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Assessing Environmental Impacts of ICT integration in Asian Economies

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ABSTRACT

Objective: This study is intended to explore how integration of ICT with increment in production level alters the environmental quality of a region.
Secondly how the three income groups of Asia region are able to maintain their environmental quality and achieve sustainable development by the adoption of ICT.

Research Gap: No such study exists in literature which identifies the validity of EKC hypothesis in three income groups of Asia by incorporating Variable of ICT and makes comparison of the effects of ICT penetration in three income groups of Asia.

Design/Methodology/Approach: The impact is analyzed for three Asian income groups i.e., lower, middle and higher. Impact of digitization is captured by constructing ICT index using four variables as its proxies i.e., Internet users (IU), mobile cellular subscribed (MCS), fixed broad band subscribed (FBS) and fixed telephone lines subscribed (FTS). The study uses the data for the period of 1990-2016 due to the limitation of data availability of CO_2 which is dependent variable of the study and depicts the quality of environment and hence sustainability. Panel time series estimation procedure is followed by application of second-generation tests such as cross-sectional dependent test (Pesaran CD, Pesaran scaled LM and Breusch Pagan LM test), second-generation unit root tests (CADF and CIPS) test and Westerlund cointegration test.

Findings: This study evidences the existence of EKC hypothesis in middle and high-income groups of Asia, whereas it favors rejection of the theory in low-income countries. Impacts of digitization on environmental quality are diversified. It reduces carbon emissions and significantly improves environmental in low and middle-income countries of Asia. However, it intensifies carbon emissions level in high-income Asian countries. Policies are suggested in the relevant chapter of the study accordingly.

Theoretical / Practical Implications of the Findings: findings of the study can be helpful to formulate policies to improve environmental quality while considering the impact of economic growth and ICT adoption.

Originality value:
The study employees the model with self-created ICT index incorporated in EKC frame work along with control variables chosen from literature.

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1. Introduction

In the present era of increasing digitization and ICT penetration sustainable development is the most debatable issue for policy makers and researchers. According to a report provided by united nations in 1987, sustainability is defined as preservating natural resources which allow future generations to enjoy if not better then equal standards of living. Maintaining pure and healthy environment and preserving natural resources is one of the major goals among all the goals of sustainability. Undoubtedly ICT adoption and its penetration enables societies to achieve sustainable development goals however production of ICT equipment, their use and disposal is energy intensive process (Charfeddine & Umlai, 2023). Fewer studies are found in literature which explores the link between the two. Ionescu-Feleagă et al., 2023 and Kumar & Jyoti (2023) depicts the positive relation between digitization and sustainable development in the respective area of their study.

In academic discourse, ICT or digitization serves as an extension of the conventionally recognized notion of Information Technology (IT). It prominently grew after World War II, but the actual trajectory of ICT development commenced in the early 2000s. While a universally accepted definition of the term remains elusive. It generally encompasses all entities, elements, networks, and systems facilitating digital interactions among individuals. This overarching concept finds wide-ranging applicability, encompassing entertainment products, household technologies, and including personal electronics devices and not limited to computers, televisions, radios, music and gaming equipment and other communication devices such as cell phones (Ropke & Christensen, 2012).

Digitization serves as a catalyst that fosters greater connectivity among societies, thereby facilitating social, economic and interpersonal communications and transactions. Its significance becomes evident through the lens of the neo-classical growth model, which underscores the pivotal role of technology as a determining factor of output. Proponents of the theory argued that sustained growth cannot be achieve without continual advancement in technology. In the contemporary landscape, ICT has emerged as a vital force in driving economic growth and promoting human development. This technology and its associated tools empower economies to efficiently access and exchange information at a reduced cost, consequently contributing to enhanced production efficiency, increased productivity, improved energy efficiency and hence sustainability. These collective benefits, in turn, catalyze growth across various sectors of economies (Kaplan, 2006).

