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DRIVERS AND BARRIERS TO THE ADOPTION OF RENEWABLE ENERGY: INVESTIGATING WITH THE ECOLOGICAL LENS

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Abstract

The growing energy demand amidst unprecedented climatic patterns pose a significant challenge of the century. Given this backdrop, the exploration of renewable energy as a viable solution for ensuring energy security becomes imperative. Considering Asia's significant contribution to global energy consumption and emissions, this study examines the impact of renewable and non-renewable energy consumption on environment across 24 developing countries in Asia. Employing the Pooled Mean Group model within Panel Auto Regressive Distributed Lag framework facilitates the examination of panel-specific heterogeneity and cross-sectional dependencies. This research differs from much of the existing literature by incorporating ecological footprint as an additional measure of environmental degradation, alongside CO2 emissions. The findings suggest that increased consumption of renewable energy is associated with a reduction in emissions and ecological footprint, underscoring the potential of renewable energy to achieve energy security in Asian countries without exacerbating climate and environmental degradation.

Keywords: *Renewable and non-renewable energy consumption, Ecological footprint, CO2 emission, Economic growth.*

JEL Codes: *C3,*

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INTRODUCTION

The energy sector is a primary contributor, accounting for three-quarters of the emissions responsible for raising global average temperatures by 1.1°C since the pre-industrial age (*Executive Summary – World Energy Outlook 2021 – Analysis - IEA*). As a result, decarbonizing the energy sector has become a focal point in numerous climate initiatives. Renewable energy (hereafter RE) has emerged as a pivotal solution for curbing emissions while meeting energy demands, with two-thirds of the necessary reduction in energy-related CO_2 emissions achievable through its promotion (*IRENA_Climate_policy_2017*).

By the year 2020, renewables accounted for nearly 29 percent of global electricity generation (*Renewables – Global Energy Review 2021*), with forecasts indicating a projected increase of over 60 percent in renewable electricity capacity between 2020 and 2026 (*Executive Summary – Renewables 2021 – Analysis*). Notably, RE is also poised to play a significant role in achieving the Net Zero Emissions target by 2050.

Given the growing importance of RE in climate action endeavors, it is imperative to comprehensively assess its environmental impact. While numerous studies have examined energy consumption effects, research specifically analyzing the consequences of RE consumption remains limited. Moreover, while most of the existing studies on RE focused on its economic implications, investigations into its environmental repercussions are relatively scarce (He *et. al.*, 2019; Mahmood *et. al.*, 2019). Thus, this study aims to bridge this gap by analyzing the environmental impact of RE consumption.

Despite the increasing prominence of RE, non-renewable energy sources (non-RE) continue to dominate the global power landscape (UN Environment, 2019). Therefore, to ensure a comprehensive understanding of the impact of RE consumption and facilitate comparative analyses, this study includes an assessment of non-RE consumption as well.

In this context, the study seeks to examine the long-term and short-term effects of RE and non-RE consumption on the environment in developing countries across Asia. Given that Asia leads in both energy consumption and carbon emissions, with projections indicating its consumption to comprise half of global levels by 2050 (*EIA International Energy Outlook 2020 - Issue in Focus*), and being responsible for a significant portion of the increase in global anthropogenic CO_2 emissions (UN Environment, 2019), the region holds paramount importance in global climate action efforts. Thus, focusing on Asia as the study area is appropriate for analyzing the impact of energy (RE and Non-RE) consumption on the environment.

The subsequent sections of this paper are organized as follows: Section 2 provides a comprehensive review of existing literature. Section 3 explains the model, variables, and econometric methodology employed for analysis. Section 4 presents empirical findings, while Section 5 discusses the result. Finally, Section 6 concludes the paper and offers policy recommendations.

LITERATURE REVIEW

Energy consumption and its impact on the environment have been subjects of extensive research in the field of energy economics. Numerous studies have investigated the complex nexus between energy consumption and various socio-economic and environmental factors. While a considerable body of literature exists on the relationship between energy consumption and economic growth, studies specifically analyzing the environmental impact of energy consumption, particularly focusing on RE consumption, are relatively scarce.

Several studies have analyzed the environmental implications of energy consumption, with a few focusing on the role of RE sources. For instance, Shaari *et. al.*, (2020) conducted a comprehensive analysis of oil and gas consumption and their effects on CO_2 emissions in 20 Organization of Islamic Cooperation (OIC) countries. They found that oil and gas consumption significantly contributed to emissions in both the short and long run. Similarly, He *et. al.*, (2019) examined the non-linear relationship between RE investment and green economy development, highlighting the significant role of RE in promoting sustainable economic growth.

Munir and Riaz (2019) explored the relationship between energy and electricity consumption and CO_2 emissions in Bangladesh, India, and Pakistan using a Nonlinear Autoregressive Distributed Lag (NARDL) model. They identified non-linear relationships between CO_2 emissions and electricity consumption, as well as coal consumption, in the long run. In addition, Mahmood *et. al.*, (2019) investigated the interaction between RE consumption and economic growth on CO_2 emissions in Pakistan. Their findings revealed that while RE consumption individually reduced emissions, its interaction with GDP led to increased emissions, indicating a complex interplay between economic growth and environmental sustainability.

Furthermore, Bhuiyan *et. al.*, (2018) analyzed the impact of climate change, energy sources, and growth-specific factors on biodiversity loss in Asia, employing panel fixed effect and quantile regression models. Their study highlighted the diverse impacts of these factors on various aspects of biodiversity and emphasized the need for region-specific evaluations of energy policies. Similarly, Zaman *et. al.*, (2016) examined the environmental impact of biofuel production across different regions, revealing mixed results in terms of its effects on climate change, agricultural land, water resources, and biodiversity.

