Information and Communication Technology and CO_2 emissions Nexus for Asian Economies: Evidence from Heterogeneous Income Groups

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Abstract:
Over the last decade a rapid technological advancement has been causing a revolutionary change in the countries, affecting every sphere of the economies. This study explores the impact of information and communication technology (ICT) and economic growth on CO_2 emissions for three income groups of Asia. ICT is proxied by constructing an index of ICT using fixed telephone (FTS), fixed broadband (FBS), mobile cellular subscriptions (MCS) and individuals using internet (IUI). The analysis covered the period of 1990 to 2016 and performed by exploiting panel time series techniques such as cross-sectional dependence tests (Brusch Pagan LM, Pesaran scaled LM and Pesaran CD), unit root tests (CADF and CIPS), cointegration test (Westerlund), and fully modified ordinary least square (FMOLS) and dynamic ordinary least square (DOLS). The results indicate the existence of cross-sectional dependence among Asian economies and long run relationship among the selected variables. Our findings of FMOLS indicate the existence of EKC for middle income and high-income Asian countries whereas reject the EKC for low-income Asian countries. The study reveals heterogenous effects of ICT on CO_2 emissions. The ICT significantly mitigates CO_2 emissions in low- and middle-income countries while escalates CO_2 emissions in high income Asian countries.

Keywords: CO_2 emissions, GDP, ICT

1. Introduction:

Information and communication technology (ICT) is an extension of traditionally known concept of information technology (IT). The notion got popularity after the World War II, but the ICT actually started developing since the 2000s. Although, the term (ICT) has no universal definition, it generally means all devices, components, networking and systems that allow people to interact with each other in the digital world. The concept is, therefore, so broadly applicable including entertainment products, households, electronics consumed by individuals like computers, radios, television, music players, entertainment games, network, hardware and communication technologies like mobile phones (Ropke & Christensen, 2012).

ICT is considered as an agent which brings societies closer to each other. By doing this, ICT support societal, economic and interpersonal interactions and transactions. In the field of economics its importance can be recognized from the concept of neo-classical growth model in which technology is considered an important determinant of output. The advocates of this theory claim that economies can never achieve stable growth without technological advancement. Khater & Allah (2017) assert that in the present era ICT has emerged as an important agent for increasing economic growth and human development. As use of such technology and equipment helps individuals and businesses to use and communicate information efficiently at low cost. Therefore, it leads to efficient production by improving productivity and energy efficiency that in turn enhance growth in many sectors of the economies (Kaplan, 2006).

Further, ICT assists in trade and create opportunities for the new business, jobs, and revenues (Carayannis & Popescu, 2005). Its diffusion promotes market competition and in turn the domestic and foreign investment that also contribute to the growth of the economy (Gruber & Verboven, 2001). However, by improving the economies' growth (Latif et al., 2018; Toader et al., 2018) ICT changes the level of CO_2 emissions (Bengochea-Morancho, 2001; Hossain, 2011). According to Akin (2014) economic growth and CO_2 emissions are highly linked. Theoretically, this relation of economic growth and CO_2 emissions is evidenced by the famous theory of Environment Kuznets curve (EKC). EKC hypothesis states that in the initial stage of development, level of CO_2 emissions increases in an economy with the increase in per capita income, reaching to the highest level and worsening the environmental quality. However, after a threshold level increase in income causes reduction in CO_2 emissions, improving the environmental quality (Grossman & Krueger, 1991).

Regardless of the economic growth channel ICT directly affects environmental quality by increasing or reducing the climatic burden in the form of greenhouse gases mainly CO_2 which is major contributor of greenhouse gas emissions (World Bank, 2007). According to Hilty et al. (2006) and Ishida (2014) ICT by improving efficiency in production processes and enhancing the use of environmentally friendly products exerts positive externalities in the transport sector and help to mitigate climatic burden. Chavanne et al. (2015), Mathiesen et al. (2015), Zhang & Liu, (2015) and Monzon et al. (2017) also states that application of ICT technology in transport and industrial sector help to control the environmental degradation.

However, ICT also has major undeniable impact on environmental quality as its use, disposal and recycling directly contributes a lot in greenhouse gas emission. E-waste, which is discarded ICT and other electronic equipment, is a major contributor in deterioration of environmental quality. According to global E-waste monitor report (2017) from 2014 to 2017 around 44.1 million metric tons of e-waste generated worldwide which further predicted to increase by 52.2 million metric tons in 2021. Gonel & Akinci (2018) said that ICT contributes nearly 2% in global CO_2 emissions and hence plays a role in degradation of the environmental quality. Because ICT employed devices increases energy and fuel consumption for production activities and then the CO_2 emissions (Asongu et al., 2017).

