Impact of Energy Efficiency on CO2 Emissions: Empirical Evidence from Developing Countries

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Abstract: Attaining higher level of the energy efficiency is being considered as a preferred and cost-effective policy option to achieve economic propensity, environmental sustainability and improved energy security in recent years. This drive to achieve higher energy efficiency levels is mainly motivated by higher international oil prices during last two decades, the concerns regarding energy supply security and rising CO_2 emissions globally. In this background, this study decomposes energy intensity into structural and activity effects, and empirically examines their impact on CO_2 emissions in environmental Kuznets curve framework for the developing economies. Second generation methodological approach is adopted. The decomposed indices reflect that energy efficiency has played a key role in decreasing energy intensity, while structural shifts have caused only a minor reduction in energy intensity. The findings suggest that energy efficiency improvements have largest influence on CO_2 emissions mitigation. In developing countries as a whole, energy efficiency has positive while structural shifts have negative relation with CO_2 emissions in long run. The findings presented that energy efficiency is major contributor of CO_2 emissions reduction. While structural shifts in developing countries tend to increase CO_2 emissions because these countries are moving towards the sectors that are producing more pollution. However, the income is one of the major contributors of CO_2 emissions. While renewable energy consumption has negative and industrialization has positive impact on CO_2 emissions in developing countries. The study outcomes are utilized to develop a policy framework for attaining the SDG 7 and SDG 13 in the chosen countries.

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1 Introduction

The latest Sustainable Development Goals (SDG) progress report (United Nations, 2020) displays the inability of the developing economies in tackling the problem of increasing emission level. At the moment, while developed nations around the world are notably advancing towards making sustainable energy future together with bringing forth improvement in environmental quality, the developing economies are struggling with rise in the emissions level. One of the major reasons behind such a situation in these countries is the predominant use of fossil fuel solutions for energy generation, and this prolonged reliance on fossil fuel-based energy solutions is also making the situation of energy security in these countries vulnerable. This energy-led growth trajectory is driving these countries depart from accomplishing the objectives of SDG 13, i.e., climate action. If economic growth pattern of these economies is analyzed, then it can be seen that policymakers have prioritized the achievement of economic growth over environmental protection. Given this situation, the economic growth pattern of these economies might not prove to be sustainable, and this might be a predicament in the way of accomplishing the objectives of SDG 8, decent work and economic growth. In the SDG progress report of 2019 (United Nations, 2019), these economies have been criticized for mobilizing the investments towards enhancing fossil fuel-based energy generation, while disregarding the environmental actions.

In order to sustain the economic growth pattern, these economies embark on the pool of natural resources, and this phenomenon can be traced back to the "*Limits to Growth*" discourse (Meadows et al., 1972). According to this discourse, recurring exhaustion of natural resources for production purpose might make the economic growth pattern unsustainable. This policy myopia might cause an unfavorable repercussion on the energy security of these nations. While discussing the scope of financing the renewable energy projects in developing countries, IRENA (2019) has specifically mentioned about these issues. They have also discussed about the role of energy innovation and alternate energy resources in accomplishing energy security in the developing countries. By gradually replacing the fossil fuel solutions, these initiatives can help the developing countries towards the accomplishment of SDG 7, i.e., affordable and clean energy. Now, given the level of technological adaptability, these economies have sufficient potential to achieve energy efficiency, which can not only solve their problem of energy security, but also enable them to tackle the issue of environmental degradation. In this context, UNEP (2017) and Langlois and Yank (2018) have identified energy efficiency to be a possible policy instrument to for transforming the developing economies to be low-carbon economies.

Nevertheless, the recent report by IEA (2020) poses a serious question before the energy transition scenario in the developing economies. The energy innovation initiatives in these economies are still at a nascent stage, and because of the financialization and scalability issues, these initiatives are yet to produce any significant results. At the same time, Bronstein (2020) from RTI International (formerly known as Research Triangle Institute) points out the design-related issues associated with the modern renewable energy solutions, which might impede the diffusion of these technologies in the developing economies. Hence, in spite of having the technological adaptability, the developing economies are yet to reap the benefit of the low-carbon energy transition, which could have brought forth the higher level of energy efficiency in these nations, while having a control over the pertaining issues of environmental degradation. During a discussion about the *Lighting Global* project, World Bank (2018) has emphasized on importance of energy innovation in the developing countries for encountering the problem of energy poverty, and they have also indicated a possible policy realignment in pursuit of attaining the objectives of SDG 7. This gives an indication that existing energy, environmental, and allied economic policies in the developing countries might require a reorientation, and in order to realize it, a comprehensive SDG framework might be required. There lies the focus of the study.

By virtue of this discussion, it can be expected that a comprehensive SDG framework is desirable for the developing countries, so that they can comply with the 2030 agenda. In order to achieve this, the present study aims at estimating the impact of energy efficiency on carbon emissions in 30 developing countries over the period of 1990-2016. In due course of this empirical exploration, this study aims at recommending a comprehensive policy framework for achieving sustainable development, and consecutively attuning low-carbon growth through energy efficiency. Given the reason that these economies are considered to be falling behind in terms of their accomplishment of the SDG objectives, a policy reorientation through recommending a comprehensive policy framework might help in designing a baseline approach, which can be used in the other developing economies as a benchmark for realigning their existing policies. Adding both energy efficiency and carbon emission within an empirical framework might aid in recommending a comprehensive policy framework for accomplishing the objectives of SDG 13, SDG 7, and subsequently SDG 8. However, while describing the policy framework, a phased-wise implementation outline might be adopted, for robustness of a policy framework encompasses the politico-economic associations and structural likenesses between these countries, and thus, a phase-wise implementation outline of the SDG framework might be recommended. Given our acquaintance of the literature, such a policy-reorientation method to tackle environmental degradation and energy security has not been executed, and there lies the policy level contribution of the study, in terms of recommending a baseline SDG framework for the developing economies.

Now, selecting an appropriate theoretical framework for analyzing this association is required, as the analysis will be carried out for capturing the evolutionary impact of energy efficiency on the target policy variable, i.e., carbon emissions. Hence, the Environmental

Kuznets Curve (EKC) hypothesis has been selected, because it is able to encapsulate the evolutionary impact across cross-sections (Dinda, 2004; Shahbaz and Sinha, 2019). Therefore, the predicted model results might endorse close to real effects for this context, which can be considered as a baseline finding for the other developing countries. Adaptation of this theoretical framework from a policy-level orientation can be considered as the analytical contribution of the study.

Lastly, in order to recommend any robust policy framework for the developing countries, it is necessary to take into account the politico-economic associations and structural likenesses between these countries, and this aspect should be incorporated in the methodological application. To comply with the research objective, second generation methodological approach has been employed, and for estimating the long run coefficients, Cup-FM (continuously-updated and fully-modified) and Cup-BC (continuously-updated and bias-corrected) methods are employed. This methodological adaptation complements the contextual setting by encapsulating the interdependence between the nations. This can be considered as the methodological contribution of the study.

The rest paper is ordered as follows: Section II proffers the review of relevant literature. Section III encompasses the research methodology. Results from decomposition and empirical analysis have been discussed in section IV, and the study is concluded with relevant policy suggestions in section V.

2 Literature Review

The present work is based on the groundbreaking study of Metcalf (2008) where energy intensity of US was decomposed into its various components at country and province level. Partial correction model was applied to quantify the impact of energy prices, capital to labor ratio, income and other environment related variable on energy intensity of US. The results demonstrated that energy efficiency improvement was the key factor in declining energy intensity whereas structural shifts did not contribute much in reducing energy intensity. The study also concluded that income and prices have a significant impact on energy intensity through the energy efficiency channel. Fan et al. (2006) reconnoitered the influence of technology, population and economic growth on CO_2 emissions of nations from different income groups by using data of 1975-2000 in STIRPAT model. The results suggested that economic growth is the major determinant of emissions in low-income countries while energy intensity has huge impact on CO_2 emissions in middle income countries.