Moreover, ICT plays an important role in facilitating trade and for creating opportunities to establish new businesses, jobs, and revenue generation (Carayannis & Popescu, 2005). The diffusion of ICT not only fosters market competition but also stimulates both domestic and foreign investments, thereby contributing significantly to economic growth (Gruber & Verboven, 2001). Nevertheless, as ICT contributes to economic growth (Toader et al., 2018 & Latif et al., 2018) which in turn exerts an influence on CO2 emission level (Hossain, 2011; Bengochea-Morancho, 2001). Akin (2014) speculates that economic progress and CO2 discharge level of a region are strongly corelated. Theoretically, this relationship aligns with the Environment Kuznets Curve (EKC) theory, suggesting that during earlier stages of economic growth and development carbon emissions escalate with rise in income per person reaching a peak and exacerbating environmental degradation. However, beyond a certain level called thresh hold level, further increase in income results in reduced CO2 emissions, ultimately purifies the environment (Grossman & Krueger, 1991).

Irrespective of the economic growth pathway, ICT also exerts a direct impact on environmental quality by influencing the environmental burden accompanying to greenhouse gases (GHG) particularly CO2 a major contributor to such discharges (World Bank, 2007). Monzon et al. (2017), Zhang & Liu (2015), Mathiesen et al. (2015) and Chavanne et al. (2015) affirm that digitization within industrial and transport sectors contributes significantly to the management and mitigation of environmental degradation.

However, it is crucial to acknowledge that ICT also exerts a significant and irrefutable effect on quality of environment, primarily through its usage, disposal, and recycling practices which directly contribute to GHG emissions. The disposal of electronic waste (e-waste), including unusable ICT and other electronic devices, represents a substantial contributor to environmental degradation. E-waste monitor report (2017) witnesses of the global generation of 44 Million metric tons e-waste from 2014 to 2017. Gonel & Akinci (2018) assert that ICT accounts for about 2% of global CO2 emissions, thereby playing role in the deterioration of environment. This is primarily attributed to the fact that ICT devices increase energy and fuel consumption during production activities, consequently leading to increased CO2 emissions (Asongu et al., 2017).

In a wider context, the impact of ICT unfolds across two dimensions i.e., economic and environmental. through this study we are intended to examine its environmental aspects in the region of Asia. The choice of Asia as our study area is grounded in the region's prolonged exposure to severe environmental pressures over the past few decades. In the context of carbon emissions, China has consistently held the position of the top emitter whereas India and Indonesia are lying on second and third position (Alam et al., 2016). Despite the region's overall high economic growth rates in recent years, there has been a conspicuous lack of emphasis on preserving environmental quality. Consequently, maintaining environmental integrity poses a significant challenge for policymakers across Asian economies.

Limited research available in which explores the relation between digitization and environmental quality. Lee and Brahmasrene (2014), Zhang et al. (2015), Danish et al. (2018), Majeed (2018), Asongu (2018), Notley (2019) and Raheem et al. (2020) carries out analysis on different regions other than Asia and its income groups. A noticeable gap is however left in literature regarding the impact of ICT on CO2 emissions in Asian countries.

1.2. Contribution in literature:

Our study makes noteworthy addition into the already existing literature. Firstly, it stands as inaugural investigation of its kind that systematically explores the varied impacts of digitization on CO2 emissions within three distinct income groups in Asia i.e., low, middle and high. Secondly, this study incorporates ICT as focused variable of the study along within EKC framework.

The study enables us to compare the sustainability in environment by the three income groups of Asia when they increase their production level with the adoption of ICT.

1.3. Theoretical framework

Neo classical growth model also known as Solow Swan model provides strong theoretical framework to our study which addresses technological improvement as a crucial factor for output level and growth of an economy. According to this model output is obtained by the combination of labor, capital at given level of technology. Technology is kept constant or controlled by some exogenous factor and hence it is also named as exogenous growth model. Diminishing marginal returns of capital and labor due to exogenous technological advancement is limitation of this model which can be overcome by A-K model in which technology is endogenous factor.

1.4. Sequence of the study

Remaining sections of the paper are sequenced as follow: section 2 comprises on comprehensive review about literature relevant to our study. Section 3 provides details pertaining to the data, econometric model, methodology used in our study. Section 4 offers an in-depth discussion of obtained empirical findings, and Section 5 which is last section gives conclusion of the study by summarizing key insights and policy implications.