This means that, in broader term, ICT has two dimensional economic and environmental aspects. We are aiming to explore its impact on CO_2 emissions for the Asian region. The selection of the Asia is based on the fact that from the past few decades the regions is facing severe environmental pressure. Among the other factors ICT also contribute to this environmental pressure as according to the global e-waste monitor report (2017) the problem of e-waste in Asia is difficult to ignore as it generated most of world's e-waste around 40.7%. From 2010 to 2015, the size of discarded electronics in South-East and East Asia surge almost two-thirds (Honda et al., 2016). The region has the most complicated geographical and economical structure consisting both developing and industrial economies having diversity in economic development, emissions level and ICT consumption. In the region, rise in income has increased the demand for new appliances and gadgets and in turn affected the countries e-waste level. Cambodia, China, Hong Kong, Indonesia, Japan, Malaysia, Philippines, Singapore, South Korea, Taiwan, Thailand and Vietnam e-waste increase about 63% in the past five years (2010-2015) and totaled 12.3 million tons, a weight 2.4 times that of the Great Pyramid of Giza. China alone is contributing to this waste and generated more than doubled e-waste between 2010 and 2015 to 6.7 million tons (Honda et al., 2016), up 107% which increase to 7.2 mt in 2017 (global e-waste monitor report, 2017). Also, China remained the top CO_2 emitter in the recent past followed by India, then Indonesia (Alam et al. 2016). The whole region has experienced high growth rates over the last years, but they did not focus to retain their environmental quality. Hence, environmental quality remained a serious challenge for policy makers within the Asian economies.

Few studies are available on this topic. Lee & Brahmasrene (2014) explore the impact of ICT (using ICT index) on CO_2 for ASEAN countries, Zhang et al. (2015) study the ICT impact for Chinese regions, Danish et al. (2018) used two indicators of ICT and explore the impact for Next-11 countries, Majeed (2018) take five proxies of ICT and their index for examining their effect in developed and developing economies, Asongu (2018) tested ICT impact for African countries, Notley (2019) analyze the ICT impact on Asian economies conducting a descriptive study and Raheem et al. (2020) incorporate the three proxies of ICT and checked the impact for G-7 countries. Hence, there is dearth in the literature regrading Asian countries.

Therefore, our study contributes to the existing literature in many ways. First, to the best of our knowledge this is first study of its kind which explore the difference of impact of ICT on CO_2 emissions in three income groups of Asia i.e. low-, middle- and high-income Asian countries. Second, this study exploits the recently develop second generation econometrics techniques whereas previous studies in this area mainly employed first generation econometrics methods. Third, through this analysis the study presents a comparative analysis of ICT-environmental quality relationship for low-, middle- and high-income group of Asia region. Fourth, in the presence of ICT checking the validity of EKC theory for these income groups also add new insight in the existing available literature.

The reminder of the paper is structured as follows: section 2 presents the review of literature. Section 3 gives information about data, econometric model and methodology. Section 4 discusses the empirical findings and section 5 concludes the study.

2. Literature Review

In the present era, particularly during the time period of 2000 to 2013 ICT has emerged as an important agent for increasing economic growth and human development (Khater & Allah, 2017). But during this period climatic burden also increased in the form of greenhouse gas emissions. Among these gases, carbon dioxide (CO_2) has highest proportion and hence considered as a major cause of climatic burden. One of the major concerns of policy makers in the present era is to achieve sustainable development. Hence, there is need to concentrate on both economic and environmental issues. From a theoretical point of view, scholars and researchers used the EKC framework to build link between the environmental quality and economic growth. This study focuses on the following strands of literature: nexus between economic CO_2 emissions and economic growth involving the theory of EKC, ICT and economic growth, and in the end ICT and CO_2 emissions.

2.1. Nexus between Economic Growth and CO_2 Emissions involving EKC Theory

After the theoretical establishment of concept of EKC, studies have provided its empirical evidence (Grossman & Krueger, 1991; 1992; Panayotou, 1993; Dogan, et al. 2020). Jalil & Mahmud (2009) observed two-way causality between economic growth and CO_2 emissions and gave confirmation of environment Kuznets curve in case of China for the period 1975 to 2005. There are some other studies in literature that provided evidence for acceptance or rejection of EKC by carrying time series analysis on single economy. Saboori et al. (2012) favored EKC for the economy of Malaysia over the period of 1980-2009. Shahbaz et al. (2013) carried out analysis on the economy of Turkey for time period 1970-2010 and rejected the EKC theory. Al-Mulali et al. (2015), using the data of 1981 to 2011 also rejected the EKC for the economy of Vietnam. Their study finds energy exhaustive and increasing environmental degradation impact of production in the economy. Similarly, Farhani & Ozturk (2015) rejected EKC in case of economy of Tunisia and Dogan, et al. (2020) rejected the EKC for BRICST (Brazil, Russia, India, China, South Africa, Turkey) countries. Javid & Sharif (2016) and Mikayilov et al. (2018) on the other hand, provided evidence for validity of EKC in economy of Pakistan and Azerbaijan, respectively.

Beside these studies a few studies carried panel data analysis for more than one region and provided different evidence regarding the validity of EKC for their observed region. Arouri et al. (2012) conducted their study for MENA region by taking the sample of 12 MENA countries and the period from 1981 to 2005. They provided the evidence of EKC in these economies. A study of Apergis & Ozturk (2015) also provided the evidence EKC hypothesis for 14 Asian economies using the data from1990 to 2011 and employing the GMM methodology. Al-Mulali et al. (2015) checked this relation for the economies of Latin America and Caribbean countries as these economies have high CO_2 emissions. Their findings were in favor of EKC for the observed region.

