Brazil and China, GDP has an optimistic effect on emissions, while the square of GDP shows an adverse effect.

Jakob (2017) established climate targets, initiatives to decarbonize the power sector, and efforts to curb deforestation provide a solid foundation for transitioning to a low-carbon economy. On the basis of existing research on credible climate policies and our own interview research, it is argued in this paper that, although currently pursued policies can potentially contribute to reducing emission levels in the coming years, they do not form a feasible point of entry for a transformation strategy at this stage. Various feasible options at the mitigation side are identified with the help of a dynamic sequencing perspective to establish their viability to pave a way for stricter emission cuts in the future. These measures include reforms related to driving restrictions, public transportation enhancements, vehicle efficiency standards, support for electric vehicles, and results-based payments aimed at reducing land-use emissions. Implementing these reforms should occur gradually and be integrated into a broader fiscal reform framework.

Jiang and Guan (2016) focused on the causes of global CO_2 emission growth in developed and developing and industrial countries. The dependent variable was CO_2 emission growth along fossil

fuel type (coal, oil or gas). Using time series data spanning 1995 to 2009. This study used structural decomposition model (SDA). The main findings of this study are magnitude of CO_2 emission from coal use increase of 2794Mt. CO_2 emission from coal and gas use developing countries except China increase 967 Mt and 814Mt. In developed nations CO_2 emission from gas has also increase by 471Mt, China uses from gas increased only by 132 Mt. Conversely in developed countries CO_2 emissions use from oil decrease by 506 Mt.

Camarero et al. (2013) analyzed the determinants of CO_2 emissions converging among OCED countries. Dependent variable used CO_2 emission where explanatory variable included energy intensity and carbonization index. Using time series data spanning 1960 to 2008 sample size 23 OECD countries. This study under the OECD economy. Analytical technique was used is Phillips and Sul methodology (2007). The findings of this study are there are four convergence clubs over GDP for CO_2 emissions, Greece and Portugal are first convergence club. In second convergences clubs included countries are Australia, Finland, Japan, New Zealand, Norway and Switzerland. In third convergence Austria, Canada, Denmark and Netherlands and last Belgium, France, Germany, Iceland, Sweden and UK are all included in fourth convergence club; however, Italy and Spain indicate the upward trend.

2.1 Theoretical Framework

2.1.1 Environmental Kuznets Curve (EKC) Hypothesis

This hypothesis states that the association among the quantity of environmental devastation and the average income of an individual resembles an inverted U. Many individuals have interpreted this to mean that the subsequent stage of economic development will ultimately repair the environmental damage between GDP expansion and ecological impact. After a certain point on the inverted U-shaped Ex's, the point on the income and sulfur dioxide concentration reverses, and the correlation between per capita opposite relationship is observed.