In addition to these studies, several others have explored the dynamic relationships between energy consumption, economic growth, and environmental sustainability. Liu and Liang (2019) investigated the causal links between energy consumption, economic growth, and biodiversity in Lancang-Mekong Cooperation (LMC) countries, while Zeb *et. al.*, (2014) analyzed the relationship among RE production, CO_2 emissions, poverty, and GDP in South Asian Association for Regional Cooperation (SAARC) countries. Pao and Tsai (2011) and Apergis and Payne (2010) examined the dynamic relations between energy consumption, economic output, and CO_2 emissions in various regions, supporting the existence of Environmental Kuznets Curve (EKC) hypothesis in some cases.

Furthermore, Soytas *et. al.*, (2007) analyzed the potential EKC in the United States by incorporating energy consumption. They found no causality from economic growth to CO_2 emissions but observed unidirectional causality from energy consumption to emissions. Saint Akadiri *et. al.*, (2019) examined the effect of RE consumption on economic growth, finding a positive relationship between RE consumption and economic growth in the long run. Mensah *et. al.*, (2019) explored the causal link between economic growth, fossil fuel consumption, carbon emission, and oil price in Africa, revealing bidirectional causality between energy consumption and emissions.

The existing literature provided valuable insights into the complex interactions between energy consumption and environmental sustainability. However, there remain significant gaps in research, particularly in understanding the specific impacts of renewable and non-renewable energy consumption in developing countries. Therefore, the present study aims to address this gap by examining the environmental effects of energy consumption from the perspective of developing countries in Asia.

METHODOLOGY

Theoretical Model

This study tried to find out the environmental impact of energy consumption (RE and Non-RE) using CO_2 emission and ecological footprint as the indicators of environmental degradation. Existing studies have pointed out that in addition to energy consumption certain socio-economic variables also determines environmental degradation. Hence to avoid the problem of omitted variable bias this study considered some of such variables in the analysis.

Most of the existing studies provided evidences for economic growth as a major determinant of the environmental degradation (Behera and Mishra, 2020; Mahmood *et. al.*, 2019; Mensah *et. al.*, 2019; Shaari *et. al.*, 2020; Liu and Liang, 2019; Soytas *et. al.*, 2007; Panayotou, 1993). Present study also included economic growth as a control variable and expected a positive impact on environmental degradation. Another variable used by the existing literature was the trade openness, but a consistent result was not existing about its impact. Kasman and Duman (2015) and Mahmood *et. al.*, (2019)] showed evidence for positive relation between CO_2 emission and trade openness in EU member countries and Pakistan respectively. But Charfeddine (2017) and Sharma (2011) found the relation to be inconclusive. However, Charfeddine's analysis with ecological footprint showed evidence for positive relation. Other variable commonly used in existing analysis was urbanization. Growth in urban population would create more pressure on urban resources which in turn creates more pollution. Some studies (Kasman and Duman, 2015; Rizk and Slimane, 2018) found positive relation between environmental degradation and urbanization. But some other studies (Sharif Hossain, 2011; Sharma, 2011) found the relation to be negative. A study by Charfeddine (2017) found the effect of urbanization to be changing with the indicators environmental degradation. To analyze the impact of all the specified variables on the environment following model was proposed;

$$co_{2it} = Are_{it}^{\alpha 1i} non\text{-}re_{it}^{\alpha 2i} gdp_{it}^{\alpha 3i} trade_{it}^{\alpha 4i} urban_{it}^{\alpha 5i} \quad (1.a)$$

$$footprint_{it} = Are_{it}^{\alpha 1i} non\text{-}re_{it}^{\alpha 2i} gdp_{it}^{\alpha 3i} trade_{it}^{\alpha 4i} urban_{it}^{\alpha 5i} \quad (1.b)$$

The subscript i and t denote country and time period respectively. A is the technology parameter. CO_2 and footprint represent CO_2 emission and ecological footprint, re and non-re represent renewable and non-renewable energy consumption, gdp, trade, and urban represent GDP per capita, trade openness, and urbanization respectively. Here α1, α2, α3, α4, and α5 are the elasticity of environmental indicators with respect to each of the independent variables. Logarithmic transformation of the equations is given by;

$$lnco_{2it} = lnA_{it} + \alpha_{1i} lnre_{it} + \alpha_{2i} lnnon\text{-}re_{it} + \alpha_{3i} lngdp_{it} + \alpha_{4i} lntrade_{it} + \alpha_{5i} lnurban_{it}$$

(2.a)

$$lnfootprint_{2it} = lnA_{it} + \alpha_{1i} lnre_{it} + \alpha_{2i} lnnon\text{-}re_{it} + \alpha_{3i} lngdp_{it} + \alpha_{4i} lntrade_{it} + \alpha_{5i} lnurban_{it}$$

(2.b)

$lnA_{it} = \alpha_{0i} + \varepsilon_{it}$ where α_{0i} captures the country specific fixed effects and ε_{it} measures the deviations from the long run equilibrium relationship.

Data and Their Source

This study analyzed a panel consisting of 24 developing countries of Asia (Armenia, Azerbaijan, Bangladesh, Cambodia, China, Georgia, India, Indonesia, Islamic Republic of Iran, Iraq, Jordan, Kazakhstan, Kyrgyzstan, Lebanon, Malaysia, Mongolia, Nepal, Pakistan, Philippines, Sri Lanka, Tajikistan, Thailand, Uzbekistan, and Viet Nam) from 1990 to 2018. Choice of panel unit and time period was determined by the availability of data for the variables chosen for analysis. Explanation of the variables used and their data source is provided in Table 1.