Cantore (2011) decomposed energy intensity for developing countries by using Fisher Ideal Index. The results reflected that most of the developing countries are experiencing decreasing energy intensity over time. For these countries, the main contributor for the change in energy intensity is energy efficiency. It was also observed that their structural shift towards more dirty sectors increase the energy intensity. However, the study was unsuccessful in providing any policy suggestion due to limited time period and heterogeneity of results. Song and Zheng (2012) applied decomposition analysis to decompose energy intensity into various components using panel data on Chinese provinces for the period between 1995-2009. The results reflected that 90 percent reduction in energy intensity was because of energy efficiency enhancements and role of structural shift in this regard was very small. The econometric analysis concluded that price do not have much impact in achieving energy efficiency.

Chen et al. (2013) decomposed CO_2 emissions into energy structure, population, energy intensity, economic activity and structure of economy by using LMDI of period 1985-2011. All factors played positive role in increasing CO_2 emissions except energy intensity. Energy intensity plays major role in declining energy related CO_2 emissions. The main cause of declining energy intensity is improving energy efficiency. Income per capita is prime factor of CO_2 emissions however economic structure and energy structure of China also have positive impact on CO_2. The results suggested the policy makers to implement energy efficient technologies to efficiently reduce CO_2 emissions.

Jimenez and Mercado (2014) inspected the trend of energy intensity for Latin American countries. The study decomposed energy intensity by using Fisher Ideal Index for evaluating the influence of energy efficiency and action effects into energy intensity change. The energy intensity has been declining in these countries with the increase in income level. The study concludes that improvement in income results in the reduction of energy intensity in these countries. It also shown that the main determinant of declined energy intensity is energy efficiency whereas, structural changes do not play a major role. Lin and Liu (2015) considered economic factors those regulate CO_2 emissions in China' residential and commercial buildings by applying LMDI decomposition method. The study decomposed CO_2 emissions related to buildings into intensity effect, scale effect, structure effect and income effect. The results indicated that income effect has leading role in increasing CO_2 emissions while energy efficiency improvement and energy structure offset the income effect. Population growth also has minor effect in increasing in CO_2 emissions.

Tajudeen (2015) inspected the impact of energy efficiency and non-economic aspects (life style, human life style, consumer preferences etc.) in Carbon dioxide emissions and energy demand modelling. The study estimated UEDT to measure non-economic factors and energy intensity used as proxy for energy efficiency. The results revealed that non-economic factors are determinants of CO_2 emissions while energy efficiency is major factor of CO_2 emissions and energy demand in Nigeria. The result encourages to use energy efficient technologies as well as imports of energy efficient appliances to reduce CO_2 emissions.

Moshiri and Duah (2016) decomposed energy intensity in energy efficiency and structural shifts by using Fisher Index at country, provincial and industry level in Chanda during 1981-2008. The results stated that energy efficiency is main reason of declining energy intensity and activity effect has less influence on energy intensity in Canada. Technological advancement plays major role in improving energy efficiency. The results suggested to encourage Research and development and improve energy efficiency to meet CO_2 emissions goals.

Tajudeen et al. (2018) investigated the impact of energy efficiency on CO_2 emissions in OECD countries. The study used Fishers' Ideal Index to decompose energy intensity and examined the effect of energy efficiency on CO_2 emissions during enumerating the influence of non-economic factors on carbon dioxide emission in these countries by applying STSM and LSDVC techniques. The results revealed that as a whole, energy efficiency is a prime basis of declining energy intensity while structural changings have less effect on energy intensity change. The country level evidence suggests that the results are mixed as both energy efficiency improvements and activity effects are the cause of declining energy intensity. The study outcomes illustrate that income plays a key part in increasing CO_2 emissions, when energy efficiency plays a key part in reducing it. Non-economic factors also play significant role in driving carbon emissions down. Chen et al. (2018) examined the impact of economic output, CO_2 emission intensity, size of population, energy intensity, population distribution, and structure of power utilization on carbon discharge in the OECD nations. The results explained that energy intensity and economic output are prime driving factors behind increased CO_2 emissions, followed by the influence of population. Furthermore, the structure of power utilization and carbon discharge intensity has minor consequence in increasing CO_2 emissions.

Zafar et al. (2019a) explored the link between renewable and non-renewable energy consumption and CO_2 emissions. The paper also inspected EKC hypothesis for emerging economies by using data of period 1990 to 2015. The study applied second generation unit root tests and applied Westerlund cointegration test approach. To estimate long run relationship the study applied CUP-FM and CUP-BC approaches. The results revealed that renewable energy usage has negative while non-renewable energy consumption has positive effect on CO_2 emissions in emerging economies. The results of study also support EKC hypothesis and trade unpleasantly affects the environment of emerging economies. The study advised policy makers to improve the portion of renewable energy consumption in energy consumption, increase expenditures on research and development to innovate environment friendly technologies and increase public awareness about renewable energy consumption.

Through this brief review of literature, it is evident that the studies on the impact of energy efficiency and level of economic activities on CO_2 emissions provide inconclusive evidence. Perhaps that is the reason behind the absence of a comprehensive policy framework in the developing economies for attaining sustainable development. The present study addresses this persisting policy void by decomposing energy intensity into its various components and estimate their impact on CO_2 emissions for the case of developing economies. Moreover, incorporation of the EKC hypothesis allows capturing the evolutionary impact of the policy instruments over a temporal frame. This theoretical foundation has allowed to bring additional policy insights, which was absent in the earlier studies in the literature. This can describe the contribution of the study.

3 Data and Econometric Methodology

While deciding upon the methodological application, it is necessary to take into account the politico-economic associations and structural likenesses between the developing countries, and this aspect should be incorporated in the methodological application. To comply with the research objective, second generation methodological approach has been employed. The major reason behind is that the second-generation methodological approach is able to encompass the cross-sectional dependence, which is a crucial factor for developing policies for the countries being considered in the study. For checking order of integration, presence of cointegration, and long run coefficient estimation, second generation methods have been employed. This methodological adaptation complements the contextual setting by encapsulating the interdependence between the nations.

This section describes two stage assessment method employed in the present work. In the first step, we decompose energy intensity into its various components by using index decomposition analysis. In the second step, we employ econometric model based on modified 3Es (Energy, Environment and Economy) framework to pragmatically estimate the consequence of energy efficiency index and activity index on CO_2 discharge for the case of developing nations.

3.1 Decomposition of Energy Intensity

Different decomposition techniques have been used to quantify the contribution of various factors on energy intensity. Hoekstra and van den Bergh (2003) classified these approaches into Index decomposition analysis (IDA) and Structural decomposition analysis (SDA). For decomposing energy intensity, we have opted to use IDA which can be applied on data that is accessible in time series and at the disaggregated level. In the absence of detailed input-output data on energy use, IDA method provides reliable results (Inglesi-Lotz & Pouris, 2012).