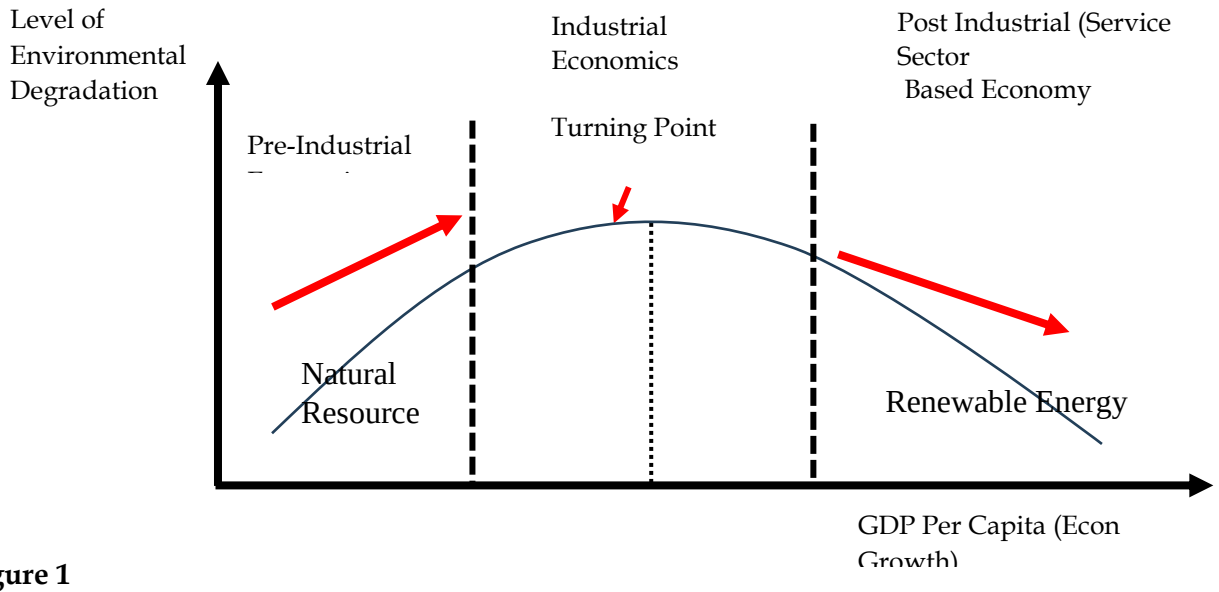

Figure 1
Theoretical Framework

The name of the EKC was inspired by Kuznets proposed a link between income disparity and economic progress in 1955. Later, the EKC centers, and sulfur dioxide levels. This climate change, population addressed global generalization has been criticized for lacking sufficient evidence (Stem, 2004), The tot ion thar environmental problems and per capita affluence are inversely related remains valid.

The EKC hypothesis says no straight line exists between natural resources, ecological footprint and economic growth. Grossman and Krueger (991) were the first to suggest the EXC hypothesis. Claiming a comparable non-linear connection among growth and environmental quality. The EKC theory states that environmental deterioration is related GDP in U-shaped fashion 9 but in a negative direction. The figure above illustrates how economic growth intimately Researched compensates in for this the ecological harm brought on Pie the initial phases of economic expansion. Doctorate are the effects of both human and natural wealth on ecological integrity Measured in the EKC paradigm; ecological footprints indicate environmental degradation's potential.

2.1.1 Conceptual Framework

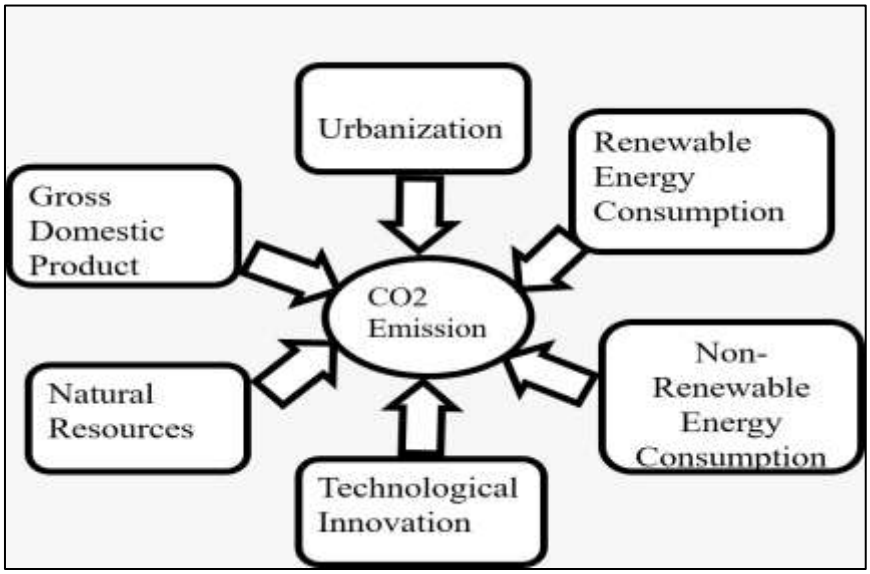

Figure 2
Conceptual Frame Work
Diagram show the relationships of CO_2 emission with other variables in a geometrical.(Source: Inspired by Baloch et al. (2019).