Table 1: Summary of Data Set

Variable	Explanation	Source
CO_2	CO_2 emission (metric tons per capita)	WDI
Footprint	Total ecological footprint (GHA)	Global ecological footprint network
Gdp	GDP per capita (constant 2015 US$)	WDI
Re	Renewable energy consumption (percent share in total final energy consumption)	WDI
Non-re	Non-renewable energy consumption (percent share of coal, natural gas, and petroleum and other liquids in total primary energy consumption)	US EIA
Trade	Trade (percent of GDP)	WDI
Urban	Urban population (total)	WDI

Source: compiled by authors

Econometric Approach

Often analysis with panel data assumes the existence of no panel specific heterogeneity and cross-sectional dependence. But homogeneity hypothesis is very often rejected and the differences in the estimates between countries can be large (Bhattacharya *et. al.*, 2016). And if cross-sectional dependence is not dealt with proper estimation techniques, panel estimators won't be better than single time-series. Presence of these two issues also plays a significant role in the selection of econometric tests like unit root and co-integration (Mensah *et. al.*, 2019). Hence this study tested for cross sectional independence using Pesaran CD test and panel specific heterogeneity using Pesaran-Yamagata's homogeneity test. Since first generation unit root tests cannot provide efficient estimators (Bhattacharya *et. al.*, 2016; Mensah *et. al.*, 2019) for cross-sectionally dependent and heterogeneous panel units this study used CIPS (Cross-sectionally Augmented IPS), a second-generation test for analyzing the stationarity of the variables. Existence of long run relationship between the variables was tested using Pedroni co-integration test. Finally long run and short run relationship between the variables was estimated using panel ARDL (Auto Regressive Distributed Lag) model. The model was employed due to its advantages over conventional co-integration methods. It remains applicable regardless of the integration order of the variables, whether they are I (0), I (1), or a combination of both (Mensah *et. al.*, 2019; Saint Akadiri *et. al.*, 2019). Additionally, it can address endogeneity issues and provide both short-run and long-run coefficients within a single model.

Panel ARDL model

An ARDL (p,q)[1] model can be expressed as follows. Where p and q are the lag order of dependent and independent variables respectively.

$$y_{i,t} = \mu_i + \sum_{j=1}^{p} \lambda_{i,j} Y_{i,t-j} + \sum_{j=0}^{q} \delta_{i,j} z_{i,t-j} + \varepsilon_i \quad (4)$$

Here i=1, 2, ……, N is for countries and t = 1, 2, ……, T is for time period. Y is the dependent variable. Z is a vector of explanatory variables. While μ is the country-level fixed effects, λ, represents the coefficient of the lagged dependent variable and δ represents the coefficients of the lagged independent variables. Model can be represented in the form of Error Correction Model (ECM) as follows:

$$\Delta y_{i,t} = \phi_i (y_{i,t-1} - \theta_i z_{i,t}) + \sum_{j=1}^{p-1} \lambda_{i,j}^{*} \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \delta_{i,j}^{*} \Delta z_{i,t-j} + \varepsilon_{i,t} \quad (5)$$

where

[1] Specification of ARDL equations with the variables used in this study is provided in the Appendix B

$$\phi_i = -(1-\sum_{j=1}^{p}\lambda_{i,j}), \theta_i = -\frac{\sum_{j=0}^{q}\delta_{i,j}}{\phi_i}, \lambda_{i,j}^{*} = -\sum_{d=j+1}^{p}\lambda_{i,d} \, and \, \delta_{i,j}^{*} = -\sum_{d=j+1}^{q}\delta_{i,d} \tag{6}$$

Here the former part of the equation (5), $\phi_i(y_{i,t-1} - \theta_i z_{i,t})$ repress ents the speed of adjustment in the dependent variable to a deviation from the long-run equilibrium level, while the latter part represents the short-run dynamics. θ_i Shows the long run relationship between the dependent and independent variables. $\boldsymbol{\delta_{ij}^{*}}$ are the short term coefficients of the explanatory variables. Whereas $\delta_{i,j}$'s are the long term co-efficient. ϕ_i represents Error Correction Term (ECT). Long run equilibrium relationship between the variables requires ϕ_i to be negative and significant. ARDL model can be estimated by three different estimators: the MG (Mean Group) estimator of Pesaran and Smith (1995), the PMG (Pooled MG) estimator developed by Pesaran *et. al.* (1999), and the DFE (Dynamic Fixed Effect) estimator. MG estimator runs separate regressions and produce different and heterogeneous coefficients for every panel unit for the long run and the short run. Coefficients of the model are calculated from the un-weighted average of estimated coefficients of panel units. In PMG estimator short-run estimates including the intercept, the speed of adjustment, and the error variance will be heterogeneous but the long-run slope coefficient is limited to be homogenous. The third estimator DFE is similar to the PMG estimator but the long run and the short run slope coefficients, error variances and the speed of adjustment coefficient are equal across all countries but it allows panel specific intercepts[2]. Hausman test was used to choose one among the three estimators. Null hypothesis of the test is that homogeneity restrictions hold. Non rejection of null hypothesis between PMG and MG indicates the existence of long

[2] Information on these three estimators of ARDL is obtained from (Samargandi *et. al.*, 2015; and Shaari *et. al.*, 2020).

run homogeneity hence PMG estimator is to be preferred over MG. In the similar way, between PMG and DFE, non-rejection of null hypothesis prefers PMG over DFE.