Jebli et al. (2016) further confirmed this relation for 25 OECD countries for the period 1980 to 2010 by incorporating the role of renewable and non-renewable energy consumption and trade openness. This relation of EKC is also valid for top four CO_2 emitters i.e. Brazil, China, India and Indonesia for the time period 1970-2012 (Alam et al., 2016). While EKC relation is rejected for some emerging economies i.e. economies of West Africa (Adu & Denkyirah, 2017). Some studies checked the causality between economic growth and CO_2emissions. In this regard, the study of Halicioglu (2008) favor causal relationship among GDP and CO_2 emissions whereas, Tiwari (2011) rejected their causality relation.

2.2. Nexus between ICT and Economic Growth

ICT is found as most significant factor for increasing growth of economies in existing era. According to Sassi & Goaied (2013) and Shahiduzzaman & Alam (2014) ICT diffusion in the form of mobile cellular phone subscriptions and internet both have a positive influence on economic growth. ICT has a great contribution in economic growth and development not only in the developed economies but also in the developing and low-income countries. Latif et al. (2018), Toader et al. (2018), and Lopez & Armendia (2012) empirically proved it for developing and developed world. According to them spending on ICT greatly improve economic growth of the countries.

Asongu & Le Roux (2017) evidenced it for low-income countries of sub-Saharan Africa. However, lesser investment incentives by ICT adoption are found in case of developing countries as compared to developed one (Niebel, 2018). This may be due to the different absorptive capacities, structure, institutions, free market competition and innovation capacity of developed and developing countries (Avgerou, 2003).Beside this, one-way causality and bidirectional causality between ICT and economic growth is also observed (Kuppusamy, 2007; Kuppusamy et al., 2009; Lam & Shiu, 2010; Pradhan et al., 2018).This ensures that not only ICT promote economies' growth but in turn growth of an economy indorses ICT adoption in the country.

2.3. Nexus between ICT and CO_2 Emissions

As it is discussed earlier that ICT promote economies' growth. This growth in turn changes level of CO_2 emissions in the economies and effect environmental quality. This is the indirect impact of ICT on environmental quality. However, use of ICT employed technology also directly contributes to the level of CO_2 emissions therefore its environmental impacts are undeniable. On one hand, ICT devices increase climatic burden due to large scale energy consumption and through E-waste. On the other hand, it decreases climatic burden through clean technologies. Both these arguments are empirically proved in the existing literature.

According to Lee (2014) Belkhir & Elmeligi (2018), Pohl et al. (2019) and Iqbal et al. (2019) ICT increases climatic burden in the form of greenhouse gas emissions by increasing energy consumption. However, a number of studies found mitigating impact of ICT on greenhouse gas emissions (Zhang & Liu, 2015; Monzon et al., 2017; Asongu, 2018). According to them ICT involves the technology of enhancing efficiency and low-carbon way of living as ICT change the societal way of living. This in turn assists in minimizing pollution. Furthermore, there are some studies which shows insignificant impact of ICT on CO_2 emissions (Shahiduzzaman & Alam, 2016; Amri et al., 2019).

The literature shows that ICT and environment are highly linked with each other as ICT have both positive and negative effects on environmental quality. Other than this, ICT also contribute towards the development of economies and thereby affect the productivity and overall growth. The growth is the macroeconomic phenomenon and affects every aspect of the country including environment. However, it influences environment linearly and non-linearly describing the EKC theory. We are adding to the literature by performing an analysis of ICT and CO_2 emissions for three income group of Asia (low, middle and upper). Further, checking the validity of EKC theory for these income groups in the presence of ICT in the EKC model is another contribution of the study.

3.Data, Econometric Model and Methodology

This study examines the impact of ICT adoption on CO_2 emissions and the validity of EKC hypothesis for low, middle and high income Asian countries. Data is taken from World Bank (2019) database. Due to data limitation time period chosen for analysis is 1990 to 2016. CO_2 emissions is dependent variable which is a widely accepted measure of environmental quality (Mikayilov et al., 2018; Asongu, 2018; Amri et al., 2019). To capture the impact of ICT, by using four proxies of ICT we constructed an index through principal component analysis (PCA). These proxies included percentage of fixed telephone subscriptions ***FTS*** (Pradhan et al., 2015; Khater & Allah 2017; Amrie et al., 2019), percentage of fixed Broadband subscriptions (***FBS)*** (Pradhan et al., 2015; Toader et al., 2018; Latif et al., 2018), percentage of Mobile cellular subscriptions ***(MCS)***(Toader et al., 2018), and percentage of individuals using internet (Pradhan et al., 2015; Toader et al., 2018; Latif et al., 2018). To check the validity of EKC hypothesis GDP measured in constant 2010 US dollars (Latif et al., 2014; Toader et al., 2018) and its square term is incorporated in the econometric model.

Beside these independent focused variables (ICT, GDP and its square term), few control variables are used in the model namely urbanization, electricity use and inflation. Urbanization is proxied through urban population in percentage which is initially used by (Zhang & Liu, 2015; Farhani & Ozturk, 2015; Al-Mulali & Ozturk, 2016). Electricity use is measured though electric power consumption in kilo watt per hour as previously used by (Al-Mulai et al., 2015; Al-Mulali & Ozturk, 2016) while determining the validity of EKC. Urbanization and electricity consumption directly influence level of CO_2 emissions. Moreover, use of ICT devices and equipment also increases consumption of electricity and other energy resources hence increases CO2 emissions. Inflation is measured as a percentage of GDP deflator (see Ahmad et al., 2020; Ullah et al., 2020). Inflation instability indirectly influences environment by affecting the performance of the capital market (Ahmad et al., 2020). The econometric model is as follows:

$$\mathbf{lCO_2 = \beta_{0+}\beta_1 lGDP_{it} + \beta_2 lGDP^2_{it} + \beta_3 ICT_{it} + \beta_4 upp_{it} + \beta_5 epc_{it} + \beta_6 infl_{it} + \mu_{it} \ldots . eq. 1}$$