Trends: Main Relationship between CO_2 Emissions and Various Factors

Consumption of Renewable Energy: Renewable energy consumption has a low carbon footprint, thereby decreasing the amount of CO_2 emissions, hence increasing the role of renewable energy towards sustainability of the environment.

Technological Innovation: The effect of technological innovation on the emissions of CO_2 depends on the country and the economic system. Most countries within the MENA region have shown that technological innovation is a factor that increases the emissions of CO_2 when the DOLS method is applied. The main reason for the increase is the presence of technologies such as storage and cloud services that consume a lot of energy and thus cause emissions.

Natural Resources: There is an inverse relationship between the emissions of CO_2 and natural resources. Natural resources play an essential role in shaping policies and strategies for fighting climatic change and protecting the environment. Natural resources also include land use patterns, land degradation due to deforestation and agriculture, fossil fuels including coal, oil and gas, water resources, and mineral resources. Fossil fuels and gas are prominent emitters of CO_2, while urbanization diminishes the absorptive capacity of the planet for CO_2.

Urbanization: The relationship between CO_2 emission and urbanization is intricate in nature. There is potential for increased CO_2 emission as a result of urbanization, but there is also potential for a reduction in CO_2 emission as a consequence of proper implementation of smarts cities and energy

efficiency. There is potential for increased and decreased emission as a result of implementation of rapid technological changes in cities, contributing to economic development. Proper management of urbanization and controlling CO_2 emission is necessary.

Consumption of Non-Renewable Energy: The non-renewable energy resources of coal, oil, gas, and nuclear resources highly correlate with the consumption of CO_2. The non-renewable resources pose some constraints as they entail waste disposal problems.

GDP: The relationship between CO_2 emissions and GDP is positive because emissions rise in relation to economic expansion in industry and agricultural sectors. The data reiterates the sustainability challenge in balancing economic and environmental objectives.

3 Models and Methods

3.1 Model Specification

To assess how renewable energy consumption, technological innovation, natural resources, urbanization, non-renewable energy consumption, and GDP growth rate dynamically affect CO_2 emissions in developing Asian countries, we developed the following econometric model:

CO_2 emission = f (Renewable Energy consumption, Technological Innovation, Natural Resources, urbanization, Non-Renewable Energy Consumption and GDP growth rate,)

$$CO2_{it} = \propto_0 + \propto_1 (REC_{it}) + \propto_2 (TI_{it}) + \propto_3 (NR_{it}) + \propto_4 (URB_{it}) + \propto_5 (NREC_{it}) + \propto_6 (GDP_{it}) + \varepsilon_{it}$$

Where:

$\propto_0$ is the intercept

$\propto_1, \propto_2, \propto_3, \propto_4, \propto_5, \propto_6$ the coefficient of explanatory variables.

ε_{it} denotes the error term which shows omitted variables in the specified model.

3.2 Data and Source

Research is based upon panel data from 1990 to 2022 of 30 countries Pakistan, Bangladesh, India, Indonesia, Malaysia, Myanmar, Thailand, Viet Nam, Nepal, Maldives, Bhutan, Armenia, Azerbaijan, Kazakhstan, China, Tajikistan, Kyrgyz republic, Sri Lanka, Turkmenistan, Uzbekistan Japan, Korea rep, Kuwait, Saudi Arabia, Singapore, Oman, Qatar, Bahrain, Israel, United Arab Emirates. Data was collected from WDI and UNCATD

Table 1

Summary of Variables

Code	Variable Name	Measurement Unit	Source	E. Sign
Dependent Variable				
CO_2	Carbon Dioxide Emission	Kt (kiloton)	WDI	
Independent Variables				
REC	Renewable energy Consumption	Dividing the consumption of primary renewable energy by the total gross inland consumption of energy	WDI	_
TI	Technology Innovation	Patents and Intellectual Property Rights Index and R&D expenditure	WDI	**+**

		to measure the Technological innovation.		
NR	Natural Resources	Total Natural Resources rents % of GDP	WDI	**-**
Control Variables				
URB	Urbanization	Urban population (% of total population)	WDI	-
NREC	Non-Renewable Energy Consumption	Fossil fuel energy consumption (% of total)	WDI	+
GDP	Gross Domestic Product	Gross Domestic Product	WDI	+

3.3 Estimation technique

The study's methodology clarifies in a structured categorization. To begin with, the selection of data and methodology takes priority, followed by a comprehensive literature review and an analysis of cross-sectional dependence. Subsequently, Hausman test is conducted on the dataset. Finally, Generalized Moment Method (GMM) analysis is employed to draw insightful conclusions from the data.