Following Metcalf (2008), we have employed Fisher ideal index for decomposing energy intensity into its subcomponents. The Fisher Ideal Index perfectly decomposes the prime variable of interest without leaving any residuals. This is the only index number theory which satisfies the factor reversal, time reversal, positivity and quantity reversal properties (Boyd & Roop, 2004). The aggregate energy intensity e_t can be represented as;

$$e_t = \frac{E_t}{Y_t} = \sum_i \frac{E_{it}}{Y_{it}} \frac{Y_{it}}{Y_t} = \sum_i e_{it}\, s_{it} \quad (1)$$

Where e reflects energy intensity, E_t denotes aggregate energy consumption, Y_t represents aggregate GDP, E_{it} and Y_{it} reflect energy consumption and output of an economy for i^{th} economic sector in year t. e_t equals product of economic structure of the given sector and energy intensity of the given sector. Equation 1 indicates that the aggregate energy intensity depends on the sum of product of energy intensity of a particular sector (e_t) and structure associated with economic activity (s_{it}) in different sectors[2]. Therefore, the aggregate energy intensity can be constructed through dividing energy intensity of year t (e_t) by base year energy intensity (e_0) implying;

$$I_t = \frac{e_t}{e_0} = \frac{\Sigma e_{it} s_{it}}{\Sigma e_{i0} s_{i0}} \quad (2)$$

The energy intensity index I_t , is further decomposed into energy efficiency index and activity index. Energy efficiency index which is denoted by D^{EFF} reflects the change in energy intensity as a result of change in energy efficiency, keeping economic structure constant (Moshiri & Duah, 2016). The activity effect denoted by D^{ACT} represents energy intensity to change in structure of an economy while holding energy efficiency constant within the sector (Moshiri & Duah, 2016). The decomposition of energy intensity index can be done using Laspeyres index and Paasche index. Laspeyres index uses fixed weight of base period and Paasche index uses fixed weight of end period values expressed below:

$$\text{Laspeyres index: } L^{EFF} = \frac{\Sigma_i e_{it} S_{i0}}{\Sigma_i e_{i0} S_{i0}} ; L^{ACT} = \frac{\Sigma_i e_{i0} S_{it}}{\Sigma_i e_{i0} S_{i0}} \quad (3)$$

[2] In various studies, energy consumption is decomposed into three components including economic activity, structural change and efficiency. In this research, we follow Moshiri and Duah (2016) and decompose energy intensity into two components: namely, structural change (activity index) and efficiency (efficiency index).

Paasche index: $P^{EFF} = \frac{\Sigma_i e_{it} S_{it}}{\Sigma_i e_{i0} S_{it}}$: $P^{ACT} = \frac{\Sigma_i e_{it} S_{it}}{\Sigma_i e_{it} S_{i0}}$ (4)

These two indices produce different decomposition results because their base years are not the same and can produce residual (Metcalf, 2008). The Fishers' Index overcomes this drawback, by perfectly decomposing energy intensity into energy efficiency index and activity index devoid of any residuals. The weighted average of these two indices, has been used by Fisher to obtain efficiency and activity index as follows

$$F^{EFF} = (L^{EFF} \times P^{EFF})^{1/2} \quad ; \quad F^{ACT} = (L^{ACT} \times P^{ACT})^{1/2}$$

In this manner, the total energy intensity can be written as follows

$$F^{ACT} = \sqrt{(L^{ACT} \times P^{ACT})} \; ; F^{EFF} = \sqrt{(L^{EFF} \times P^{EFF})} \quad (5)$$

We can write energy intensity index as the product of energy efficiency index and activity index as;

$$\mathrm{I}_t = \mathrm{e}_t/\mathrm{e}_0 = F^{EFF} . F^{ACT} \quad (6)$$

By using equation 6 we can also compute the energy savings in years t due to improvements in energy intensity. The change in energy savings due to changes in energy efficiency and activity of economy are reflected as;

$$\Delta \mathrm{ESt} = E_t - \hat{E}_t = \Delta ES_t \left[\frac{\ln(F_t^{EFF})}{ln(I_t)}\right] + \Delta ES_t \left[\frac{\ln(F_t^{ACT})}{ln(I_t)}\right] = \Delta ES_t^{EFF} + \Delta ES_t^{ACT} \quad (7)$$

In equation 7, E_t is the real power consumed while $\hat{E}_t$ is the energy consumption that occur when energy intensity remained at base year level. The change in actual energy consumption and energy consumption in the base year depends on the difference in energy efficiency and structural activity. Using equation 7, energy saving in the economy is obtained which is equal to the difference between actual energy consumption (E_t) and energy consumption when energy intensity remained at base level ($\hat{E}_t$). This indicates that energy savings in an economy is attributed to the improvement in energy efficiency and structural changes in economic activity.

3.2 Energy Efficiency and CO_2 Emissions

The above method considers the decomposition of energy intensity in a purely descriptive manner. It does not empirically investigate the outcome of energy efficiency improvement and temporal transferences in an economy on CO_2 emissions in developing countries. In this section, we thus analyzed the impact of decomposed indices on CO_2 emission in selected developing countries using econometric method.

The relationship flanked by energy efficiency and energy consumption is clear, but the connotation amid energy efficiency and CO_2 emissions is not direct and can be observed through energy consumption. The use of energy in an efficient manner decreases energy spending, improves energy savings and boosts productivity. All these factors lead to change in energy consumption affecting the environment.

Following Adetutu et al. (2016), we specify that energy consumption directly depends upon energy efficiency and we can incorporate structural shifts as a determinant of energy consumption. The model as follows:

$$E_{it} = \pi_0 + \pi_1 EFF_{it} + \pi_2 y_{it} + \pi_3 ACT_{it} + \pi_4 Z_{it} + U_{it} \quad (8)$$

Where subscript t refers to time and i refers to country in the panel of data. E_{it} is the per capita energy usage, EFF_{it} refers to the measure of energy efficiency, ACT reflects structural changes, Z_{it} accounts for other exogenous variables and Y_{it} presents the per capita income.

Following Ang (2007), we combine EKC and hypothesis to link energy consumption, CO_2 emissions and economic growth.

$$CO_{2\,it} = \vartheta_0 + \vartheta_1 Y_{it} + \vartheta_2 Y_{it}^2 + \vartheta_3 E_{it} + U_{it} \quad (9)$$

Whereas $CO_{2\,it}$ represents per capita carbon dioxide emissions, Y_{it} is per capita income, Y_{it}^2 is squared per capita income, E_{it} pertains to per capita energy usage and U_{it} is error term. The coefficients ϑ_1 and ϑ_2 are used to test environmental Kuznets curve hypothesis.

We can construct the following model to study the impact of energy efficiency on CO_2 emissions by substituting equation 8 into 9 as;

$$CO_{2\,it} = \beta_0 + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 EFF_{it} + \beta_4 ACT_{it} + \beta_5 ES_{it} + \beta_6 IND_{it} + U_{it} \quad (10)$$

Whereas EFF_{it} is energy efficiency index and ACT_{it} is the activity index obtained from Fishers' Ideal Index. Here we control the effect of income, structural changes, renewable energy consumption and industrialization to avoid omitted variable bias (Tajudeen et al., 2018; Sharma et al., 2021; Zafar et al., 2020, 2021). In equation 10, we have added Y_{it}^2 to assess EKC hypothesis for developing nations. The present work is focused at assessing the EKC hypothesis in presence of energy efficiency and structural index parameters which has not been done in the earlier literature.

3.3 Estimation methodology

The prime objective of the study is to empirically examine the determinants of CO_2 emissions in developing countries. Our study studies the long-term relationship therefore the cointegrating relationships among the variables and its magnitude carry great importance. In this regard, the estimation process involves the following steps. Initially we test the cross-sectional dependence in panel data set followed by the first generation and second-generation unit root tests. In presence of same order of integration, the next step is to examine the cointegrating relationship between variables. After determining the long run relationship between variables, in the last step we quantify the magnitude of the relationship among variables using Cup-FM and Cup-BC techniques.

3.3.1 Cross-sectional dependence

The countries are linked with each other in numerous ways including socioeconomic linkages, trade, borders sharing, financial integration and global economic shocks. These influences may become the reason of cross-sectional dependence in panel data sets. De Hoyos and Sarafidis (2006) explained that unobserved shocks may become the reason for the existence of cross-sectional dependence in panel data and this unobservable portion becomes part of the error term. If these cross-sectional dependence effects are not controlled, the resulted standard errors can be inconsistent and estimators would be biased and inconsistent (Phillips & Sul, 2003). Consequently, evaluating cross-sectional dependence in dataset is essential. In this pursuit, cross-sectional dependence test devised by Pesaran (2004) is utilized and it can be reflected as:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \rho_{ij}\right) \quad (11)$$

Where N is cross-section, T is time series, P_{ij} illustrates association of errors between cross sections. The null hypothesis is that error terms from regression are uncorrelated.