Where ***i*** represents cross sections and ***t*** is for time period which is from 1990 to 2016.In this model ***ICT*** represents ICT index, ***UPP*** is for urban population in percentage, ***EPC*** denotes electric power consumption and ***INFL*** used as short form of inflation and μ_{it} is error term. Among all GDP, its square and CO_2 emissions are converted into logarithmic form to make their interpretation convenient. β0 is intercept and β1, β2,….,β6 are unknown parameters that are to be estimated. Signs of β_1 expected to be positive and that of β_2 expected be negative for validity of EKC. Sign of ICT with CO_2 emissions may be positive or negative depends on methods and modes of ICT adoption. Whereas signs of the two control variables among three i.e. urban population and inflation predicted to be positive or negative depending upon geographical conditions of a region however, we anticipate positive sign of electric power consumption.

After deciding our sample and econometric model, our next step is to choose appropriate econometric techniques for the empirical analysis. In our sample time period (T) is greater than number of countries (N). This means that time factor dominants suggesting the analysis of panel suitable. Panel time series involves certain steps, checking the cross-sectional dependence

(CSD), unit root, cointegration and then coefficient estimates for both long run and short run or preferably for long run.

In the first step, we will check CSD through Brush pagan LM test (1980), Pesaran scaled LM test (2004) and Pesaran CD. Null hypothesis of all these tests is “there is no cross-sectional dependence”. In our case Brush pagan LM test (1980) is more appropriate as in all income group T>N. According to Haseeb et al. (2019) in case where T>N, Brush pagan LM test (1980) is more suitable then other.

The second most important step in panel time series estimations is to move towards stationarity check of the variables being used. To check stationarity of the variables we applied second generation unit root tests CADF and CIPS, proposed by Pesaran (2007). These tests take into account CSD and are robust to heterogeneity. Therefore, these tests give more appropriate results than first generation unit test IPS (Im, Pesaran and Shin W-stat), LLC (Levin, Lin & Chu, test) Fisher-PP, Fisher-ADF tests, in case of CSD in data.

The third step after determining level of stationarity of variables is to check co integration among variables. For this purpose, tests are generally used which are Pedroni (1999, 2004) co integration tests Pradhan et al. (2018). Other than these recent studies are frequently using another test namely Westerlund (2007) co-integration test proposed by Westerlund in 2007. This test is suitable for small sized samples and also it accounts for both between and within unit CSD. Its results are divided into panel statistics (Pt, Pa) and group statistics (Gt, Ga). Beside these, variance ratio statistics also tells about presence of co-integration among our variables. We chose to apply second generation Westerlund co-integration test (Saud et al., 2019; Haseeb et al. 2019).

In the next step we will obtain long run estimates by using fully modified ordinary least square (FMOLS) proposed by Hensen & Phillips (1990). FMOLS takes into consideration the intercept and endogeneity issue, hence provide efficient and asymptotically unbiased results in the presence of endogeneity (Pedroni, 2001). It also removes the problem of omitted variable bias and homogeneity restrictions on long-run parameters. FMOLS is more appropriate to use where the data does not fulfill the requirements of application of OLS (ordinary least square) and have issues like endogeneity, serial correlation and co-integration.

Further, for robustness check of long run estimates we applied dynamic ordinary least square (DOLS) proposed by Saikkonen (1992) and Stock & Watson (1993). This estimate is robust for the case where sample size is small having lesser number of cross sections and does not eliminate the simultaneity problem. Cointegrating vectors obtained by using DOLS are asymptotically efficient (Sallahuddin et al. 2016). It involves augmentation of cointegration regressions with lags and leads and hence the cointegration equation obtained as a result is orthogonal to the entire history of the regression. Moreover, by using single lag and lead of the differenced co-integration regressors this technique eliminates long run correlation. Hence, this technique is efficient in the presence of long run correlation (Lee & Brahmasrene, 2014).

4.Results and Discussion

4.1. Summary Statistics of Data

Summary statistics of data gives brief description of different statistical properties of data like mean value of variables, median, their standard deviation, maximum and minimum value of variables, skewness kurtosis and some others. Table 2 gives information about important statistical properties of the data. Mean value of CO_2 emissions for whole Asia is 7.24 and it deviates 8.25 from its mean value. Mean value of gross domestic product is 552 billion and its deviation from mean value is 1520. Internet is most commonly used application of ICT its mean value is 28.80 percent. Maximum value of CO_2 emissions is 70.04 metric tons for country of Qatar in 1997. While Macao remained least CO_2 emitter having minimum value of CO_2 emissions 0.028407 metric tons in 2011. Maximum value of GDP is 9490 which lies in china for the year 2016 whereas its minimum value is 3380 in 1991 for Bhutan. Minimum value of percentage of internet users was 1 percent which is for Saudi Arabia in 1995. Also, percentage of internet users remained 0 percent in many countries for many years. Whereas maximum value of percentage of internet users is 100 percent in Kuwait in the year 2017.