3.4 Dynamic Panel Data Model-System GMM

This study's hypothesis is tested using System Generalized Techniques of Moments analysis. The use of dynamic panel data can lead to a numeral of econometric issues, such as:

Fixed influences, such as a country's demographics and geography, are persistent over correlate with the independent variables. The residual term (U) of the model contains the unobserved country-specific effects, v and the observations -specific errors

1. UI-Vte....

The fixed effect is contained in error term in all three equations.

2 The existence of dependent variable. GEN increases the autocorrelation problem in the model.

3 The panel data has a small time period e. g T-16 and a large country size i. e N = 29. For the solution of problems one, two-stage least square (2SLS) is typically used in the studies.

Yet, the statistics from the first stage of a 2SLS regression may provide unreliable tools. When instruments are weak, both the OLS and fixed-effects IV estimators are susceptible to bias.

To cope with the problem number two the difference GMM uses first Blundell and bond (1998) used a difference to transform equations and found that the effectiveness of first differenced GMM estimators is poor if both time and the time series are limited. This is due to the fact that weak solutions exist for the differenced equations. Solution 2k is achieved by utilizing historical data for the first-differenced dependent variable. For short-T and large-N panels, the Arellano-Bond first-differ the nation fixed estimators were developed. The persistence of a shock to a country's fixed effect diminishes over time in panel data, and the correlation between the dependent variable and the error term becomes negligible in later periods. This context is important for understanding the choice of estimator. Arellano and Bond (1991) developed a first-differenced GMM estimator to address endogeneity in dynamic panel models. However, Blundell and Bond (1998) demonstrated that this first-differenced estimator can be weak and biased when working with short time panels or when the dependent variable is highly persistent. This weakness arises because lagged levels of the variables become poor instruments for the first-differenced equations.

To overcome this limitation, Blundell and Bond (1998), building on work by Arellano and Bover (1995), developed the System GMM estimator. This method augments the first-differenced equations with equations in levels. It uses a system of two sets of equations: one that instruments differences with lagged levels, and another that instruments levels with lagged differences. A key requirement for this approach is the additional moment condition that the first differences of the explanatory variables are uncorrelated with the country-specific fixed effects. This allows the lagged first differences to serve as valid instruments for the equations in levels, leading to a more efficient and consistent estimator.

4 Empirical Findings and Discussion

Table 03 provides statistical data regarding the variables that were part of the study.

Table 3

Descriptive Statistics of the Variables

Descriptive Statistics

Variables	Minimum	Maximum	Mean	Std. Deviation
CO_2	5.051140336	9223.37203685	9223.37203685	9223.37203685
REC	.0025839646	75.3659098606	6.50134116719	9.95079868758
TI	1	1426644	42774.62	158844.596
NR	.0001692661	95.9000000000	29.4011949906	27.4662285952
URB	66.10200000	10944686.2000	293270.718589	922337.203685
NREC	8.854000000	100.000000000	52.6465023356	27.6747907732
GDP	41.80000274	82.8093290262	4.75032616928	6.78353076004

The table of descriptive statistics provides insights into the nature of variables utilized in the study.