H_0: Cross sectional independence

H_i: Cross sectional dependence

3.3.1 Panel unit root tests

To examine the unit root properties of panel data we have used two groups of methods. Levin- Lin-Chu (2002) panel unit root test assumes that several cross-sectional orders have common unit root in panel data. Im, Pesaran, and Shin (2003) test has also been applied to evaluate stationarity of model parameters. It relaxes assumption of no serial correlation and homogenous panel. Other Unit root tests like Fisher Augmented Dickey Fuller (1979) and Phillips & Perron (1988) are too utilized to unwind the postulation of homogeneity as the test allows for first order autocorrelation. The null hypotheses of all these tests state the existence of unit root.

If panel data encounters cross-sectional dependence, use of conventional unit root tests like LLC, IPS, Hadri etc. can increase the possibility of misleading unit root results. Therefore, we have also employed second generation unit root tests; to take into account the cross-sectional dependence while examining the stationarity of data. In the second-generation unit root tests, there have been three major approaches. The first approach proposed by Maddala and Wu (1999) uses bootstrap on panel unit root tests which was further expanded by Chang (2004) and Palm et al. (2011). The second approach proposed by Bai and Ng (2004, 2010) stems from unobservable elements and common factors obtained from decomposed observed series. The third group of tests anticipated by Pesaran (2007) augments Dicky-fuller regression with cross sectional averages and their first differences of series to remove the influence of cross-sectional dependence and to take into account serial correlation in error. The following regression is regarded as cross-sectional augmented Dicky Fuller (CADF) test (Pesaran, 2007).

$$\Delta y_{it} = \alpha_{it} + \rho_i y_{i,t-1} + \beta_i \bar{y}_{t-1} + \sum_{j=0}^{K} \Upsilon_{ij} \Delta\bar{y}_{i,t-1} + \sum_{j=0}^{K} \delta_{ij} y_{i,t-1} + \varepsilon_{it} \quad (12)$$

Whereas $\bar{y}_{t-1} = \left(1/_N\right) \sum_{i=1}^{N} \Upsilon_{i,t-1}$ and $\Delta\bar{y}_t = \left(1/_N\right) \sum_{i=1}^{N} \Upsilon_{i,t}$. t_i is the test statistics for each CADF of individual cross section of the panel which is estimated through OLS. Cross-sectionally augmented IPS (CIPS) follow the same process of CADF but the only difference between these two tests is that it is the cross-sectional average of CADF.CIPS test is presented as follows

$$CIPS = \left(\frac{1}{N}\right) \sum_{i=1}^{n} T - 1(N,T) \quad (13)$$

CADF provide efficient results in both case where T<N and also where T>N. CADF test for panel unit root can be performed for every cross-sectional unit separately in the panel. This test can also check the stationarity of series for each cross section and also for overall panel.

The null hypothesis of the test states that all series have unit root against the alternative hypothesis that only fraction of series does not contain unit root. This study has employed CIPS and CADF proposed by Pesaran (2007), respectively.

3.3.4 Panel Cointegration test

After testing for the stationarity of data, we have found that all variables are first difference stationary. Therefore, we need to test for the presence of long run relationship among the variables using methodology proposed by Pedroni (1999, 2004). The reason for selection of Pedroni (1999) test is that it controls for heterogeneity and size of country. Pedroni's method differs from other approaches like Kao (1999) due to its assumptions and null hypothesis. It provides seven different cointegration test statistics and divides them into two groups. The first group of tests looks at within dimension whereas the second test focuses on amid dimension individualities. Within dimension assessment indicators are regarded by panel cointegration indicators, whereas between dimension indicators are referred to as mean group indicators. Within dimension assessment indicators pool autoregressive coefficients across various cross-sectional units for unit root test on predicted residuals (Apergis & Payne, 2009). The between dimension statistics report the average of individually estimated autoregressive coefficient for each cross section in the panel (Apergis & Payne, 2009; Shahbaz et al., 2017). Between group statistics allow the heterogeneity across the individual cross section of the panel but within group test statistics are restrictive in this matter (Apergis & Payne, 2009).

We have employed the following equation to test for long run relationship among variables in conducting the Pedroni's test.

$$Y_{it} = \alpha_i + \delta_i + \beta_{1i}X_{1i,t} + \beta_{2i}X_{2i,t} + \beta_{ki}X_{ki,t} + \varepsilon_{i,t}$$

(14)

Whereas α_i represents individual effects and δ_i represents trend effects, $\varepsilon_{i,t}$ is the error term. To estimate these test statistics, the first step is to estimate the equation (14) and obtain residuals. Secondly, take the first difference of series for each cross-sectional unit and store residuals.

$$\Delta x_{i,t} = \theta_{1i}\Delta Z_{i,t} + \ldots\ldots + \theta_{mi}\Delta Z_{mi,t} + \eta_{it} \quad (15)$$

The third step is to estimate long run variance from residuals generated from differenced regression. The last step is to estimate autoregressive model by using residuals from first step. The null hypothesis for all seven test statistics is same and as follows:

H_0: $\rho_i = 1$, $i \in \mathbb{R}$

While the alternative hypothesis for panel statistics and group statistics as given:

Heterogeneous alternate hypothesis: H_I: $\rho_i < 1$, $i \in \mathbb{R}$

Homogeneous alternate hypothesis: H_I: $\rho_i =: \rho < 1$, $i \in \mathbb{R}$

Panel statistics are related to heterogeneous alternative hypothesis while group statistics are linked with homogeneous alternative hypothesis (Abdullah et al., 2017). To reject null hypothesis, "Panel V" statistics required left tail with large positive values while remaining test statistics required large negative values (Apergis & Payne, 2009). The major benefit of this test is that it takes into account heterogeneity by assuming that parameters can diverge through cross-sections following the H_I of between dimension.

In presence of cross-sectional dependence, the cointegration results by Pedroni and other first generation cointegration tests could be ambiguous because they assume cross sectional independence. To solve this issue, Westerlund cointegration test is proposed. Westerlund (Westerlund, 2007) cointegration test consider diverse forms of heterogeneity in panel and takes into account cross sectional dependence. Westerlund test is based on structural dynamics instead of residual dynamics and it does not impose common factor restrictions (Westerlund, 2007). Therefore, it uses information more efficiently than tests based on residual dynamics as residual based tests lose their power due to common factor restrictions (Persyn & Westerlund, 2008).

The Westerlund test presents four test statistics, two of them (G_a and G_t) test whether panel as a whole is cointegrated or not, and other two test statistics (P_t and P_a) test whether minimum a single cross section is cointegrated, or not. The Westerlund panel cointegration test is presented the as follows;

$$\Delta Y_{it} = \delta_i d_t + \alpha_i Y_{i,t-1} + \wedge_i X_{i,t-1} + \sum_{j=1}^{pi} \alpha_{ij} \Delta Y_{i,t-1} + \sum_{j=qi}^{pi} \gamma_{i,j} \Delta X_{i,t-1} + \varepsilon_{it} \quad (16)$$

Whereas $\wedge_i = -\alpha_i \beta_i$ while α_i defines the speed of adjustment towards equilibrium after abrupt shock. If $\alpha_i = 0$ then error correction does not exist and there is no cointegration but if $\alpha_i < 0$ then error correction exists and Y_{it} and X_{it} has a long run relationship. Thus, the null hypothesis assumes H_0: $\alpha_i = 0$ for all i against the alternative hypothesis that group mean statistics (G_a and G_t) is H_1 : $\alpha_i < 0$ for at least for one cross-sections. It means that cointegration exists in at least one cross sectional unit in panel data. The alternative hypothesis for panel tests (P_t and P_a) is H_1 : $\alpha_i < 0$ for all i which means that cointegration exist in panel as a whole.