Table 2: Table of Summary Statistics of Data

Variables	**No of Obs.**	**Mean**	**Std. Dev.**	**Minimum**	**Maximum**
Asia: Complete panel					
CO2 emissions	452	7.24	8.25	0.10	43.86
Gross domestic product	452	552	1520	3380	9490
Fixed telephone subs	452	21.61	17.49	0.38	62.62
Fixed broadband subs	452	7.19	9.74	0.00	32.81
Mobile cellular subs	452	78.56	52.48	0.26	239.44
Internet users	452	28.80	26.72	0.06	100
Urban population	452	61.71	26.51	15.46	100.00
Electricity use	452	4507.56	5130.83	74.85	21508.36
Inflation	452	6.72	8.54	18.89	52.92
Low Income Asian Countries					

CO2 emissions	28	0.53	0.35	0.098	1.0908
Gross domestic product	28	17	9460	4	31
Fixed telephone subs	28	4.07	0.86	2.35	5.34
Fixed broadband subs	28	0.30	0.40	0.00015	1.32
Mobile cellular subs	28	48.05	29.12	0.73	96.93
Internet users	28	9.76	6.37	0.065	22.5500
Urban population	28	25.18	6.34	15.46	34.17
Electricity use	28	709.32	813.97	83.48	2138.640
Inflation	28	12.30	8.17	-8.71	28.15
Middle Income Asian Countries					
CO2 emissions	315	4.54	5.68	0.17	35.92
Gross domestic product	315	450	1120	3	8
Fixed telephone subs	315	12.92	9.012	0.19	38.82
Fixed broadband subs	315	2.62	3.88	0.0000	19.97
Mobile cellular subs	315	63.65	44.39	0.263	182.53
Internet users	315	19.37	19.65	0.07	90.40
Urban population	315	51.75	19.8038	18.19600	90.00
Electricity use	315	2120.92	2447.72	50.33	12502.70
Inflation	315	8.86	8.76	-19.52	59.74
High Income Asian Countries					
CO2 emissions	158	16.73	12.4619	4.3426	63.83
Gross domestic product	158	727	1700	12	5900
Fixed telephone subs	158	33.82	16.89	8.71	62.61
Fixed broadband subs	158	10.96	10.70	0.00	32.81
Mobile cellular subs	158	105.67	46.09	11.93	239.44
Internet users	158	46.49	23.82	4.68	91.49
Urban population	158	88.07	11.31	67.03	100
Electricity use	158	9374.38	4801.49	3455.26	21508.40
Inflation	158	3.82	8.69	-25.12	33.75

4.2. Cross Sectional Dependency in Data

We are taking the data of countries from the same geographical region i.e. from Asia so the countries may be similar in terms of their economic, geographic, social and political conditions. Increase or decrease in GDP of one country may affect GDP of another country. There are many chances that Asian economies may integrate with each other. In order to know this, we applied cross sectional dependence test separately on three data sets. Their results are discussed in table 3. According to the results, probability values are less than 0.05 for all the income groups according to the three types of cross-sectional dependence tests. So, we can reject the null hypothesis of no CSD and can proceed our estimations based on the conclusion of presence of cross-sectional dependence.

Table 4: CSD Test Across Income Groups of Asia (Low, Middle and High)

Low Income Asian Countries						
Variables	**Brush pagan LM test**		**Pesaran scaled LM test**		**Pesaran CD**	
	Statistics	**Probability**	**Statistics**	**Probability**	**statistics**	**Probability**
lCO_2	73.4513***	0.0000	13.0701***	0.0000	-1.9165***	0.0000
GDP	33.3575***	0.0000	11.1686***	0.0000	5.4047***	0.0000
$lGDP^2$	33.4595***	0.0000	11.210***	0.0000	5.4047***	0.0000
ICT index	61.8641***	0.0000	14.9719***	0.0000	7.8606***	0.0000
Urban population	189.469***	0.0000	39.0125***	0.0000	3.2839***	0.0000
Electricity use	127.446***	0.0000	25.1438***	0.0000	0.9804***	0.0000
Inflation	17.2805***	0.0000	0.5099***	0.0000	3.0445***	0.0000
Middle Income Asian Countries						
Variables	**Brush pagan LM test**		**Pesaran scaled LM test**		**Pesaran CD**	
	Statistics	**Probability**	**Statistics**	**Probability**	**statistics**	**Probability**
lCO_2	5326.47***	0.0000	158.397***	0.0000	44.7085***	0.0000
GDP	10025.24***	0.0000	312.476***	0.0000	99.3429***	0.0000
$lGDP^2$	10051.30***	0.0000	313.306***	0.0000	99.4803***	0.0000
ICT index	4266.998***	0.0000	123.656***	0.0000	63.8189***	0.0000
Urban population	9525.577***	0.0000	296.0915***	0.0000	57.3132***	0.0000
Electricity use	3796.329***	0.0000	135.1396***	0.0000	35.2656***	0.0000
Inflation	1861.645***	0.0000	44.78125***	0.0000	28.16438***	0.0000
High Income Asian Countries						
Variables	**Brush pagan LM test**		**Pesaran scaled LM test**		**Pesaran CD**	
	Statistics	**Probability**	**Statistics**	**Probability**	**statistics**	**Probability**
lCO_2	318.01***	0.0000	18.7560***	0.0000	1.6907*	0.0909
GDP	-	0.0000	-	0.0000	-	0.0000
$lGDP^2$	-	0.0000	-	0.0000	-	0.0000
ICT index	918.411***	0.0000	73.14840***	0.0000	30.2648***	0.0000
Urban population	-	0.0000	-	0.0000	-	0.0000
Electricity use	804.549***	0.0000	70.4179***	0.0000	26.45674***	0.0000
Inflation	443.840***	0.0000	28.2498***	0.0000	8.32376***	0.0000