2. Literature Review

In the contemporary era, heightened spendings on ICT equipment to promote digitization have emerged as a significant cause of economic progress for countries (Nasab & Aghaei, 2009). Concurrently, this period has witnessed a rise in the climatic burden, manifested in the form of GHG emissions. Among these gases, CO2 emissions hold the highest proportion and are thus recognized as a major contributor to the climatic burden. A paramount concern for policymakers in the present age is the pursuit of sustainable development, necessitating a dual focus on both economic and environmental considerations. Theoretically, researchers and scholars have frequently employed EKC theory to investigate the environmental impacts of economic progress. This study is centered on two key aspects of literature: Nexus between CO2 emissions and economic growth through the context of EKC theory, and examination of CO2 emissions level.

2.1. Economic growth and CO_2 emissions linkage

EKC hypothesis links economic progress of a region with its environmental quality through GDP, its quadratic term and CO2 emissions level as proxies of these indicators and predicts an inverted u-shaped relation of these two variables. After the concept had established theoretically, several researches evidenced it through empirical analysis. Studies of (Grossman & Krueger, 1991) and then (Panayotou ,1993) provided its empirical evidence initially.

Theory of EKC has proved valid for the region of China for the time period of 1975 to 2005 and two-way causality is observed between the two variables being involved (Jalil & Mahmud, 2009). Many other studies exist in literature which are conducted for single economy by applying panel time series analysis. They provided heterogenous results for acceptance or rejection of environment Kuznets curve theory for their focused region of analysis. The theory is proved valid for the region of Malaysia (Saboori et al.,2012) and for the kingdom of Saudi Arabia (Kahia et al., 2021). Sarkodie & Ozturk (2020) confirmed EKC hypothesis for the economy of Keynia for the time span of 1971 to 2013. Economy of Pakistan (Javid and Sharif, 2016) and Azerbaijan (Mikayilov et al., 2018) also exhibit EKC relation. Recently, Mahmood et al. (2023) verified the EKC relation for China.

Contradictory to the EKC theory, GDP and CO2 emissions exhibit u-shaped relation for the Economy of Greenland (Arnaut & Lidman, 2021). This theory is also rejected for the economy of Turkey (Shahbaz et al., 2013), economy of Vietnam Al-Mulali et al. (2015). According to their study increased production leaves environmental degrading and energy exhaustive impacts on the economy. Similarly EKC curve is rejected for the economy of Tunisia (Farhani & Ozturk, 2015), BRICST economies (Dogan et al., 2020) and for BRICS economies (Latif et al., 2018).

Numerous studies conducted panel data analysis and provided heterogenous results regarding the theory's validity. EKC hypothesis is proved for MENA region (Arouri et al., 2012). Apergis & Ozturk (2015) proved it for 14 countries of Asia, Al-Mulali et al. (2015) for Latin American economies and Caribbean countries, (Le & Ozturk, 2020) for 47 emerging markets and developing economies favored EKC hypothesis. Ansari et al. (2020) used ecological footprints as a measure of environmental quality and provided different results regarding acceptance or rejection of EKC theory in Asian sub regions. Environmental Kuznets curve hypothesis is validated for Central and East Asian countries but it is not the case for west and southeast Asian countries. However, when material footprints were used to identify environmental quality EKC proved to be valid for all sub-regions of Asia except Central Asia. This relation is further confirmed by Demissew (2023), Maneejuk et al. (2020), Alam et al. (2016) and Jebli et al. (2016).

2.2. Digitization and Sustainability

Digitization has direct role to enhance the concentration of CO2 emissions and hence we cannot deny its environmental impacts. No doubt increased digitization in production and other activities reduces climatic burden via use of smarter equipment but at the same time they add pollutants in the form of greenhouse gases of which CO2 is a major contributor. Which may be helpful to achieve sustainability or may be an obstacle. The major fact behind, is the huge amount of energy consumption by utilization of ICT equipment and through E-waste. Heterogenous impacts of digitization on environmental quality are observed in literature i.e., positive, negative and insignificant depending upon the level of ICT penetration, its patterns of energy consumption, and the treatment of waste products produced by discarded ICT equipment.