Existence of equilibrium relationship indicates that there will be granger causality at least in one direction. As there was panel specific heterogeneity and cross-sectional dependencies in the data we used Dumitrescu-Hurlin pairwise granger causality test to analyze the causal relationship.

EMPIRICAL RESULTS

Descriptive Statistics

The descriptive statistics presented in Table 2 reveal that the countries included in this analysis emit, on average, 2.85 metric tons of CO_2 per capita, with a standard deviation (SD) of 2.79. These countries require an average of 25.3 crore GHA of natural resources, with a SD of 74.6. Renewable energy (RE) contributes an average of 28.49 percent to total final energy consumption, while non-RE accounts for an average of 85.33 percent of primary energy consumption. This suggests that despite the efforts to promote RE, non-RE still plays a significant role in meeting the region's energy demand. The standard deviation of energy consumption (26.524 for RE and 18.204 for non-RE) indicates considerable variation in the energy mix across Asian countries.

On average, these countries have a per-capita income of US$2850, with a standard deviation of 2295.48 US$. Trade also plays a substantial role in the economy, contributing an average of 80 percent to GDP, although the standard deviation of 41.07 suggests significant variation among countries. Additionally, a large urban population is prevalent in these countries, with an average of 5.38 lakh people residing in urban areas.

Table 2: Descriptive Statistics of the Variables

	CO_2	Footprint	GDP	RE	Non-RE	Trade	Urban
Mean	2.85	253000000	2850.34	28.50	85.34	80.21	53803921
Median	1.90	51416138	2026.94	23.84	94.95	73.72	9623064
Maximum	15.55	5540000000	11075.58	95.12	99.90	220.41	830000000
Minimum	0.05	3215892	364.88	0.30	18.55	0.02	1245680
Std. Dev.	2.80	746000000	2295.49	26.52	18.20	41.08	128000000
Observations	696	678	693	691	682	679	696

Pesaran-Yamagata's Homogeneity Test

This study tested for panel specific heterogeneity using Pesaran and Yamagata's homogeneity test (2008). The test is based on the difference of the weighted fixed effects estimator imposing slope homogeneity, and cross-sectional unit specific OLS regression model. Large values of the test statistic imply a disagreement between the two estimates indicating the presence heterogeneity. The test results for the two indicators of environmental degradation are shown in Table 3. As per the result delta and adjusted delta statistics were found significant at 1 percent level of significance level, hence the null hypothesis of slope homogeneity was rejected. This indicated that heterogeneous panel model should be used for analysis.

Table 3: Results of the Pesaran-Yamagata's Homogeneity Test

	CO_2 model	Footprint model
Delta	15.397***	10.724***
Adjusted delta	18.325***	12.801***

Pesaran *CD Test*

Cross sectional dependence within the panel variables was tested using Pesaran CD test (2015). This test is based on the correlation co-efficient between panel units, it can be performed either for the error term or for the variables. Null hypothesis is that the error term (or variable) is weakly cross-sectional dependent, i.e. correlation between observations of unit i and j in time t is zero. Result of Pesaran CD test for the variables is presented in Table 4 where the null hypothesis is rejected at 1 percent significance level for all the variables. Thus, the result shows that cross-sectional dependence is presented within the variables.

Table 4: Results of Cross-Section Independence Test

Variables	CO2	Footprint	GDP	RE	Non-RE	Trade	Urban
CD-test value	11.30***	64.95***	70.43***	5.35***	17.32***	11.34***	89.46***

Source: computed by authors
Notes: variables are used in natural logarithmic form, ***indicates statistical significance at 1 percent level.

Panel Unit Root Test

Since the second-generation unit root test can account for cross sectional dependence, CIPS test was used to test the stationarity of the variables. Null hypothesis of the test assumes that all the series are non-stationary with the alternative a fraction of the series being stationary. Result of the test is provided in Table 5. It is clear that the variables CO_2 emission, footprint, GDP, and urbanization are stationary at levels (at 5 percent significance level) whereas the remaining variables become stationary at their first difference indicating that variables under concern are of mixed order of integration. Before proceeding to make the variables stationary it is appropriate to check whether they exhibit any long run relationship, hence the study tested for the presence of long run relationship using Pedroni's co-integration test.

Table 5: Result of CIPS Panel Unit Root Test

Variable	Level (constant)	Level (constant and trend)	First difference
co_2	-2.21069**	Not required	Not required
Footprint	-2.34462**	Not required	Not required
Gdp	-2.95999***	Not required	Not required
Re	-1.08052	-1.67922	-3.40871***
non-re	-1.27521	-1.95457	-3.72120***
Trade	-1.30000	-1.69995	-2.94248***
Urban	-2.39076***	Not required	Not required

Note: Variables were used in natural logarithmic form, *,**, *** indicates statistical significance at 1 percent, 5 percent, and 10 percent level respectively. Source: analyzed by authors

Panel Co-integration Test

Though inference on co-integration can be obtained from the result of ARDL model we tested for it using Pedroni co-integration test. Pedroni proposed seven test statistics under the null of no co-integration in a heterogeneous panel with one or more non stationary regressors; the panel v-statistic, panel rho-statistic, panel PP-statistic, panel ADF-statistic, group rho-statistic, group PP statistic, and group ADF-statistic. Results of the co-integration test with CO_2 emission, and footprint as dependent variables are presented in Appendix Tables A1.a and A1.b. In both the cases four out of seven statistics rejected the null hypothesis, therefore we conclude that variables considered for this study exhibits long run equilibrium relationship.