4.3.Unit Root Tests

In the next step second generation unit root tests CADF and CIPS are applied for checking the stationarity properties of the variables. Results are given in table 4 in which test statistics along with probability values are mentioned. Results of CADF test for low income countries shows variables of GDP, its square and inflation are stationary at level with 1% significance level as their probability values are less than 0.05. Whereas urban population is stationary at level with 10% significance level. Other variables like CO_2, ICT, electricity use and inflation are stationary at first difference. In the group of middle-income countries, only urban population and inflation are stationary at level according to CADF test while all other variables are stationary at first difference. The results of CIPS test for this income group shows stationarity at first difference for all the variables accept urban population as its probability value is 0.000 at level. In the data of high-income countries, GDP, ICT, urban population and inflation are stationary at level with 1% significance level according to CADF test. Square of GDP is stationary at level with 5% significance. Results of CIPS test for this income group reveals stationarity of all variables at first difference.

Table 5: Results of Unit Root Tests for Low-, Middle- and High-Income Asian Countries

	CADF Test Results		**CIPS Test Result**	
	t-stats	**Probability**	**t-stats**	**Probability**
Low Income Asian Countries				
	Level	**1st diff**	**Level**	**1st diff**
lCO2	0.991	0.010	0.969	0.584
lGDP	0.001	-	0.977	0.110
lGDP^2	0.000	-	0.978	0.115
ICT	0.215	0.012	1.000	0.002
Urb pop	0.081	0.002	0.025	-
Elec use	0.879	0.004	0.999	0.548
Inflation	0.000	-	0.880	0.634
Middle Income Asian Countries				
	Level	**1st diff**	**Level**	**1st diff**
LCO2	0.081	0.000	0.870	0.000
lGDP	0.732	0.000	0.921	0.000
lGDP^2	0.685	0.000	0.881	0.001
ICT	0.997	0.591	0.766	0.066
Urb pop	0.000	-	0.000	-
Elec use	0.761	0.000	0.999	0.000
Inflation	0.000	-	0.800	0.000
High Income Asian Countries				
	Level	**1st diff**	**Level**	**1st diff**
lCO2	0.476	0.000	0.352	0.000
lGDP	0.05	0.000	0.122	0.040
lGDP^2	0.07	0.000	0.123	0.044
ICT	0.007	-	0.141	0.000
Urb pop	0.001	-	0.000	-
Elec use	0.788	0.000	0.566	0.015
Inflation	0.038	-	0.722	0.008

4.4. Panel Cointegration Tests

Our next step of panel time series analysis is to check the cointegrating relationship among the variables. We have applied the second generation cointegration test namely Westerlund cointegration test. In table 5, variance ratios and probability values confirm presence of co-integration for all the three income groups i.e. data of low income and middle-income countries is integrated at 1% significance level whereas, the data of high-income countries is integrated at 5% significance level.

Table 6: Results of Westerlund Cointegration Test

Income Groups	Variance ratio	
	Statistics	**Probability**
Low-income countries	5.0318 ***	0.0000
Middle income countries	-2.2554***	0.0121
High income countries	-1.5824**	0.0568

4.5. Results of FMOLS

Results of FMOLS regressions are given in table 6 where in the first panel the result of low-income Asian countries, in the second panel the results middle income Asian countries and in the third panel the results of upper income Asian countries are reported. The findings of low-income Asian countries showing that the signs of GDP and GDP square negative (-2.84) and positive (0.12) also coefficients are statistically significant for low-income countries of Asia. This means that the impact of economic growth on CO_2 emissions is non-linear however, taking the U shape which is against the EKC theory (which take an inverted-U shape). Therefore, our findings from FMOLS clearly indicate that EKC is not valid for countries belonging to low-income groups of Asia. These findings are consistent with that of Omisakin & Olusegun (2009) who worked on Niegerian economy, Omojolaibi (2010) who worked for selected West African economies and with the conclusion drawn by Alam et al. (2016) for four highly populated and emerging economies i.e. Brazil, China, India and Indonesia. This result is also consistent with Majeed & Mazhar (2020) who found the similar results for south Asian economies and for the low-income group of global economy. According to them low-income countries often follow middle- and upper-income countries and also their economy's size is small comparative to middle- and upper-income countries. Therefore, low-income countries give priority to the environment and adopt effective measures to conserve the environment. For example, countries tried to import environmentally friendly technology and save energy. Further, they can also control the import and use of the pollution creating products and therefore, protect the environmental quality. However, considering environmental problems in control they prioritize economic development which result in higher pollution. Our finding of significant impact of GDP on CO_2 emissions contradicts with that of Tiwari (2011) who found no causality running from GDP to CO_2 emissions.