Digitization contributes to much greater extent in greenhouse gases due to increased energy consumption (Pohl et al., 2019); (Belkhir & Elmeligi, 2018); (Lee & Brahmasrene, 2014). Whereas, Avom et al. (2020) discovered increasing impact (direct and indirect) of digitization on CO2 discharge level. The study also proves that ICT usage and CO2 emissions have inverted U shaped relation.

However, several studies explored the decreasing impact of digitization on GHG emissions (Asongu, 2018; Monzon et al., 2017; Zhang & Liu, 2015). According to these studies, digitization is the use of technology with enhanced efficiency and hence it provides a way of living with low carbon consumption which in turn minimizes environmental pollution. A study conducted for top ten Asian high emitter countries for the period of 1990-2019 using an advanced non-linear panel ARDL approach proved that digitization improves environmental quality. Some more studies confirm the mitigating impact of digitization on carbon emissions level (Brodny and Tutak, 2022; Ma and Wu, 2022; Ramos-Meza et al., 2021; Ullah et al., 2021; Yang et al., 2021). Furthermore, some studies show insignificant impacts of digitization on carbon emissions (Amri et al., 2019; Salahuddin et al., 2016).

3. Data source, Econometric Model and Methodology

The whole data of Asia is divided into three groups based on their income level i.e., low, middle and high income. Disintegration of income is based on the criterion of World Development Indicators data base (2019). Data used for analysis is also extracted from the database of World Development Indicators data base (2019). The analysis are conducted for the time period of 1990 to 2016 due to limited availability of data. CO2 emissions being a broadly accepted proxy of environmental quality and hence an indicator of sustainability is therefore chosen as a dependent variable of the study. It is initially being used in many studies (Amri et al., 2019; Asongu, 2018; Mikayilov et al., 2018). Index of ICT is created through Principal Component Analysis (PCA) in order to incorporate the effect of digitization. We used four indicators of digitization for the construction of index. The proxies being selected includes percentage of internet users IU, percentage of mobile cellular subscribed or purchased MCS, percentage of subscribed fixed telephone subscribed lines FTS, and fixed broadband subscribed in percentage FBS (Amri et al., 2019; Latif et al., 2018; Toader et al., 2018; Pradhan et al., 2015). GDP and the square of GDP are used with the purpose to check the validity of EKC hypothesis. Unit used to measure GDP is US dollars constant 2010 constant 2010 US dollars (Toader et al., 2018; Latif et al., 2018).

Besides above mentioned dependent and independent focused variables, the study also uses few control variables namely urban population measured as percentage from total population and abbreviated as UPP (Al-Mulali & Ozturk, 2016; Farhani & Ozturk, 2015; Zhang & Liu, 2015). Electricity consumption EC measured in kilowatts per hour by (Al-Mulali & Ozturk, 2016; Al- Mulali et al., 2015) and lastly inflation INF measured as percentage of GDP deflator (Ullah et al., 2020; Ahmed et al., 2020). Environmental quality is influenced indirectly by instability in inflation via performance and conditions of capital market (Ahmed et al., 2020). Definitions of all the above mentioned variables with descriptions of their units are present on WDI indicators website. Econometric model of the study is:

$$\mathrm{lCO_2} = \beta_{0+}\beta_1 \mathrm{lGDP}_{it} + \beta_2 \mathrm{lGDP}_{it}^2 + \beta_3 \mathrm{ICT}_{it} + \beta_4 \mathrm{UPP}_{it} + \beta_5 \mathrm{EC}_{it} + \mathrm{INF} + \mu_{it} \quad (1)$$

In the model given above i and t represents cross sections and time span for analysis respectively. U_{it} is the error term. Logarithmic form of GDP, its square and CO2 emissions are used for estimations in order to interpret them accordingly with other variables taken in percentage. β0 represents intercept while β1, … β6 are to be estimated as they are unknown. According to statement of EKC theory we expect positive signs of β1 and negative for β2 to prove the theory valid. Variable of ICT may have positive or negative sign with CO2 emissions which depends on the modes and methods of ICT adoption. Signs of control variables may also be negative or positive it depends upon geographical and social conditions of the selected region though we expect positive signs of electricity consumption with carbon emissions.