3.3.5 Long run estimation

Evaluating the long run relationship among variables is indispensable. Many studies estimate the long run coefficients by using first generation techniques but these techniques do not pay attention to the issue of cross-sectional dependence (Zafar et al., 2019b). To solve this problem, we have used Continuously updated and fully modified (Cup-FM) and continuously updated and Bias corrected (Cup-BC) estimators proposed by Bai and Ng (2006) and Bai et al. (Bai et al. 2009). These second-generation long run estimators solve the issue of cross-sectional dependence, serial correlation, take into account the endogeneity and allow the variables having two orders of integration, i.e. I (1) and I (0) (Bai et al., 2009). Equation (15) is used for the estimation of Cup-FM and Cup-BC estimators.

$$\left(\hat{\beta}_{CUP,}\hat{F}_{BC}\right) = argmin \frac{1}{nT^2} \sum_{i=1}^{n} (Y_i - X_i\beta)' \, M_F (Y_i - X_i\beta)$$

(17)

Whereas, β is estimated coefficient attained from FMOLS and F shows the common factors assumes by residuals. Cup-FM estimators precise the bias at each iteration while Cup-BC correct the bias only at the last step of iteration. The estimators of Cup-FM and Cup-BC delivers unbiased and consistent findings.

3.4 Data

We have used panel data comprising of 30 developing countries from 1990 to 2016 for carrying out the analysis. The data has been extracted from World Development Indicators and International Energy Agency. For developing countries this study took lower middle-income and lower income countries according to world bank countries classification, 2018 and that their GNI per capita is \$995 or less and between \$996-\$3895 respectively. The time period and number of cross-sectional units are selected on the basis of data availability. For decomposition of energy intensity, data on GDP, aggregate energy consumption, sectoral energy consumption and sectoral value added has been used.

The descriptive statistics and list of developing countries are attached in Supplementary data, Table S1 and S2.

4 Results

The results of the study have been classified into two subsections. The first subsection contains the results of decomposition analysis while the other one reports the discussion on empirical findings.

4.1 Outcomes of energy intensity decomposition

Our study has used Fishers' Ideal index shown in equation (6) for decomposition of energy intensity into structural and efficiency indices by using data of period 1990-2016. The results of energy intensity decomposition for developing countries are display in the Figure 1. The

Figure 1 illustrates that the energy intensity of these developing countries has decreases over the period of time. The decrease in indices from their base period represents improvement. The trends suggest that by holding activity effect constant, efficiency index causes an enhancement in energy intensity index through improvement in efficiency and by holding efficiency effect constant activity index causes enhancement in energy intensity index through structural shifts in the economy.

By taking 1990 as reference period, the energy intensity index in 2016 is 31 percent of level in 1990. In other words, the total decline in energy intensity between 1990 and 2016 is 69 percent for the case of developing countries. The efficiency and activity index are 32 percent and 92 percent of their base period level. This implies that if energy efficiency is held perpetual at its reference period level, energy intensity of economy would have decreased by 6 percent. While if economic structure has remained unchanged between 1990-2016, the energy intensity of economy would have decrease by 68 percent of its 1990 level. The results express that energy efficiency has been the major contributor to this decline in energy intensity while the role of structural shift is very small. During the period of high-income growth, developing countries tends to shift production from dirtier sectors and the structural shifts become the prime source for increasing energy intensity.

The study calculated energy hoarded proportionate to the energy units probably been used up, if energy intensity remains constant at its level in 1990 by using equation (8) and the results are plotted in Figure 2. In 2015, total 19148.88 KTOE was less utilized attributable to diminution in energy intensity of developing countries. The study outcomes designate that 90.3 percent of energy saving occurred due to efficiency improvements while the savings due to structural change remained only 9.6 percent of the total energy savings. The Figure 2 further illustrates the trend of energy saving due to energy efficiency improvements and changes in the structure of economy. It is reflected that almost entire energy savings came from energy efficiency improvement. Structural changes contribute very small proportion of energy savings and during 1992,1994 and 1995, the structural effects caused energy dissaving.

Table 2 shows the summary statistics of decomposed energy intensity indices across 29 developing countries for several intervals between 1990 to 2016. The average annual rate of change of energy intensity, energy efficiency and activity index are -2.303, -2.265 and -0.045 respectively. The change in energy efficiency and activity index was sharp till 2010 but remained slow during 2011-2016.

4.1.1 Region wise decomposition results

The Figure 2 shows the results of decomposed indices at group level. The improved energy efficiency does not mean that the overall energy efficiency is improving in all developing countries. Therefore, we plot region wise data of energy intensity index, efficiency and activity index to examine the trends more carefully. Figure 3 shows the trends of energy intensity index, efficiency and activity index for different geographical regions of the developing world. Energy intensity in all of the regions is decreasing and major factor behind the energy intensity change is the energy efficiency improvements. However, structural effect plays very small role in decreasing the energy intensity. The regions like South Asia, Latin America and Caribbean, Middle East and North Africa register smooth decreasing trend in their energy intensity. In South Asia, the contribution of energy efficiency and activity effects in decreasing energy intensity is 70% and 4% respectively. Almost same situation is observed in Middle East and North Africa and energy intensity consistently decrease by 71% during 1990-2016. Comparatively, structural changes in Latin America & Caribbean have more influence on energy intensity than any other developing regions as the regions' energy efficiency and structural shifts contribute decline in energy intensity of the region by 69% and 17% respectively.

The energy intensity of East Asia declined by 84% between 1990 to 2016. Whereas in 1998, volatility in energy intensity in East Asia was driven primarily by East Asian financial crisis of 1997. The heavy dependence of East Asia on the bank based financial system made the crisis more severe. Therefore, the economic growth of the region and especially for Indonesia and Philippines was affected adversely. After that the region tackled the crisis, decline in energy intensity occurred due to rapid economic expansion.

In contrast to other regions, the structural shifts caused to 17% increase in energy intensity in Europe and Central Asia. However, the energy intensity of the region decreases by 79% during 1990-2016. The fluctuations in energy intensity in Europe and Central Asia during 1990s was due to several factors. Firstly, Tajikistan suffered from Civil war during 1992-1997 and Russian financial crisis in 1998. Civil wars affected the economic growth of Tajikistan badly. Moreover, the economic situation worsened due to Russian economic crisis. Secondly, the energy intensity increased during 1998-2000 due to industrial structure collapse in Ukraine.

Sub Saharan Africa contains the some of the world least developed countries. This region is considered Dark Continent of the modern age because only 35 percent of population has access to electricity and having lowest per capita energy consumption in the world (WDI 2012). Moreover, the highest energy intensive countries are also the low-income countries of Sub-Saharan Africa. From 1990 to 2002, energy inefficiencies contributed to rising energy intensity in Sub-Saharan Africa. However, during 1990-2016, the energy intensity decreases by 57% and energy efficiency and activity indices contributes 56% and 14% in decline in energy intensity respectively. The Figure 3 illustrates that energy intensity in Sub Saharan Africa faced fluctuations in 1990s and after 2000, the energy intensity has registered a declining trend. The rise in energy intensity during early 1990s occurred during the period of slow economic growth. After that, since 1995 the energy intensity of the region declined with minor fluctuations because the growth rate has remained consistent because of improvement in macroeconomic environment, trade and suitable financial situations etc. The key factor behind the declining energy intensity since 2000 is improvement in economic growth which was due to infrastructural improvements.

4.2 Empirical results

4.2.1 Cross sectional dependence

Table 3 outlines the outcome of cross-sectional dependence analysis. The test results for CO_2 emissions, energy efficiency, economic growth, squared term of economic growth and economic structure are significant and all these variables contain cross-sectional dependence. However, only activity effect has insignificant results (Pesaran, 2004). test sanctions the presence of cross-sectional dependence in all variables except activity effect.