CO_2 measures from 5.05 to 9223.37, with high mean and standard deviation, reflecting high variability in data. Renewable Energy Consumption (REC) measures from 0.0026 to 75.37, with a mean of 6.50, reflecting negligible to some varied use of renewable sources. Technological Innovation (TI) measures from 1 to over 1.4 million, reflecting high variability in trade activities among nations. Natural Resource Rents (NR) measures with high variability, ranging from nearly zero to nearly 95.90%, with a mean of 29.40%. Urbanization (URB) measures from a minimum of 66.10 to a maximum exceeding 10,000,000, reflecting huge variability in the number of urban dwellers. Non-Renewable Energy Consumption (NREC) has a mean of 52.65%, with a minimum measure of 8.85 to a maximum of 100%, reflecting its primary use in the industry's total consumption. Finally, GDP per capita measures with a mean of 4.75, reflecting a minimum measure of approximately 41.80 to a maximum measure of 82.81, with a moderate standard deviation, reflecting a degree of variability in development among the dataset measures.

Table 04

Hausman Test Result

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG (GDP PER CAPIT)	-9942.827	3337.293	-2.979309	0.0030
C	84661.76	28807.90	2.938839	0.0034
R-squared	0.017240	Mean dependent var		1.51E-11
Adjusted R-squared	0.015297	S.D. dependent var		107482.9
S.E. of regression	106657.7	Akaike info criterion		25.99657
Sum squared resid	5.76E+12	Schwarz criterion		26.01322

Log likelihood	-6601.128	Hannan-Quinn criter.	26.00310
F-statistic	8.876285	Durbin-Watson stat	0.076663
Prob(F-statistic)	0.003028		

Hausman Test

For CO_2 = f (GDP), as well as GDP = f (CO_2), hence due to this simultaneity, endogeneity existed in the model. We initially examined the existence of endogeneity by Hausman test. Which verifies its existence; hence we used instrumental models. Table 05 Results of Panel Generalized Method of Moments (Middle-Income Countries)

Table 5

Panel GMM Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
RE	-2343.488	531.7818	-4.406860	0.0000
TI	2.310519	0.136816	16.88772	0.0000
NR	-354.0145	149.5067	-2.367884	0.0182
URB	-0.119860	0.013335	-8.988171	0.0000
NREC	488.0937	123.2455	3.960337	0.0001
GDP	7.27E-08	9.18E-09	7.917442	0.0000
C	36911.37	10837.94	3.405756	0.0007
Period fixed (dummy variables)				
R-squared	0.894923	**Mean dependent var**		112330.1
Adjusted R-squared	0.888451	**S.D. dependent var**		266819.0
S.E. of regression	89114.58	**Sum squared resid**		4.90E+12
Durbin-Watson stat	0.431148	**J-statistic**		3.21E-26
Instrument rank	39			

The result on how panel GMM works in countries classified as mid-income is presented in Table 05, whereas the differences between the results of panel GMM in mid-income countries and low-income and mid-to-high countries in developing Asia are shown in Table 06. The endogenous variable considered in this study is carbon emission in kilotons. The weight of the 2SLS instruments is 656 unbalanced panel observations over 33 periods in 20 cross-sectional units from 1990 to 2022.

Perception of Renewable Energy Consumption on CO_2 Emissions: A unit increase in the exogenous variable of renewable energy consumption triggers a large decrease in CO_2 emissions by 2343.49 units. This negative association is highly significant (p = 0.0000), which indicates that renewable energy has been proven effective in decreasing emissions. This result supports existing research Cai et al. (2022), Esmaeili et al. (2023), Ulucak (2020).

Impact of Technology Innovation on CO^2 Emissions: A unit increase in the value of technology innovation is accompanied by a 2.31-unit hike in CO_2 emissions. This is a positive relationship, which is statistically significant because the probability value is 0.0000. This might be because of the fact that some technologies stimulate industrial activities.

Impact of Natural Resources on CO_2 Emissions; Increasing utilization of natural resources causes CO_2 emission to decrease because an increase in the use of natural resources by one unit causes a decrease in the CO_2 emission by 354.01 units. The significant model has a marginal significance of 0.0182 which means that there is a moderating effect between the use of natural resources and the CO_2 emissions.