3.1. Methodology

For the data of each income group time factor T is larger than the number of cross sections (N) which means the time factor is dominant indicating our data samples are of panel time series type. Hence we will proceed our estimations with panel time series estimation technique and steps involved in it. This technique uses certain steps i.e. determining cross-sectional dependence (CSD), stationarity of variables, their cointegration, and then finding their long run and short run estimates.

Asian countries sharing the same geographical territory hence there is a huge chance of similarity in them in terms of geographical and social conditions and political circumstances as well. Any change in economic indicators of a country may bring change in other country. Hence at first step the data is analyzed for the presence of CSD by using more recent Pesaran Scaled LM test (2004); Pesaran Cross-sectional dependent test (2004) and Breusch Pagan LM test (1980). Previously used by Haseeb et al., 2019 and suggested to be more suitable for dominant time series.

Secondly, we moved towards the identification of stationarity of variables which is an important step in panel time series estimation procedure. To fulfil the purpose panel unit root tests of second-generation i.e., CIPS and CADF are applied being suggested by (Pesaran,2007). They are robust to heterogeneity and take into account CSD. Therefore, we can get more appropriate results from this test in comparison with first-generation unit root test (Haseeb et al., 2019).

Moving further is to identify cointegration relation of variables. Generally used tests for this purpose are Pedroni's (1999, 2004) previously used by (Pradhan et al., 2018). Co-integration tests of second-generation proposed by Westerlund (2007) recently used in different studies (Haseeb et al., 2019 and Saud et al., 2019). It takes into accounts both types i.e., within and between units CSD and is suitable for samples of small size. In addition to these, cointegration among variables can also be observed through the values of variance ratio statistics. Therefore, Westerlund cointegration test (a second-generation test) is applied to tests co integration among variables (Haseeb et al., 2019 and Saud et al., 2019).

We used FMOLS estimation technique proposed by Phillips & Hansen (1990) to obtain long run estimates lastly. Further this technique is appropriate to encounter the problem of endogeneity (Pederoni, 2001) and also when data is not fulfilling the assumptions of classical linear regression model and hence ordinary least square OLS is inappropriate.

DOLS estimation technique is applied for robustness check (Stock and Watson, 1993; Saikkonen, 1992) is appropriate in our case as we have small sample size having lesser number of cross sections and hence gives asymptotically efficient cointegrating vectors (Salahuddin et al., 2016). This technique uses lags and leads by involving excessive cointegration regressions and hence it is efficient in the case when variables are cointegrated in the long run (Lee & Brahmasrene, 2014).

4. Discussion of Results

Table A: Summary Statistics

Variable name	Observations	Mean	Std. Dev.	Minimums	Maximums
CO_2	452	7.23	8.3	0.1	44
GDP	452	553	1520	3380	9490
FTS	452	22	17	0.4	63
FBS	452	1.2	9.7	0	33
MCS	452	79	52.3	0.26	239
IUI	452	29	27	0.06	100
UPP	452	62	27	15.5	100
EC	452	4508	5131	75	21508
INF	452	6.72	8.5	18.9	53

Source: Author's estimation.

4.1. Cross-sectional Dependence Test Results

The results of these tests are discussed in table 1. Probability values less than 0.05 and value of T- stats greater than two for all the three income groups leads to rejection of null hypothesis of 'no cross- sectional dependence'. Hence our results indicate the existence of CSD among variables. Therefore, we will proceed with this conclusion of existence of cross-sectional dependency among variables.