Panel ARDL Model

Confirmation of long run equilibrium relationship between the variables (of different order of integration) of heterogeneous panels with cross sectional dependence implied the scope of using ARDL model for estimating the short run and long run parameters. Since ARDL model can be estimated using PMG, MG and DFE, we used Hausman test to choose the appropriate method. For both the model we failed to reject the null hypothesis of the Hausman test indicating that pooling of long run coefficients is supported hence we chose PMG over MG. Similarly, when the test was performed to choose between PMG and DFE, we cannot reject the null hypothesis, thus PMG estimator had chosen for final analysis.

While analyzing the impact of energy consumption on the environment most of the existing studies used CO_2 emission to indicate the environmental degradation. In addition to that this study intended to find out how RE and Non-RE consumption is affecting the natural resources. Hence, we choose ecological footprint to indicate the use of natural resources. ARDL model was performed with CO_2 emission and ecological footprint respectively as the dependent variable. Estimation result is provided in Table 6.

Table 6: ARDL Model Result

Independent variable	Dependent variable					
	CO_2			Footprint		
	Coeff	SE	P value	Coeff	SE	P value
Long run						
re	-0.419***	0.094819	0.0000	-0.037**	0.017	0.030
non-re	1.021***	0.136285	0.0000	0.276***	0.053	0.000
gdp	1.115***	0.107482	0.0000	0.325***	0.016	0.000
trade	-0.130***	0.046155	0.0052	0.093***	0.022	0.000
urban	-0.435***	0.060684	0.0000	0.852***	0.025	0.000
ECT	-0.146***	0.038245	0.0002	-0.415***	0.099	0.000
Short run						
D.re	-0.664**	0.261	0.011	-0.176**	0.081	0.029
D.non-re	0.596	0.406	0.143	1.350**	0.638	0.035
D.gdp	0.313*	0.176	0.077	0.356*	0.193	0.065
D.trade	0.021	0.062	0.738	-0.023	0.045	0.610
D.urban	1.040	2.695	0.700	-1.497	2.483	0.547
constant	-0.587	0.180	0.001	-0.131	0.101	0.195
Hausman test	.62		.987	.85		0.974

Source: analyzed by authors using E-Views10. Variables were used in natural logarithmic form. Model selection criteria was AIC, chosen model is ARDL (3, 2, 2, 2, 2, 2). ***, **, * indicates statistical significance at 1 percent, 5 percent, and 10 percent respectively. Hausman test is for MG/PMG (this test is used after running ARDL model with the software stata)

Result of the ARDL model with CO_2 emission as dependent variable showed that RE consumption had negative impact on CO_2

emission in both the short run and the long run. That is a percentage increase in RE consumption reduced CO_2 emission by 0.41 percent in the long run and 0.66 percent in the short run. Whereas non-RE consumption was found to have a positive impact in the long run, that is a percentage increase in non-RE consumption was found increasing CO_2 emission by 1.02 percent, its impact was insignificant for the short run. Regarding the influence of economic growth on emission, positive impact was found for both the long run and the short run, i.e. a percentage increase in GDP increased CO_2 emission by 1.12 percent in the long run and by 0.31 percent in the short run. The other two determinants, trade openness and urbanization showed negative impact on the emission. That is a percentage increase in the trade and urban population reduced emission in the long run by 0.13 percent and 0.44 percent respectively. It didn't have any significant impact in the short run. Error correction term (ECT) in the model was found to be negative and significant which confirms the Pedroni's co-integration test result. Quantitative value of ECT, -0.146 informed that any deviation from the equilibrium relation would get corrected by 14.6 percent in the next period.

ARDL model with footprint consumption also provided similar result. RE consumption was found to have a negative impact on ecological footprint in both the time period, i.e. a percentage increase in RE consumption reduced ecological footprint by 0.04 percent in the long run and by .18 percent in the short run. As in the case of CO_2 emission, non-RE consumption had positive impact on the ecological footprint. That is a percentage increase in non-RE consumption increased ecological footprint by 0.28 percent in the long run and by 1.4 percent in the short run. When it comes to the impact of economic growth on ecological footprint, a percentage increase in GDP was found accelerating the ecological footprint by 0.33 percent in the long run and 0.36 percent in the short run. Unlike the impact on CO_2 emission trade openness and urbanization increased the ecological footprint. That is a percentage increase in the trade and urban population was found increasing the ecological footprint by 0.09 percent and 0.85 percent respectively in the long run. But they didn't have any significant impact in the short run. Here also ECT appeared to be negative and significant. Value of the ECT, -0.415 indicated that any deviation from the equilibrium will be corrected by 42 percent.

Thus, the result with two alternate proxies for environment indicated that RE consumption helps to reduce the emission and ecological footprint in both the short run and the long run. But non-RE consumption increased emission in the short run and ecological footprint in both the time period. This indicates that transition from non-RE to RE is essential for reducing emission and protecting natural resources. The result further indicates that economic growth in the countries considered is happening at the risk of increased emission and ecological footprint. While planning for economic growth considerable attention should be given to environment and its protection. Trade and urbanization were found reducing emission but increasing ecological footprint in the long run.

To analyze these results varies across countries, this study utilized the short run country specific resulted provided by ARDL model. This result is provided in Table 7. It is clear that in 19 out of the 24 countries RE consumption was found to reduce CO_2 emission. But in the remaining countries; Cambodia, Georgia, Iran, Iraq, and Malaysia, RE consumption resulted in increased emission. The result also showed that non-RE consumption increased emission in seven countries, and reduced it in six countries. For the remaining countries non-RE doesn't have any significant impact. When it come to the effect of economic growth, for a majority of the countries (13 out of 24), GDP was found increasing the emission, but in Lebanon, Philippines, and Kyrgyzstan this effect was negative. Trade openness was found reducing the emission in Armenia, Cambodia, Nepal, and Vietnam, but in 17 countries it increased the emission. The variable urbanization was found having a significant impact on CO_2 emission only in Lebanon.