Effect of Urban Population on CO_2 Emission: One percent increase in urban population impacts the reduction of carbon emissions by 0.1199 units, which is highly significant (p = 0.0000). This indicates

that the process of urbanization can also lead to the reduction of emissions, perhaps due to resource or technological efficiency. These results contradict some studies which were previously conducted Cai et al. (2022), Abbas et al. (2023). Table 06 Results of Panel Generalized Method of Moments (Low- & High-Income Countries)

Table 6

Panel Generalized Method of Moments (Low- & High-Income Countries)

Low income					**High income**				
Var	**Coeff.**	**Std.error**	**t-Stat**	**Prob.**	**Var**	**Coeff.**	**St. Error**	**t-Stat**	**Prob.**
RE	-4331.90	1763.713	-1.91	0.05	**RE**	-8672.5	3744.8	-2.3	0.00
TI	1.40532	0.527711	8.34	0.00	**TI**	1.9	0.1	10.4	0.00
NR	-1948.5	3463.424	-0.85	0.39	**NR**	197.3	449.9	0.4	0.66
URB	-20521.9	3724.648	-2.82	0.00	**URB**	-3834.1	724.7	-5.2	0.00
NREC	2321.50	474.3902	6.28	0.00	**NREC**	455.9	161.8	2.8	0.00
GDP	2.52E-01	4.18E-08	8.40	0.00	**GDP**	9.62E-08	1.28E-08	7.5	0.00
C	265675.5	192356.2	2.42	0.01	**C**	392804.7	68036.1	5.7	0.00
R^2	0.654522	**Mean dep var**		427689.6	**R^2**	0.900377	**Mean dep var**		141989.9
Adj. R	0.651298	**S.D. dep var**		1495397.	**Adj. R**	0.898515	**S.D. dep var**		338347.2
S.E.R.	883046.0	**S.S resid**		5.01E+14	**S.E. R**	107777.9	**S.S resid**		3.73E+12
F-stat	203.0317	**D-W stat**		0.428090	**DW stat**	0.486720	**J-statistic**		8.51E-24

Consumption of Non-Renewable Energy Resources: An Increase of one unit of non-renewable energy consumption raises CO_2 emissions by 488.09 units, ceteris paribus. The result shows strong positive association, which is statistically significant at p = 0.0001. This result confirms earlier research. Ulucak (2020).

GDP vs. CO_2 Emissions: For every one dollar rise in GDP, a small increase in CO_2 is seen. Even though it is a small percentage rise, in the large magnitude of GDP, it could create a large impact. It is statistically significant (p-value of 0.0000) and is in accordance with studies conducted by Raza Abbasi and Adedoyin (2021).

The regression results show a strong positive association among fossil fuel consumption and GDP with CO_2 emissions, while renewable energy consumption, urbanization, and natural resource usage are linked to lower emissions. Technological innovation, despite its positive correlation, may indicate increased industrial activities that contribute to emissions. The model has a robust fit with a high R-squared value, though potential autocorrelation in the errors warrants further investigation.

Robustness Check

In economics and finance, robustness assessments are an integral part of applied empirical study. After researchers have established their primary findings, they usually look for other processes that might explain them and provide further analyses to the control and 2sls Substitute models. LIML (LIMITED INFORMATION MAXIMUM LIKELIHOOD)

Table 07

The Result of Robustness Check

Variable	**Coeff.**	**Std. Error**	**t-Statistic**	**Prob.**
RE	-2248.320	543.3556	-4.137843	0.0000
TI	2.504736	0.131469	19.05188	0.0000
NR	-228.6160	140.7394	-1.624392	0.1048
URB	-0.097898	0.013428	-7.290593	0.0000
NREC	563.7935	107.1370	5.262360	0.0000

GDP	6.06E-08	8.86E-09	6.846834	0.0000
C	28272.90	9723.474	2.907695	0.0038
R^2	0.880642	**Mean dependent var**		112330.1
Adjusted R^2	0.879538	**S.D. dependent var**		266819.0
Regression S.E.	92606.44	**Sum squared resid**		5.57E+12
F-stat	798.0687	**Durbin-Watson stat**		0.487838
Prob (F-stat)	0.000000	**Second-Stage SSR**		5.57E+12

Panel 2SEGLS

One statistical method for analyzing structural equations is 2SLS regression analysis. It is an expansion of the OLS approach.