4.2.2 Results from panel unit root tests

Table 4 shows results based on first generation unit root tests. All the variables namely CO_2 emissions, economic growth and its square, energy efficiency, activity index, renewable energy and economic structure contain unit root at level. However, all the variables become stationary after taking the first difference. The results of Table 4 show that all the variables are I (1).

The results from second-generation stationarity tests have been presented in Table 5. Outcome of CADF and CIPS designate that all the model parameters are non-stationary at level, and they become stationary at their first differences.

4.2.4 Panel cointegration test

Subsequent to stationarity testing, it has been endorsed that the model parameters are I (1). This warrants us to test for the cointegrating relationship among variables. The results from

Pedroni test of cointegration have been displayed in table 6. The assessment outcome divulges that long run relationship persists amid economic growth and its squared term, energy efficiency, activity index, renewable energy consumption, economic structure, and CO_2 emissions.

The results of panel cointegration proposed by Westerlund (2007) have been displayed in second part of table 6. The assessment outcome validated the presence of cointegration, and thereby confirming long run affiliation in incidence of cross-sectional dependence.

4.2.6 Long run estimates

The results of panel cointegration tests have confirmed the presence of cointegration among the study variables. In the next step, we estimate the long run relationship among our variables of interest. The study has employed Cup-FM and Cup-BC for estimation of long run equation are reported in table 7. All the variables are in log form therefore the parameters of long run model can be explained in terms of long run elasticities.

Overall, the results from CUP-FM and CUP-BC are consistent and carry similar signs. In both the estimates, the signs of GDP and GDPS are positive and negative respectively. More precisely, we can say that in developing countries, the environmental degradation increases with the increase in income level but after reaching certain threshold level of income, then increase in income improves the environmental quality. This indicates that Environmental Kuznets Curve hypothesis exits for the case of developing countries. The results of this study are consistent with previous literature (Ahmed et al., 2017; Zafar et al., 2019b). The estimates of energy efficiency from CUP-FM and CUP-BC are also nearly same.

The energy efficiency has positive and statistically significant influence on CO_2 emissions. The positive signs suggest that when the energy efficiency index decrease (shows energy efficiency has improved) CO_2 emissions decline (Tajudeen, 2015; Tajudeen et al., 2018). In long run, energy efficiency improvements reduce CO_2 emissions in developing countries. If we look at the coefficients, energy efficiency is major contributor to CO_2 emissions reduction while income effect is also large but it is less than energy efficiency. The results of the study highlight the significance of energy efficiency in reducing environmental pressures, energy imports and improve energy security.

The structural shifts have dampening consequence on CO_2 emissions. It designates that when activity index decreases (structural shifts occur) CO_2 emissions will increase. The result specifies that structural shifts in developing countries encourage CO_2 emission because they are not moving towards less energy intensive sectors. The developing countries are shifting from less energy consuming sectors to more consuming sectors. As the economy grows, it moves from primary industries to secondary and tertiary industries that are more energy intensive and leads to rapid economy growth. Industrial sector is more pollution concentrated than agriculture and services sector (Neumayer, 2003). The energy productivity of developing countries reduces due to increasing industrialization. The results are in line with earlier literature Alam (2010), Shironitta (2016) and Tajudeen et al. (2018) and support the hypothesis that the environmental pollution of the country will increase when it shifts from agriculture-based economies (less energy intensive) to the industrial based economies (more energy intensive) because of increasing energy demand (Ali et al., 2017).

The industrialization in developing countries has positive and significant impact of CO_2 emissions. It means that by increasing industrial value added, the environmental pollution increases. The outcome of the study reveals that industrial sector of developing countries is not environmentally friendly. The results may also be due to the composition of economic growth, as in early stages, increase in economic growth causes shifts in the economy from agricultural sector to the industrial sector, which becomes the reason of environmental degradation. However, after reaching desirable economic development level, the structure of economy shifts from more energy intensive to less energy intensive sectors. The results are consistent with previous literature (Apergis & Ozturk, 2015; Chen et al., 2013; Wang et al., 2011).

Renewable energy consumption is found to be dampening the pattern of carbon discharge in developing countries. The renewable energy consumption in developing countries helps to enrich ecological eminence, and therefore, the developing countries require taking steps for improving the share of renewable energy consumption in energy portfolio. The results are on the similar lines with the propositions of (Al-Mulali et al., 2015; Bölük & Mert, 2015; Farhani & Shahbaz, 2014). The findings of the study highlight the importance to regulate production of energy through renewable energy sources. It will reduce the dependence on energy imports and improve energy security. The shift of energy mix from more polluting energy sources to less polluting energy sources would be very important to achieve sustainable development goals.

In the nutshell, the empirical results suggested that energy efficiency, renewable energy consumption and real income reduce pollution in the long run. The activity effect, industrialization and economic growth contribute to environmental damages. The results confirm the existence of Environmental Kuznets Curve hypothesis for the case of developing countries. Study suggests policy makers to take steps to improve energy efficiency and fulfill the energy demands through renewable source of energy.

4.2.7 Robustness check

In order to verify the robustness of the study outcomes, another second generation long run estimation test, i.e., cross-sectional autoregressive distributed lag (CS-ARDL) test has been carried out. The test outcomes reported in Table 8 show that the signs and magnitudes of long- and short-run coefficients are not deviating in comparison with the coefficients reported in Table 7. It validates the robustness of the empirical model outcomes.

5 Takeaway for practice

By far, the study has estimated the possible impacts of energy efficiency, renewable energy consumption and real income on carbon emissions for 30 developing countries, and the study outcomes endow us with several insights, which might be significant for the policymakers. The EKCs have found to be inverted U-shaped and the turnaround points of the EKCs are within the sample range. This phenomenon shows that the economic growth pattern being followed in these nations is ecologically sustainable. While saying this, it is also important to observe that the negative environmental impact of industrialization is found to be more than the positive environmental impact of renewable energy. Hence, possibility of environmental degradation in future cannot be overruled, and this is where the policy intervention should come in. While designing the policy interventions, it should be noted that the positive environmental impact of energy efficiency is more than the negative environmental impact of industrialization. Therefore, for designing an SDG-oriented policy framework, energy efficiency and its antecedents (i.e., energy innovations) might be considered as the viable policy instruments.

Industrialization pattern of these economies being largely dependent on the fossil fuel-based solutions, any overnight transformation in the existing energy portfolio might have undesirable negative impact on the economic growth pattern. The major reason behind this is the high implementation cost of the renewable energy solutions. In such a situation, the policymakers might rely on the energy innovations, which might bring forth energy efficiency. Saying this, it is also needed to mention that it might be difficult for the policymakers to diffuse the energy innovations across the country and realize its full potential, given the rise in energy demand with the rise in economic growth. Therefore, for the short run, the countries can import the technological solutions to be used in production processes for achieving energy efficiency (Cheng et al., 2021). It is evident that this move will have a negative impact on the trade balance, and this financial loss can be recovered by means of the financialization channel. The firms can be endowed with these solutions, and in order to acquire these solutions, they might require loans from banks. While giving loans, the banks can make use of differential rates of interest, based on the carbon footprint of the firm, i.e., higher carbon footprint will result in higher rate of interest (Sinha et al., 2021). This initiative might have several benefits. First, the fiscal loss incurred by the policymakers will be recovered through the interest income. Second, firms will receive a signal that the policymakers are prioritizing the betterment of environmental quality, and hence, the firms will try to bring forth transformations in their existing processes to reduce their carbon footprint. Third, firms will be motivated towards developing in-house environment-friendly technological solutions, which will not only bring forth energy efficiency, but also reduce their carbon footprint. These consequences will gradually reduce the demand for fossil fuel-based solutions in the economy, and increase the demand for renewable energy solutions. Moreover, gradual improvement in the energy efficiency will help to ensure energy security of the nations, while having a control over the carbon emissions. This move will help these nations to make a progression towards attaining the objectives of SDG 7 and SDG 13.