Table 1: Cross-sectional Dependence Test Results

Results for LICs

Variable name	B-Pagan LM test	Scaled LM test	Pesaran CD test
	Statistics	**Statistics**	**Statistics**
CO_2	73.4513***	13.0701***	-1.9165***
GDP	33.3575***	11.1686***	5.4047***
GDP^2	33.4595***	11.210***	5.4047***
ICT index	61.8641***	14.9719***	7.8606***
UPP	189.469***	39.0125***	3.2839***
EC	127.446***	25.1438***	0.9804***
INF	17.2805***	0.5099***	3.0445***
	Results for MICs		
Variable name	**B-Pagan LM test**	**Scaled LM test**	**Pesaran CD test**
	Statistics	**Statistics**	**Statistics**
CO_2	5326.47***	158.397***	44.7085***
GDP	10025.24***	312.476***	99.3429***
GDP^2	10051.30***	313.306***	99.4803***
ICT index	4266.998***	123.656***	63.8189***
UPP	9525.577***	296.0915***	57.3132***
EC	3796.329***	135.1396***	35.2656***
INF	1861.645***	44.78125***	28.16438***
	Results for HICs		
Variable name	**B-Pagan LM test**	**Scaled LM test**	**Pesaran CD test**
	Statistics	**Statistics**	**Statistics**
CO_2	318.01***	18.7560***	1.6907*
GDP	459.322***	81.123***	21.421***
GDP^2	458.77***	81.0274***	21.407***
ICT index	918.411***	73.14840***	30.2648***
UPP	186.3604***	31.286***	10.462***
EC	804.549***	70.4179***	26.45674***
INF	443.840***	28.2498***	8.32376***

Source: Author's estimation.

4.2. Unit Root Test

Results of unit root tests are provided in table no 2. Where probability values and t-stats value given against each variable indicate about stationarity of variables. Probability values less than one confirm the stationarity of the variable. According to the given results some variables become stationary at level whereas all the variables remaining get stationary at first difference. Hence the order of integration for all the variables is one.

Table 2: Unit Root Test Results

Variables' name	Probability values			
	CADF Test Results		**CIPS Test Result**	
	Results for LICs			
	Level	**1st difference**	**Level**	**1st difference**
CO_2	0.991	0.01	0.959	0.585
GDP	0.001	-	0.978	0.111
GDP^2	0.000	-	0.978	0.115
ICT index	0.214	0.013	1.000	0.003
UPP	0.082	0.003	0.026	-
EC	0.878	0.004	0.998	0.547
INF	0.000	-	0.881	0.634
	Results of MICs			
	Level	**1st difference**	**Level**	**1st difference**
CO_2	0.082	0.000	0.871	0.000
GDP	0.731	0.000	0.921	0.000
GDP^2	0.695	0.000	0.881	0.001

ICT index	0.997	0.591	0.766	0.006
UPP	0.000	-	0.000	-
EC	0.762	0.000	0.999	0.000
INF	0.000	-	0.800	0.000
	Results for HICs			
	Level	**1st difference**	**Level**	**1st difference**
CO_2	0.475	0.000	0.351	0.000
GDP	0.05	0.000	0.121	0.041
GDP^2	0.07	0.000	0.123	0.045
ICT index	0.008	-	0.142	0.000
UPP	0.001	-	0.000	-
EC	0.787	0.000	0.566	0.015
INF	0.038	-	0.722	0.008

Source: Author's estimation

4.3. Panel Cointegration Test Results

Cointegration test results are given in Table 3, where variance ratios and probability values obtained for each income group confirm the existence of cointegration in the data of all the three income groups of Asia with 1% significance level (low income group and middle income group) and 5% significance level (high income group).

Table 3: Westerlund Cointegration Test Results

Regions	**Variance ratio values**	
	Statistics	**Probability**
Results of LICs	5.032***	0.000
Results of MICs	-2.256***	0.012
Results of HICs	-1.582***	0.057

Source: Author's estimation

4.4. FMOLS test results

Long run coefficients are obtained by applying FMOLS estimation technique. First panel of the table comprises the results of lower income countries. Where the sign of GDP and its square with dependent variables CO2 emissions denies the existence of EKC theory for this income group of Asia. These findings are consistence with that of Majeed and Mazhar (2020) for low-income group of the global economy and South Asian countries, Alam et al. (2016), Omojolaibi (2010), Omisakin & Olusegun (2009). EKC curve has proved valid for middle income and high income Asian countries. Our findings are consistent with the study of Alam et al. (2016) which proves it for Indonesian, Chinese and Brazilian economy. Javid and Sharif (2016) obtained such results for Pakistan's economy, Apergis & Ozturk (2015) provided such results for 14 countries of Asia. Jalil &Mahmud (2009) found the same results for the economy of China. These studies provide confirmation for EKC theory for their region of analysis. for the case of high income countries our results match with the results obtained by (Majeed & Mazhar, 2020). Their study proved the existence of EKC for upper-income countries. According to them the existence of EKC in these countries is the evidence of structural transformation in these countries and hence the sustainable level of development is achieved by these countries. Also consistent with Higón et al. (2017) & Al-Mulali & Ozturk (2016), who proved the validity of EKC theory for 27 advanced economies and 26 developed economies correspondingly. However, our finding is in contradiction with the findings of (Al-Mulali et al. , 2015), (Farhani & Ozturk, 2015) also contradict with the findings of (Chandran & Tang, 2013).