Table 7: A Short Run Country Specific Effect on CO_2 Emission

Country	Re	non-re	GDP	Trade	Urban
Armenia	-0.339***	-0.255*	0.871***	-0.630***	39.433
Azerbaijan	-0.300***	-3.827	0.474***	0.204***	-0.002
Bangladesh	-1.386***	2.285	-0.316	0.155***	11.221
Cambodia	0.386**	1.18***	2.85***	-0.955***	14.705
China	-0.519***	1.516*	0.336*	0.047***	4.147
Georgia	0.153**	0.553**	0.555**	0.455***	-24.939
India	-0.268*	1.089**	0.030	0.008	-13.147
Indonesia	-0.726***	2.106	-0.108	0.028***	-2.469
Iran	0.089***	5.252	0.100**	0.020***	-20.191
Iraq	0.065***	1.772	0.161***	0.006***	8.639
Jordan	-0.230***	3.315	0.391	0.067***	1.025
Kazakhstan	-0.305***	-1.260	-0.37	0.149**	1.84
Kyrgyzstan	-0.555***	-0.545***	-0.611***	0.641***	17.888
Lebanon	-0.176***	-3.737***	-0.500**	0.117***	-2.374*
Malaysia	0.044***	2.143	0.467***	0.022	8.766
Mongolia	-0.108***	1.499	0.475**	0.083***	8.95
Nepal	-6.136***	-0.327***	1.874***	-0.147***	-2.723
Pakistan	-0.975***	0.122**	0.102**	0.001	-8.474
Phillipines	-1.131***	-0.751**	-0.516***	0.07***	1.003
Srilanka	-1.728***	1.017***	0.158	0.252***	-8.976
Tajikistan	-1.266***	-0.113***	0.55***	0.003*	-13.417
Thailand	-0.154***	1.28	1.084***	0.045***	-0.050
Uzbekistan	-0.143***	-1.0369	-1.51	0.017***	2.49
Vietnam	-0.237***	1.038***	0.97	-0.154***	1.611

Note: ***, **, * indicates statistical significance at 1 percent, 5 percent, and 10 percent respectively. Variables are in natural logarithmic form. Source: analyzed by authors

When it comes to the country specific effect on ecological footprint, RE consumption was found to reduce ecological footprint in 13 countries, but it had increased in 8 countries, and for the remaining 3 countries it was insignificant. Non-RE consumption was found to increase ecological footprint in 6 countries, it was reduced in 5 countries, and for the remaining countries it appeared to be insignificant. For half of the countries considered GDP resulted in increased ecological footprint. But in China, Iran, Mongolia, Tajikistan, and Uzbekistan ecological footprint reduced with GDP. Trade was found to increase ecological footprint in 11 countries and reduce in 9 countries. Urbanization had positive significant impact for Jordan and Uzbekistan, and negative impact for Sri Lanka.

Panel Causality Test

Identification of causal relation is essential for determining appropriate policies (Charfeddine, 2017). Hence to find out the direction of causality Dumitrescue and Hurlin pairwise granger causality test was used. This test allows for panel specific heterogeneity and cross-sectional dependence. Causal relation between the variables considered in the model is provided in Table 8 and 9[3] respectively.

The result showed similar causal relation for both the indicators of environment. Bidirectional causal relation was found between environmental indicators, and GDP and urbanization respectively. Unidirectional causality was found to exist from environmental indicators to RE consumption[4] and trade openness respectively. No causal relation was existing between non-RE consumption and environmental indicators.

[3] Though all the possible causal relation between the variables is examined, for simplicity only those showing the relation between the dependent variables and each of the independent variables is presented here.

[4] Though causal relation is found from RE consumption to ecological footprint, it is significant only at 10 percent level.

Table 8: Causal Relation Between CO_2 and the Independent Variables

Null Hypothesis:	Zbar-Stat.	Prob.
re does not homogeneously cause co2	0.16304	0.8705
co2 does not homogeneously cause re	5.04468***	5.E-07
Non-re does not homogeneously cause co2	0.89082	0.3730
Co2 does not homogeneously cause non-re	1.20973	0.2264
gdp does not homogeneously cause co2	10.4491***	0.0000
Co2 does not homogeneously cause gdp	9.76583***	0.0000
trade does not homogeneously cause co2	1.59624	0.1104
Co2 does not homogeneously cause trade	2.18642**	0.0288
urban does not homogeneously cause co2	10.3383***	0.0000
Co2 does not homogeneously cause urban	7.50923***	6.E-14

Note: ***,** denoted rejection of null hypothesis at 1 percent and 5 percent respectively. Source: calculated by authors

Table 9: Causal Relation Between Footprint and The Independent Variables

Null Hypothesis	Zbar-Stat.	Prob.
lre does not homogeneously cause lfootprint	1.91942*	0.0549
lfootprint does not homogeneously cause lre	2.95236***	0.0032
lff does not homogeneously cause lfootprint	-0.68754	0.4917
lfootprint does not homogeneously cause lff	1.43188	0.1522
lgdp does not homogeneously cause lfootprint	11.0499***	0.0000
lfootprint does not homogeneously cause lgdp	2.08296**	0.0373
ltrade does not homogeneously cause lfootprint	0.90043	0.3679
lfootprint does not homogeneously cause ltrade	2.80678***	0.0050
lurban does not homogeneously cause lfootprint	14.3597***	0.0000
lfootprint does not homogeneously cause lurban	6.36726***	2.E-10