As the structural transformation of the economy is coming out to be environmentally degrading, it can be assumed that the economic activities need to take a transition from the heavy manufacturing activities to service-oriented activities. Once the heavy manufacturing firms start achieving energy efficiency and an organic technological development is initiated, the policymakers might consider advancing the sectoral transformation towards being service-oriented. This will not only create more jobs in the economy, but also these industries will be able to enjoy the benefits of energy efficiency being brought forth through the technological development. In such a situation, these nations will be able to create green jobs, and with graduation of time, the service-oriented firms might make an advancement in diffusing the renewable energy solutions. The policymakers might use the financialization channel to boost this diffusion by providing low-cost loans or interest rate holidays for these firms, so that the high cost of implementation does not impede the growth of these firms. In this way, the nations will start experiencing higher demand of renewable energy solutions, along with a rise in employment. In this way, while accomplishing the objectives of SDG 7 and SDG 13, these nations will also be able to make certain progression towards achieving the objectives of SDG 8.

6 Conclusions

In this study, we have analyzed the impact of energy efficiency on carbon emissions for 30 developing countries over 1990-2016, following the analytical framework of EKC hypothesis, and second generation methollodigical approach. The findings of decomposition suggested that energy efficiency is major contributor in decreasing energy intensity of the developing economies, while the contribution of structural changes is very small in decreasing energy intensity. The empirical analysis indicates that energy efficiency and structural shifts have negative and positive relation with CO_2 emissions respectively in long run. The results indicate that energy efficiency is major contributor to CO_2 emissions reduction whereas structural shifts in developing countries tend to increase CO_2 emissions because they move towards the sectors that are more energy intensive and produce more emissions. The outcomes also provide evidence for the existence of EKCs in developing countries. The green power utilization contributes in lessening of environmental degradation and industrialization in developing countries is one of the factors contributing to CO_2 emissions.

Contribution of this study lies in terms of recommending a multipronged SDG framework, which might be helpful for these countries in treading the path towards attaining the objectives of SDG 7, SDG 13, and SDG 8. From the sustainable development perspective, attainment of the objectives of these SDGs might prove to be crucial for the developing countries, as these SDGs are having larger social consequences. For the remaining developing countries around the world, this policy framework might be considered as a baseline approach for realigning the existing policies in those countries. Considering the baseline approach might be significant, as the policies need to be replicated in other developing countries with certain modifications, which commensurate their contextual setting. During that policy realignment exercise, this framework might be considered as the primary reference point, and there lies the policy-level contribution of the study, in terms of its applicability towards a larger context.

The discussion on policy framework might be incomplete without mentioning the necessary caveats and assumptions, without which the recommended policy framework might not be able to produce expected results. The caveats and assumptions of this policy framework are:

(a) With the rise in the demand of renewable energy solutions, the traditional fossil fuel-based energy generation sector might encounter gradual reduction in demand, and it might cause unemployment in that sector. In order to handle this issue, policymakers should introduce proper skill-development programmes, so that the surplus labor from these industries can be inducted in the newly formed service sector firms. This will not only help in maintaining the social order in these countries, but will also help them in maintaining their position in the achievement of the objectives of SDG 8.

(b) While catalyzing the industrial growth towards achieving environmental sustainability, the policymakers also need to come up with stringent laws for environmental protection. This will help to control faster depletion of natural resources and maintaining intergenerational equity. This will help them in maintaining their position in the achievement of the objectives of SDG 13.

(c) The process of boosting the service industry need to be robust and transparent. Bringing robustness and transparency in the bureaucratic process for starting a new business will reduce the rent-seeking behavior, unintended mediation, and will encourage the industrial growth.

Before concluding the study, it is also necessary to mention that a policy framework might require considering additional policy instruments, as it might enhance the inclusivity of the policy framework. However, it might not be possible to encapsulate all those policy instruments under a single policy framework, and from that perspective, the present study suffers from certain limitations. Including the moderating aspects of governance quality and political stability could have made the policy framework more robust. Saying this, it needs mentioning that the present study can act as a baseline study for the developing countries, as some of the major characteristic issues of developing countries have been addressed through the framework recommended. Therefore, the framework can enjoy the benefit of generalizability. Future research on this aspect can be carried out by considering the spatial dimension of the emission pattern and the diffusion of energy innovation. Consideration of the advanced quantile modeling might also add more significant insights to the framework, as this modeling approach can address the issues at a more granular level.

Reference

Abdullah, S.M., Siddiqua, S., Huque, R., 2017. Is health care a necessary or luxury product for Asian countries? An answer using panel approach. Health Econ. Rev. 7, 201–208.

Adetutu, M.O., Glass, A.J., Weyman-Jones, T.G., 2016. Economy-wide estimates of rebound effects: Evidence from panel data. Energy J. 37(3), 251–269.

Ahmed, K., Rehman, M.U., Ozturk, I., 2017. What drives carbon dioxide emissions in the long-run? Evidence from selected South Asian Countries. Renew. Sustain. Energy Rev. 70, 1142–1153.

Al-Mulali, U., Ozturk, I., Lean, H.H., 2015. The influence of economic growth, urbanization, trade openness, financial development, and renewable energy on pollution in Europe. Nat. Hazards 79(1), 621–644.

Alam, S., 2010. Globalization, Poverty and Environmental Degradation: Sustainable Development in Pakistan. J. Sustain. Dev. 3(3), 103–114.

Ali, W., Abdullah, A., Azam, M., 2017. The dynamic relationship between structural change and CO2 emissions in Malaysia: a cointegrating approach. Environ. Sci. Pollut. Res. 24(14), 12723–12739.

Ang, J.B., 2007. CO2 emissions, energy consumption, and output in France. Energy Policy 35(10), 4772–4778.

Apergis, N., Ozturk, I., 2015. Testing environmental Kuznets curve hypothesis in Asian countries. Ecol. Indic. 52, 16–22.

Apergis, N., Payne, J.E., 2009. Energy consumption and economic growth in Central America : Evidence from a panel cointegration and error correction model. Energy Econ. 31(2), 211–216.

Bai, J., Kao, C., Ng, S., 2009. Panel cointegration with global stochastic trends. J. Econom. 149(1), 82–99.

Bai, J., Ng, S., 2004. A Panic Attack on Unit Roots and Cointegration. Economerica 72(4), 1127–1177.

Bai, J., Ng, S., 2006. Evaluating latent and observed factors in macroeconomics and finance. J. Econom. 131(1-2), 507–537.

Bai, J., Ng, S., 2010. Panel unit root tests with cross-section dependence: A further investigation. Econom. Theory 26(4), 1088–1114.

Bölük, G., Mert, M., 2015. The renewable energy, growth and environmental Kuznets curve in Turkey: an ARDL approach. Renew. Sustain. Energy Rev. 52, 587–595.

Boyd, G.A., Roop, J.M., 2004. A note on the fisher ideal index decomposition for structural change in energy intensity. Energy J. 25(1), 87–101.

Bronstein, K., 2020. The Good, Bad, and Ugly about Renewable Energy in Developing Countries. RTI International.

Cantore, N., 2011. Promoting energy efficiency in developing countries–new evidence based on firms analysis. United Nations Industrial Development Organization, Vienna.

Chang, Y., 2004. Bootstrap unit root tests in panels with cross-sectional dependency. J. Econom. 120(2), 263–293.

Chen, J., Wang, P., Cui, L., Huang, S., Song, M., 2018. Decomposition and decoupling analysis of CO2 emissions in OECD. Appl. Energy 231, 937–950.

Cheng, Y., Sinha, A., Ghosh, V., Sengupta, T., Luo, H., 2021. Carbon tax and energy innovation at crossroads of carbon neutrality: Designing a sustainable decarbonization policy. J. Environ. Manage. 294, 112957.