Significantly negative impact of ICT adoption and digitization on CO2 emissions is found for low income region and middle income region. These findings are aligned with that of (Asongu ,2018) for low-income African countries. According to the results, increased use of ICT by one percent in low income countries causes reduction in CO2 emissions by 0.116 percent and 0.04432 percent reduction in middle income countries. The reason is, these countries extend the use of ICT to protect their environment as they follow upper income countries. Thus, by making production efficient through ICT adoption in industry and conservation of energy from transport sector environmental quality can be improved. However, in high income countries of Asia ICT adoption and digitization effects positively and significantly the level of carbon emissions. According to the results obtained CO2 emissions are increased by 0.041 percent by one percent increase in ICT adoption. Nature and situation of these economies justifies this relation of ICT and CO2 emissions i.e., some characteristics of upper-income countries like greater size of their economies, diversity in their production activities, higher consumption and demand of goods and hence production which in turn increases the use of ICT equipment and hence carbon emissions level as well. Advanced technology in these countries is no more advance as these countries came out of their transition period and hence there is more scope of research and advancement in technology in these countries.

Shifting the discussion towards the results of control variables it is observed that urban population insignificantly effects CO2 emission level of low- and middle-income Asian countries. Obtained results are consistent with Zhang & Liu (2015). However it contradicts with the findings of Farhani & Ozturk (2015) and with Al-Mulali and Ozturk (2016). Contrary to the findings we have in case of middle- and low-income countries, urban population significantly effects emission level of high income countries due to high rate of urbanization in these countries. Increased consumption of electricity increases CO2 emissions significantly in all the three income groups (Al- Mulali & Ozturk, 2016; Al-Mulali et al., 2015). These results are consistent with Akadiri et al. (2020). The study predicts that electricity consumption positively impacts the level of carbon emissions which further clarifies that the use of non-renewable sources of electricity production dominates and exerts pressure on the environment. The effect of inflation on carbon emissions is insignificant in all income groups of Asia which contradicts with the conclusions of the study of Ahmed at al. (2020) and Ullah et al. (2020).

Table 4: Results from FMOLS (region-wise analysis)

	Results for LICs		
Variable name	**Coefficient values**	**Std. error**	**T-stats**
GDP	-2.837***	0.416	-6.83
GDP^2	0.117***	0.018	6.45
ICT index	-0.116**	0.053	-2.19
UPP	-0.001	0.019	0.044
EC	0.002***	0.000	5.519
INF	0.0012	0.004	0.288
	Results for MICs		
Variable name	**Coefficient values**	**Std. error**	**T-stats**
GDP	1.5601***	0.597	2.614
GDP^2	-0.0205*	0.012	-1.686
ICT index	0.0443**	0.019	-2.253
UPP	0.0107	0.008	-1.285
EC	0.0003***	0.000	7.468
INF	0.0004	0.002	0.275
	Results for HICs		
Variable name	**Coefficient values**	**Std. error**	**T-stats**
GDP	5.079***	0.855	5.938
GDP^2	-0.106***	0.017	-6.230
ICT index	0.041***	0.009	4.265
UPP	0.006*	0.004	1.715
EC	0.000***	0.000	13.683
INF	0.000	0.000	1.6171

Source: Author's estimation

4.5. DOLS Test Results

Findings of DOLS are provided in table 5. Similarity of the long run estimates of DOLS with that obtained by FMOLS indicate the robustness of these results. EKC hypothesis is again rejected for low income Asian group and accepted for other two groups. The impact of digitization and ICT penetration are also exactly similar as we obtained from FMOLS estimation technique with slight differences in their coefficient values. Shifting our discussion towards the impact of control variables it is evident that we found same results in case of DOLS as we obtained in case of FMOLS.