Moving towards the results of middle income and high-income Asian countries EKC seems to be valid as coefficient of GDP is positive and its square is negative. In case of middle-income countries, coefficient values of GDP and its square shows that one percent increase in GDP initially increases CO_2 emissions by 1.560 percent but after a certain level further increase in GDP causes reduction in CO_2 emissions by 0.0205 percent. While, for high income countries coefficient of GDP is 5.079 and that of GDP square is -0.106 which shows, at initial level one percent increase in GDP increases CO_2 emissions by 5.079 percent but after reaching a threshold level further one percent increase in GDP decreases CO_2 emissions by -0.106 percent.

These results are consistent with Jalil &Mahmud (2009) in case of china, Javid and Sharif (2016) in case of economy of Pakistan, Alam et al. (2016) in case of economy of Indonesia, China and Brazil also with that of Apergis & Ozturk (2015) in case of 14 Asian countries. All these studies confirm existence of EKC for their respective focused regions. In case of validity of EKC in high income countries our findings are consistent with the finding of Al-Mulali & Ozturk (2016), Higón et al. (2017) who proved EKC for 27 advanced countries and 26 developed countries, and Majeed & Mazhar (2020) for upper income countries. They argued that presence of EKC in these economies ensure the structural transformation in the counties. According to them these economies have attained the sustainable development level. This finding contradicts with the finding of Al-Mulali et al. (2015) and Farhani & Ozturk (2015) and also with that of Chandran &Tang (2013).

Impact of increased use of ICT on CO_2 emissions for low income and middle-income Asian countries is negative and significant which exhibits increase in ICT employed technology decreases CO2 emissions of the region significantly. This finding is consistent with the study carried out for low-income countries of Africa by Asongu (2018) which revealed significant and decreasing impact of ICT on CO_2 emissions. Results of low-income countries show one percent increased use in ICT, decreases CO_2 emissions by 0.116 percent whereas in middle income countries one percent increase in ICT employed technology decreases CO_2 emissions by 0.04432 percent. This is due to the fact that these counties follow upper income countries and enhance the use of ICT in order to protect the environment. Thus, ICT by increasing efficiency in production process in industrial sector and through energy saving in transport sector can improve environmental quality. However, for high income Asian countries ICT use has positive and significant impact on CO_2 emissions. Meaning that one percent increase in ICT use lead to 0.04081 increase in CO_2 emissions. This relationship can be justified due to the nature and situation in these economies as upper income countries have greater economy’s size, production activities, higher demand and consumption that in turn increase ICT uses and carbon emissions as well. These countries have completed their transition period and now that advance technology is no more (less) advance in these counties and did not play more beneficial role. This shows the scope of new research and technological development in these countries.

Among the three control variables urban population has insignificant impact on CO2 emissions of low-income countries and middle-income countries. This finding is consistent with that of Zhang & Liu (2015) for eastern region of Asia while contradicts with that of Farhani & Ozturk (2015) and Mulali & Ozturk (2016). Electricity use has positive and significant impact on CO_2 emissions in all income group of Asia (Mulali et al., 2015; Mulali & Ozturk 2016). One kilo watt per hour increase in electricity consumption increases CO2 emissions by 0.001972 for low-income countries, 0.000263 for middle income countries and 0.00124 percent in high income countries. This finding is in line with Saint Akadiri et al. (2020) who stats that positive relationship among electricity consumption and CO_2 emissions validate that non-renewable electricity consumption is dominates that exert pressure on the environment. Inflation has insignificant impact on CO2 emissions of low-, middle- and high-income region which is not consistent with the findings of Ahmed et al. (2020) and Ullah et al. (2020).

Table 7: Results of FMOLS for Three Income Groups of Asia

Low Income Countries			
Variables	**Coefficient**	**St. Error**	**T- stats**
lGDP	-2.837104***	0.415544	-6.827449
lGDP^2	0.117118***	0.018152	6.452213
ICT index	-0.115519**	0.052634	-2.194772
Urban pop	-0.000846	0.019156	-0.044153
Elec use	0.001972***	0.000358	5.509576
Inflation	0.001240	0.004280	0.289653
Middle Income Countries			
Variables	**Coefficient**	**St. Error**	**T- stats**
lGDP	1.560136***	0.596781	2.614250
lGDP^2	-0.020483*	0.012153	-1.685517
ICT index	-0.044319**	0.019670	-2.253099
Urban pop	-0.010712	0.008333	-1.285399
Elec use	0.000263***	3.51E-05	7.468601
Inflation	0.000476	0.001729	0.275300
High Income Countries			
Variables	**Coefficient**	**St. Error**	**T- stats**
lGDP	5.079506***	0.855432	5.937942
lGDP^2	-0.105982***	0.017011	-6.230237
ICT index	0.040806***	0.009568	4.264875
Urban pop	0.0065*	0.003829	1.714584
Elec use	8.54E-05***	6.24E-06	13.68275

Inflation	0.000803	0.000497	1.617057

******p<0.01, **p<0.05,* p<0.1***

4.5. Results of DOLS

Results of DOLS for low-, middle- and high-income countries are presented in table 7. These results are in accordance with that obtained in case of FMOLS and are robust. For the case of low-income countries EKC hypothesis is still rejected as GDP is negative (-2.8735) and its square is positive (0.1184) showing U-shaped relation between GDP and CO_2 emissions. For the middle and upper income our DOLS findings validate the EKC hypothesis as like FMOLS findings. Further, the impact of ICT on CO_2 emissions is negative and significant for the low- and middle-income group while positive and significant for the upper income group of Asia. Regarding the impact of control variables, we get the same results in case of FMOLS in all income groups.