De Hoyos, R.E., Sarafidis, V., 2006. Testing for cross-sectional dependence in panel-data models. Stata J. 6(4), 482.

Dickey, D.A., Fuller, W.A., 1979. Distribution of the Estimators for Autoregressive Time Series With a Unit Root. J. Am. Stat. Assoc. 74(366), 427.

Dinda, S., 2004. Environmental Kuznets curve hypothesis: a survey. Ecol. Econ. 49(4), 431-455.

Fan, Y., Liu, L.C., Wu, G., Wei, Y.M., 2006. Analyzing impact factors of CO2 emissions using the STIRPAT model. Environ. Impact Assess. Rev. 26(4), 377–395.

Farhani, S., Shahbaz, M., 2014. What role of renewable and non-renewable electricity consumption and output is needed to initially mitigate CO2emissions in MENA region? Renew. Sustain. Energy Rev. 40, 80–90.

Hoekstra, R., van den Bergh, J.C.J.M., 2003. Comparing structural decomposition analysis and index. Energy Econ. 25(1), 39–64.

International Energy Agency (IEA), 2020. Clean Energy Innovation: Part of Energy Technology Perspectives.

International Renewable Energy Agency (IRENA), 2019. Advancing Renewables in Developing Countries: Progress of projects supported through the IRENA/ADFD Project Facility. Abu Dhabi, United Arab Emirates.

Im, K.S., Pesaran, M.H., Shin, Y., 2003. Testing for unit roots in heterogeneous panels. J. Econom. 115(1), 53–74.

Inglesi-Lotz, R., Pouris, A., 2012. Energy efficiency in South Africa: A decomposition exercise. Energy, 42(1), 113–120.

Jimenez, R., Mercado, J., 2014. Energy intensity: A decomposition and counterfactual exercise for Latin American countries. Energy Econ. 42, 161–171.

Kao, C., 1999. Spurious regression and residual-based tests for cointegration in panel data. J. Econom. 90(1), 1–44.

Langlois, P., Yank, A., 2018. Developing countries and energy efficiency potential: Strategies for low-carbon development after the Paris agreement. International Partnership for Energy Efficiency Cooperation.

Levin, A., Lin, C.F., Chu, C.S.J., 2002. Unit root tests in panel data: Asymptotic and finite-sample properties. J. Econom. 108(1), 1–24.

Lin, B., Liu, H., 2015. CO2 emissions of China's commercial and residential buildings: Evidence and reduction policy. Build. Environ. 92, 418–431.

Maddala, G.S., Wu, S., 1999. A comparative study of unit root tests with panel data and a new simple test. Oxf. Bull. Econ. Stat. 61, 631–652.

Meadows, D., Meadows, D.L., Randers, J., Behrens-III, William, W., 1972. The limits to growth: a report for the club of Rome's project on the predicament of mankind, Universe Books, New York.

Metcalf, G.E., 2008. An empirical analysis of energy intensity and its determinants at the state level. Energy J. 29, 1–26.

Moshiri, S., Duah, N., 2016. Changes in Energy Intensity in Canada. Energy J. 37, 315–342.

Neumayer, E., 2003. Are left-wing party strength and corporatism good for the environment? Evidence from panel analysis of air pollution in OECD countries. Ecol. Econ. 45(2), 203–220.

Palm, F.C., Smeekes, S., Urbain, J.P., 2011. Cross-sectional dependence robust block bootstrap panel unit root tests. J. Econom. 163(1), 85–104.

Pedroni, P., 1999. Critical Values for Cointegration Tests in Heterogeneous Panels with Multiple Regressors. Oxf. Bull. Econ. Stat. 61(s1), 653–670.

Pedroni, P., 2004. Panel cointegration: Asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. Econom. Theory 20(3), 597–625.

Persyn, D., Westerlund, J., 2008. Error-correction-based cointegration tests for panel data. Stata J. 8, 232–241.

Pesaran, M.H., 2004. General diagnostic tests for cross-sectional dependence in panels.

Cambridge University Working Paper.

Pesaran, M.H., 2007. A simple panel unit root test in the presence of cross-section dependence. J. Appl. Econom. 22(2), 265–312.

Phillips, P.C.B., Sul, D., 2003. Dynamic panel estimation and homogeneity testing under cross section dependence. Econom. J. 6, 217–259.

Phillips, P., Perron, P., 1988. Testing for a Unit Root in Time Series Regressions. Biometrika 75(2), 335–346.

Shahbaz, M., Nasreen, S., Ahmed, K., Hammoudeh, S., 2017. Trade openness–carbon emissions nexus: The importance of turning points of trade openness for country panels. Energy Econ. 61, 221–232.

Shahbaz, M., Sinha, A., 2019. Environmental Kuznets curve for CO_2 emissions: a literature survey. J. Econ. Stud. 46(1), 106–168.

Sharma, R., Sinha, A., Kautish, P., 2021. Does renewable energy consumption reduce ecological footprint? Evidence from eight developing countries of Asia. J. Clean. Prod. 285, 124867.

Shironitta, K., 2016. Global structural changes and their implication for territorial CO2 emissions. J. Econ. Struct. 5(1), 20.

Sinha, A., Mishra, S., Sharif, A., Yarovaya, L., 2021. Does green financing help to improve environmental & social responsibility? Designing SDG framework through advanced quantile modelling. J. Environ. Manage. 292, 112751.

Song, F., Zheng, X., 2012. What drives the change in China's energy intensity: Combining decomposition analysis and econometric analysis at the provincial level. Energy Policy 51, 445–453.

Tajudeen, I.A., 2015. Examining the role of energy efficiency and non-economic factors in energy demand and CO2 emissions in Nigeria: Policy implications. Energy Policy 86, 338–350.

Tajudeen, I.A., Wossink, A., Banerjee, P., 2018. How significant is energy efficiency to mitigate CO_2 emissions? Evidence from OECD countries. Energy Econ. 72, 200–221.

United Nations Industrial Development Organization (UNIDO), 2007. Policies for promoting industrial energy efficiency in developing countries and transition economies.

United Nations, 2019. The Sustainable Development Goals Report 2019.

United Nations, 2020. The Sustainable Development Goals Report 2020.

United Nations Environmental Programme (UNEP), 2017. Renewable energy and energy efficiency in developing countries can support Paris Agreement, and benefit people.

Wang, Z., Shi, C., Li, Q., Wang, G., 2011. Impact of Heavy Industrialization on the Carbon Emissions: An Empirical Study of China. Energy Procedia 5, 2610–2616.

Westerlund, J., 2007. Testing for error correction in panel data. Oxf. Bull. Econ. Stat. 69(6), 709–748.

World Bank, 2018. Access to Energy is at the Heart of Development.

Zafar, M.W., Mirza, F.M., Anees, S., Zaidi, H., Hou, F., 2019a. The nexus of renewable and nonrenewable energy consumption , trade openness ,and CO_2 emissions in the framework of EKC : evidence from emerging economies. Environ Sci Pollut Res, 26, 15162–15173.

Zafar, M.W., Shahbaz, M., Hou, F., Sinha, A., 2019b. From nonrenewable to renewable energy and its impact on economic growth : The role of research & development expenditures in Asia-Pacific Economic Cooperation countries. J. Clean. Prod. 212, 1166–1178.

Zafar, M.W., Shahbaz, M., Sinha, A., Sengupta, T., Qin, Q., 2020. How renewable energy consumption contribute to environmental quality? The role of education in OECD countries. J. Clean. Prod. 268, 122149.

Zafar, M.W., Sinha, A., Ahmed, Z., Qin, Q., Zaidi, S.A.H., 2021. Effects of biomass energy consumption on environmental quality: the role of education and technology in Asia-Pacific Economic Cooperation countries. Renew. Sustain. Energy Rev. 142, 110868.

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