Table 5: Results from DOLS (region-wise analysis)

	Results for LICs		
Variable Name	**Co-efficient values**	**Std error**	**T- stats**
GDP	-2.8735***	0.5193	-5.5336
GDP^2	0.1184***	0.0227	5.2159
ICT index	-0.1565**	0.0669	-2.3471
UPP	0.0037	0.0244	0.1496
EC	0.0020***	0.0005	4.4208
INF	-0.00035	0.0060	0.0588
	Results for MICs		
Variable Name	**Co-efficient values**	**Std error**	**T- stats**
GDP	1.4463***	0.5293	2.7325
GDP^2	-0.0203**	0.0109	-1.8647
ICT index	-0.0399***	0.0191	-2.0888
UPP	-0.0029	0.0079	-0.4004
EC	0.0003***	0.0000	8.0990
INF	0.0007	0.0014	0.4752
	Results for HICs		
Variable Name	**Co-efficient values**	**Std error**	**T- stats**
GDP	4.1124**	1.9429	2.117
GDP^2	-0.0855**	0.0393	-2.1728
ICT index	0.0163	0.0251	0.6482
UPP	0.0137***	0.0056	2.4326
EC	0.0000***	0.0000	3.7646
INF	0.0006	0.0014	0.4513

Source: Author's estimation

5. Conclusions of Results

Outcomes of the study prove that the EKC relation does not exist for the case of Asian low-income countries. Where U shaped relation is observed between economic growth and environmental quality. However, the study validates hypothesis of environmental Kuznets curve for middle income and also for high income groups of Asia. ICT employed technology negatively and significantly effects emission level of low- and middle-income Asian countries and hence aid them to achieve sustainability. While the impact of such technology is found positive and significant on carbon emissions level in high income Asian countries as these countries are at the stage where disposal and recycling of ICT equipment and e-waist is a major problem.

5.1. Policy Recommendation

In low-income countries of Asia, the environment gets impure and its quality declines in the long term due to increase in their production level. Hence, they should remain focused on finding less energy consuming methods of production. This can be accomplished by adopting smart technology. Therefore, these countries should adopt smart equipment for their production activities such as digitization and ICT adoption has mitigating impact on CO_2 emissions of the region. The policy is also applicable for middle income countries. But the existence of Environment Kuznets curve in these countries suggests that they should attain that particular production level (threshold level) where emission level starts falling with further increase in production.

Use of ICT worsens environmental quality and increases climatic burden in high-income countries of Asia. These countries should encourage the consumption of renewable energy sources by investing more for them. Carbon pricing which is proved as effective strategy to clarify environment by the reduction in climatic burden can be implemented to control the emissions level. Building smart grid systems is another way of mitigating the effects of ICT and digitization on environmental quality in these countries. Such policies should be formed and implemented which are helpful to develop smart cities, efficient transportation and communication system also such production methods with less energy consumption and or equipment as well. Hence emissions level can be controlled on global level. Further research and development in these countries may introduce some other ways for control of carbon emissions level in these countries. Moreover the government should implement taxation system for such activities which pollute environment and make it impure. They should promote the use of renewable energy resources. The implementation of smart city pilot construction policy as implemented in China from 2013 can be helpful in mitigating the level of CO_2 emissions in other cities and countries.

5.2. Limitations of the Study

Environmental quality is only indicated by its one indicator which is carbon emissions. Undoubtedly carbon dioxide is the major contributor to greenhouse gases but other kinds of emissions such as Nitrogen and Sulphur di and tri oxides are also contributing to environmental degradation. The ability of a region to achieve sustainable growth can also be measured by using other indicators of it like use of renewable energy resources. The time period chosen for analysis is limited up to 2016 due unavailability of data of CO_2 emissions at the time of analysis. Future research needs to focus on more comprehensive measures of environmental quality and different classification of the Asian economies.

Abbreviations:

LICs	Low income countries
MICs	Middle income countries
HICs	High income countries
UPP	Urban population in percentage
EC	Electricity consumption
INF	Inflation
FMOLS	Fully modified ordinary lest square
DOLS	Dynamic ordinary lest square
ICT	Information and communication technology

*Note: ***p<0.01, **p<0.05,* p<0.1* for all tables

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Declarations

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