Note: ***, **, * denoted rejection of null hypothesis at 1 percent, 5 percent, and 10 percent respectively. Source: calculated by authors

DISCUSSION ON EMPIRICAL FINDINGS

This study aims to find out how renewable and non-renewable energy consumption affect the environment in Asia. 24 developing countries of Asia were analyzed from 1990 to 2018. In line with the existing studies

(Bhattacharya *et. al.*, 2016; Mensah *et. al.*, 2019; Shaari *et. al.*, 2020) we found the existence of homogeneity and cross sectional dependence across our panel units. In addition, CIPS test confirmed the variables were of mixed order of integration and Pedroni co-integration test indicated the existence of long run relation between the variables. Hence ARDL model was used to obtain the short run and long run estimates. Dumitrescu-Hurlin pairwise granger causality test was used to examine the causal relationship between the variables.

The result showed that RE consumption helps in protecting the environment i.e. its expansion resulted in reduced emission and ecological footprint in both the short run and the long run. But non-RE consumption on the other hand resulted in increased emission and ecological footprint in the long run. Our findings on the impact of RE consumption fully agrees with Zeb *et. al.*, (2014) and Mahmood *et. al.*, (2019). In Zeb et al study electricity production from renewable sources was found reducing CO_2 emission in 5 SAARC countries; India, Bangladesh, Nepal, Pakistan and Sri-Lanka. Mahmood *et. al.*, identified RE consumption to reduce CO_2 emission in Pakistan but it was diminished with economic growth. When it comes to the impact of non-RE consumption our result for CO_2 emission was in consonant with Shaari *et. al.*, (2020) who found oil and gas consumption to increase emission in both the short run and the long run for a panel of 20 OIC countries. To some extent we agree with the findings of Charfeddine (2017) who found electricity consumption resulting in reduced CO_2 emission and increased ecological footprint in Qatar. Our findings are also in consonant with many other studies; Mensah *et. al.*, (2019) found positive effect and two way causality between energy consumption and carbon emission in African economy, Pao and Tsai, (2011) examined elastic relation and unidirectional causality from energy consumption to emission in Brazil, Russia, India, and China, Munir and Riaz (2019) examined positive influence for oil, gas, coal, and electricity consumption to emission in south Asian countries of Bangladesh, India, and Pakistan, and Soytas *et. al.*, (2007) examined unidirectional Granger causality from energy consumption to carbon emissions in the US. Contrary to the result of the existing studies our result showed unidirectional causality running from environmental indicators to RE consumption.

While analyzing the environmental impact of energy consumption this study included GDP, trade openness, and urbanization as the control variables. Hence the result provided some insights on the impact of these variables on environment. The result indicates that economic growth in the countries considered for the analysis is coming at the risk of the environment i.e. an increase in GDP was found accelerating the emission and ecological footprint in both the short run and the long run. Bidirectional causality was also found to exist between GDP and environmental indicators. This indicates that considerable attention should be paid while going for emission reduction and resource conservation measures otherwise economic growth may be affected. Our result is in consonant with Charfeddine (2017) and Shaari *et. al.*, (2020) with respect to the effect of economic growth on environmental degradation in Qatar, and OIC countries respectively. We also agrees with some other studies including Pao and Tsai, (2011) who found the existence of EKC hypothesis and bidirectional causality between output and emission in BRIC countries, Mahmood *et. al.*, (2019) who from a study in Pakistan found that economic growth out passes the positive impact that RE consumption has on CO_2 emission, and Zeb *et. al.*, (2014) who had found GDP lead to increased CO_2 emission in 5 SAARC countries of India, Bangladesh, Nepal, Pakistan and Sri-Lanka, and Liu and Liang, (2019) who found bi-directional causality between economic growth and environmental degradation for LMC (Lancang-Mekong Cooperation) countries. Contrariwise Soytas *et. al.*, (2007) couldn't found any causality between economic growth and emission in US.

Regarding the impact of other two variables, trade openness and urbanization; CO_2 emission was found decreasing with the expansion of these variables in the long run, but ecological footprint increased with it. When it come to the causal relation, unidirectional causality was found from environmental indicators to trade openness, but bidirectional causality was found between environmental indicators and urbanization. Hence, we partially agree with Charfeddine, (2017), who had found trade openness and urbanization accelerated the ecological footprint in Qatar, but for CO_2 emission the result was insignificant. But Mahmood *et. al.*, (2019) found CO_2 emission increased with trade openness in Pakistan. Their causal relation agrees with our result i.e. unidirectional causality from CO_2 emission to trade openness.

CONCLUSION AND POLICY RECOMMENDATION

Unprecedented changes in the climatic pattern made the world aware of the need of having cleaner planet. Among the alternative measures taken for combating the climate change, RE by considering its potential for reducing the energy related emission has gained attention. But to consider it as a sustainable solution it is essential to find out how it affects the environmental resources. In this context present study estimated the environmental impact of renewable energy consumption using a panel of 24 developing countries of Asia from 1990 to 2018. We have also incorporated the effect of non-renewable energy consumption.

Presence of panel specific heterogeneity and cross-sectional dependence, and the existence of co-integrated relation among the variables of mixed order of integration made us to utilize ARDL model-PMG for analysis. The result showed that; RE consumption reduced environmental degradation in both the long run and short run whereas non-RE consumption resulted in increased degradation. This indicates that renewable energy has to be promoted for attaining energy security without harming the environment. Hence, we would suggest the policy makers especially those from developing countries to proceed with their current motive for promoting renewable energy and to adopt further measures for its massive acceleration.