Table 08

Panel Two-Stage EGLS

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
RE	-2248.320	522.8676	-4.299980	0.0000
TI	2.504736	0.126512	19.79841	0.0000
NR	-228.6160	135.4326	-1.688043	0.0919
URB	-0.097898	0.012922	-7.576267	0.0000
NREC	563.7935	103.0973	5.468560	0.0000
GDP	6.06E-08	8.52E-09	7.115120	0.0000
C	28272.90	9356.836	3.021630	0.0026
Effects Specification				
			S.D.	**Rho**
Period random			0.000000	0.0000
Idiosyncratic random			89114.58	1.0000
Weighted Statistics				
Adjusted R-squared	0.879538	**S.D. dependent var**		266819.0
S.E. of regression	92606.44	**Sum squared resid**		5.57E+12
F-statistic	798.0687	**Durbin-Watson stat**		0.487838
Prob(F-statistic)	0.000000	**Second-Stage SSR**		5.57E+12
Instrument rank	7			
Unweighted Statistics				
R-squared	0.880642	**Mean dependent var**		112330.1
Sum square Resid.	5.57E+12	**Durbin-Watson stat**		0.487838

The table display the result of a panel Two-Stage EGLS regression for CO_2 emissions (in kilotons) as the dependent variable. The model includes several autonomous variables and covers data from 30 countries or regions over 33 years (1990-2022), accounting for unbalanced panel data.

5 Conclusion & Policy Recommendations

5.1 Conclusion

This study shows that CO_2 emissions are heavily influenced by economic factors, energy choices, and technology. Fuel consumption, as well as GDP, exhibits a strong link with CO_2 emissions, thereby underlining that carbon-intensive economic growth, as well as dependence on non-renewable fuel sources, are key attributes here. Alternatively, consumption of renewable fuel sources, degree of urbanization, as well as management of natural resources, are linked to a reduction in CO_2 emissions. However, innovation exhibits a positive relationship with CO_2 emission levels, perhaps because this factor is more directly associated with industrialization rather than with clean technology sources.

5.2 Policy Recommendations

•In order to exploit the potential of renewable energy sources in reducing the rate of CO 2 emission, there is a need to ensure that policies are aimed at maximizing investment in renewable energy infrastructure. To this end, the governments can offer tax incentives or subsidies to businesses and households in order to persuade them to use renewable energy sources.

•Trends in technological innovation are currently good and are related to emissions. Sustainable practices should be addressed in the innovation policy. These can be in terms of funding research and development in green technology, encouraging industries that are involved in coming up with emissions cutting technology and offering grants and tax exemptions to companies that embrace sustainable operations.

Apparently, GHC emissions are alleviated by means of adaptive utilization of natural resources, which, to a certain extent, refer to the fact that the regulations regarding the extraction of resources should be strengthened, and the introduction of sustainable practices related to agriculture, forestry, and mineral resources management is encouraged. There may also be some use in establishing monetary rewards that will be useful to communities that are dependent on these natural resources.

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Appendix

List of Entities/ Countries

These entities of Developing Asia countries are taken in this paper to see the connection among carbon emission and other variables disaggregated analysis for carbon emission.

Table 1
Developing Asia Countries

S. No	Entities	S. No	Entities	S. No	Entities
1	Pakistan	11	China	21	Japan
2	Sri Lanka	12	Bangladesh	22	Israel
3	Armenia	13	Viet Nam	23	Singapore
4	Azerbaijan	14	Nepal	24	Bahrain
5	Kazakhstan	15	Malaysia	25	United Arab Emirates
6	Tajikistan	16	Kyrgyz Republic	26	Korea Rep
7	Bhutan	17	Indonesia	27	Kuwait
8	Maldives	18	India	28	Saudi Arabia
9	Myanmar	19	Thailand	29	Oman
10	Turkmenistan	20	Uzbekistan	30	Qatar