Table 8: Results of DOLS for Three Income Groups of Asia

Low Income Countries			
Variables	**Coefficient**	**St. Error**	**T- stats**
GDP	-2.87345***	0.519276	-5.533570
lGDP^2	0.118405***	0.022701	5.215881
ICT index	-0.156519**	0.06685	-2.347145
Urban pop	0.003656	0.024433	0.149631
Elec use	0.002020***	0.000457	4.420807
Inflation	-0.000353	0.006012	-0.058751
Middle Income Countries			
Variables	**Coefficient**	**St. Error**	**T- stats**
GDP	1.446262***	0.529289	2.732461
lGDP^2	-0.020313**	0.010893	-1.864700
ICT index	-0.039923***	0.019112	-2.088875
Urban pop	-0.002919	0.0079291	-0.400359
Elec use	0.000274***	3.39E-05	8.098960
Inflation	0.000668	0.001406	0.475197
High Income Countries			
Variables	**Coefficient**	**St. Error**	**T- stats**
GDP	4.112423**	1.942903	2.116638
lGDP^2	-0.085475**	0.039338	-2.172830
ICT index	0.016276	0.025110	0.648176
Urban pop	0.013680***	0.005624	2.432575
Elec use	6.07E-05***	1.61E-05	3.764579
Inflation	0.000639	0.001417	0.451273

******p<0.01, **p<0.05,* p<0.1***

5.Conclusion and policy Recommendation:

This study throws light on the impact of ICT adoption and GDP increase on CO_2 emissions within Asia. We compared these effects for all the three income groups of Asia i.e. low-, middle- and high-income countries from time period 1990 to 2016. Not any previous study available in literature which makes comparisons among the three income groups within Asia to examine the impact of ICT on CO_2 emissions and to determine validity of EKC based on income group concerning Asia region. However separate studies have been conducted to study the relation for different countries within Asia. Methodology we adopted for estimations is panel time series estimation procedure involving cross section dependence test, unit root tests and FMOLS and DOLS for long run estimates.

Results proves that Environment Kuznets curve do not exists in case of low-income Asian countries. In these countries we get U-shaped relation between GDP and environment. Whereas environmental Kuznets curve is valid for middle income and high-income Asian countries. We get inverted U-shaped relation between GDP increase and CO_2emissions in these groups. Negative and significant impact of ICT employed technology on CO_2 emissions of low income and middle-income countries is observed. While positive and significant impact of ICT employed technology on CO_2 emissions is observed for high income countries.

Policy recommendations:

Low-income Asian countries where environmental quality gets decline in long run with increase in production should focus their research to find out such ways of production which are lesser energy consuming and by using smarter equipment. These countries should shift their production activities by using smart equipment as ICT has mitigating effect on CO_2 emissions of the region. Same recommendation is for middle income countries too as they have negative and significant impact of ICT on CO_2 emissions. But these countries should attain that threshold level in production where carbon emissions start decreasing with further increase in production.

For high income countries where ICT equipment increases climatic burden should promote use of renewable energy resources by increasing investment in them. Carbon pricing is also an effective method to reduce climatic burden. Increase in CO_2 emissions due to increased use of ICT may be due to use of such equipment which is difficult to waste or recycle. Hence their recycling and e-waste generated may increase climatic burden. In these countries ICT should be employed to mitigate its impact on CO_2 emissions by building smart grid system.

Policies should be adopted to develop smarter cities, smart transportation and industrial equipment these policies result in the reduction of carbon dioxide emissions on a global scale. Further, these countries may control the carbon emissions by improving ICT through further research and development.

However, this study has a limitation that it used only CO_2 emissions as an indicator of environment. Though CO_2 is major contributor of greenhouse gases however other form of emissions such as nitrogen emissions and sulfur emissions are not enough less in their proportion to ignore them. But this study may prove to be helpful in examining the quality of environment by determining the changing proportion of CO_2 emissions due to ICT adoption and growth in GDP in each of the income group of Asia.

Declarations

Authors' contributions This idea was given by Muhammad Tariq Majeed. Muhammad Tariq Majeed supported in all sections of this work and completed the final write up of the paper. Amna Ahsen analysed the data and discussed the results and drafted initial versions of the other sections. Maria Mazhar wrote the introduction and literature review sections. All authors have read and approved the manuscript.

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Appendix:

Table A1. Definition of Variables and their Source.

Variable	Description	Data source
CO_2 emissions.	Carbon dioxide emissions per capita	World Bank (2019)
Gross domestic product.	Annual gross domestic product constant 2010 US$.	World Bank (2019)
Fixed telephone subscriptions.	Fixed telephone lines per 100 people	World Bank (2019)
Fixed broadband subscriptions.	No of broadband subscriptions per 100 people.	World Bank (2019)
Mobile cellular subscriptions.	Subscriptions to cellular mobile service per 100 people.	World Bank (2019)
Individuals using internet.	Individuals using internet per 100 people.	World Bank (2019)
ICT Index	Index constructed using ICT listed 4 measures	World Bank (2019)
Urban Population	Urban Population in percentage	World Bank (2019)
Electric power consumption	Electric power consumption	World Bank (2019)
Inflation	Inflation measured as GDP deflator.	World Bank (2019)