But the existence of bidirectional causal relation between GDP and the environmental indicators could be a challenge, because it indicates the possibility for emission reduction and resource conservation measures to adversely affect the economic growth. So, we would suggest the policy makers to find out the measures that could reduce the emission and ecological footprint with minimal or no impact on economic growth. RE promotion is an example for such measures because it can reduce the energy related emission and provide energy security without reducing the economic growth. Though a reduction in economic growth can be expected while transitioning to RE it won't persist for a long period i.e. in the long run RE could contribute to economic growth.

Emission is found to decrease with the growth of trade and urbanization in the long run but ecological footprint is found increasing with them. This could be because the countries considered may be adopting significant measures for reducing the emission but they may not be giving much attention for protecting other environmental resources. Hence instead of focusing only on emission reduction measures these countries should also be concerned about their natural resources and should try to implement some measures for reducing the ecological footprint.

Based on these empirical findings it can be inferred that instead of depending on fossil-based energy sources, developing countries of Asia should try for a transition to renewable energy for having energy security and economic growth without deteriorating the valuable environment. In addition to the adoption of emission reduction measures they must also be concerned about environmental resources and adopt measures for reducing the ecological footprint. Since most of the countries in Asia are at their developing stage considerable attention is required to ensure that their development is not coming at the risk of resource exploitation and carbon emission.

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Appendix A

Test for Panel Co-Integration

Table A1.a: Pedroni Panel Co-Integration Test Results with CO_2 as Dependent Variable

	Statistic	Prob.
Alternative hypothesis: common AR coefs. (within-dimension)		
Panel v-Statistic	-0.244358	0.5965
Panel rho-Statistic	1.593917	0.9445
Panel PP-Statistic	-2.012985	0.0221**
Panel ADF-Statistic	-3.141583	0.0008***
	Statistic	Prob.
Alternative hypothesis: individual AR coefs. (between-dimension)		
Group rho-Statistic	4.050376	1.0000
Group PP-Statistic	-1.703846	0.0442**
Group ADF-Statistic	-4.841809	0.0000***

Source: Estimated by authors.

Notes: Variables CO2, RE, Non-RE, gdp, trade, urban. Trend assumption: No deterministic trend. Lag selection: Automatic based on AIC with lags from 3 to 5. Newey-West automatic bandwidth selection with Bartlett kernel. ***, ** rejection of null hypothesis of no co-integration at 1 percent and 5 percent significance level respectively.

Table A1.b: Pedroni Panel Co-Integration Test Results With Ecological Footprint As Dependent Variable

	Statistic	Prob.
Alternative hypothesis: common AR coefs. (within-dimension)		
Panel v-Statistic	-0.222732	0.5881
Panel rho-Statistic	3.240958	0.9994
Panel PP-Statistic	-3.534838	0.0002***
Panel ADF-Statistic	-5.087883	0.0000***
	Statistic	Prob.
Alternative hypothesis: individual AR coefs. (between-dimension)		
Group rho-Statistic	3.961863	1.0000
Group PP-Statistic	-5.206051	0.0000***
Group ADF-Statistic	-7.022800	0.0000***

Notes: Variables footprint, re, non-re, gdp, trade, urban. Trend assumption: Deterministic intercept and trend. Lag selection: Automatic based on AIC with lags from 3 to 5. Newey-West automatic bandwidth selection with Bartlett kernel. ***Denote rejection of null hypothesis of no co-integration at 1 percent significance level. Source: Estimated by authors

Appendix B

ARDL model used in the study

To examine the environmental impact of energy consumption, separate ARDL model has run for each indicator of environment. By using the variables of this study ARDL expression shown in equation 5 can be expressed as follows.

$$\Delta lnco2_{i.t} = \beta + \phi_i\big[lnco2_{i,t-1} - \theta_i\big(lnre_{i,t} + lnnonre_{i,t} + lngdp_{i,t} + lntrade_{i,t} + lnurban_{i,t}\big)\big] + \sum_{j=1}^{p-1} \lambda^*{}_{i,j}\Delta lnco2_{i,t-j} + \sum_{j=0}^{q-1} \delta^*{}_{i,j}\Delta lnre_{i,t-j} + \sum_{j=0}^{q-1} \delta^*{}_{i,j}\Delta lnnonre_{i,t-j} + \sum_{j=0}^{q-1} \delta^*{}_{i,j}\Delta lngdp_{i,t-j} + \sum_{j=0}^{q-1} \delta^*{}_{i,j}\Delta lntrade_{i,t-j} + \sum_{j=0}^{q-1} \delta^*{}_{i,j}\Delta lnurban_{i,t-j} + \varepsilon_{i,t}$$

$$\Delta lnfootprint_{i.t} = \beta + \phi_i\big[lnfootprint_{i,t-1} - \theta_i\big(lnre_{i,t} + lnnonre_{i,t} + lngdp_{i,t} + lntrade_{i,t} + lnurban_{i,t}\big)\big] + \sum_{j=1}^{p-1} \lambda^*{}_{i,j}\Delta lnfootprint_{i,t-j} + \sum_{j=0}^{q-1} \delta^*{}_{i,j}\Delta lnre_{i,t-j} + \sum_{j=0}^{q-1} \delta^*{}_{i,j}\Delta lnnonre_{i,t-j} + \sum_{j=0}^{q-1} \delta^*{}_{i,j}\Delta lngdp_{i,t-j} + \sum_{j=0}^{q-1} \delta^*{}_{i,j}\Delta lntrade_{i,t-j} + \sum_{j=0}^{q-1} \delta^*{}_{i,j}\Delta lnurban_{i,t-j} + \varepsilon_{i,t}$$

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