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Sustainable Information and Communication Technologies: A Critical Query for CO_2 Emissions in Panel Countries*

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Abstract: *In the context of a sustainable environment, innovative information and communication technology solutions are not only an important tool for reducing the carbon footprint in the fight against global warming and climate change, but they also contribute to globalization. Using Comtrade data, this study analyzes the relationship between exports of information and communication technologies and carbon emissions in selected countries for the years 1993-2014. The study uses two models. The dependent variable of the first model is carbon emissions and that of the second model is carbon emissions from electricity and heat generation. First, a Westerlund cointegration test, a cross-sectional dependence test, and a fully modified least squares test were conducted, followed by a panel causality analysis. The results showed that exports of information and communication technology services, individual internet use, and per capita gross domestic product increased carbon dioxide emissions, and there was no causal relationship between carbon dioxide emissions from electricity and heat generation, carbon dioxide emissions, and trade.*

Keywords: Sustainable Development, ICT Export, Economic Growth, CO2 Emission, Energy

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1. Introduction

Increasing with economic growth, industrialization and urbanization cause accumulation of harmful gases causing air pollution and decreasing air quality. Carbon dioxide has the highest share of greenhouse gases that cause environmental destruction. As per the International Energy Agency (IEA), carbon dioxide (CO_2) is estimated to increase the world temperature by 3.6 degrees in the long term, from 31.2 gigatons (Gt) in 2011 to 37.0 Gt in 2035 (IEA, 2012: 1). The report of the Agency (2016) suggests that by 2040, global energy tendency will rise up by 30% and that billions of people may be lack of energy services. Climate change is one of the primary concerns of the world today. It is anticipated that the world economy should decrease CO_2 emissions by 6.3% per year until 2100 in order to reach the aimed rates in the Paris Agreement (PWC, 2018). The European Commission recently stated that the most important function of information and communication technologies (ICT) is decreasing energy frequency and enhancing energy productivity (European Commission, 2008). In 2016, the World Economic Forum (WEF) presented the Global Information Technologies Report of 2015 and the ESCAP technical reports of the United Nations. These reports stated that CO_2 emissions are of great importance for both ICT and energy policies. The increase in the environmental impact and concerns caused by human activities is also triggering the efforts to decrease energy depletion and raise energy productivity. In Europe, there is an initiative called “Energy 2020” including aims to be achieved until 2020. European Commission initiated several projects focused on information technologies, targeting two primary themes concerned with energy and ICT: (1) Energy decrement ensured

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via ICT, such as optimized production and reduced paper consumption, smart energy systems and energy efficient constructions, (2) energy usage of ICT; by 2020, the energy consumption of ICT is estimated to be equal to 15 percent of total consumption (Pernici et al., 2012: 276). The report of SMART 2020 published by GeSI (Global e-Sustainability Initiative) in 2008 estimated that the CO_2 emission of ICT sector would increase to 1.43 $GtCO_2$ (Equivalent CO_2), and five years later, SMART 2020 report revised these values to be 1.27 $GtCO_2$. While in the SMART 2030 report, it is predicted that the carbon footprint of the ICT sector will decrease to 1.25 $GtCO_2$ by 2030. According to the same report, the global carbon emission reduction potential of the ICT sector was calculated to be 7.80, 9.10 and 12.08 Gt CO_2, respectively.

When ICT is evaluated in terms of its potential to increase and decrease carbon emissions, it is seen both as a resource and a solution for problems related to global warming and climate change. These data show how the greenhouse gas reduction potential of ICT is nine times larger than its carbon footprint. All these indicators support the view that ICT has a major potential to contribute to sustainable development. Yet the function of ICT in sustainable development is not completely understood. There are two contradictory views about the function of ICT in sustainability. The first is an optimistic perspective upon the improvement and spread of ICT around the world while the other pessimistic perspective is on the contribution of ICT to the consumption of resources and pollution. Some researchers have analyzed that even though the ICT reform affects the energy sector, its potential power has not been commonly accepted yet. The literature on the effect of ICT on CO_2 emissions is not yet precise and there is not a commonly accepted opinion.

Studies on ICT should be more profound as they would have a major role in increasing and controlling the consciousness of energy productivity in a variety of fields. The main subjects that motivated this study are (i) the effects of globalization on the environment and carbon emissions (CO_2) (ii) the serious potential of ICT, (iii) different from the researchers investigating the impact of ICT on CO_2 emission, this paper also investigates the connection between ICT and CO_2 emissions from electricity and heat generation (CO_{2H}), (iv) contributing to the related literature by investigating the relevance between ICT, the effect of economic growth on CO_2 emissions and $CO_{2H.}$ The connection between the ICT exports and CO_2 emissions has been analyzed in selected countries by two distinct models for the years 1993-2014. Firstly, Westerlund Cointegration Test, cross-sectional dependence was tested and FMOLS test was applied and then Panel causality analysis was tested.

The rest of the paper is organized as follows: Under the literature review, section 2 focuses on economic growth, CO_2 emissions, and ICT. Section 3 analyses the connection between ICT exports and CO_2 emissions. Section 4, presents the findings of the study and section 5 includes the conclusion and remarks.

2. Literature Review

The literature review section of the paper includes the relationship between economic growth and CO_2 emission and then between ICT and CO_2 emissions.

2.1. Economic Growth and CO_2 Emissions

Economic growth increases the capability of a country to manufacture more advanced products and ICT makes these products more effective. For this reason, rapidly increasing production, overuse of resources and utilization of fossil fuels, cause problems such as deterioration of biological balance, environmental pollution and degradation of quality of life (Lee & Brahmasrene, 2014). In other words, the increase in the need for energy resources, which is the main input of high welfare socio-economic development, have environmental consequences that stems from growth. The issue of economic growth and environmental pollution has gained increasing attention from researchers in recent years. Therefore, there are various studies investigating the connection between carbon emissions and growth. The presence of a relationship between pollution and income was first put forward by Grossman and Krueger (1991, 1995). Environmental Kuznets Curve (EKC) has attracted attention lately because it showed that the link between per capita income and pollution is shaped as an inverted "U" (Cole, 2004: 71). According to this approach, if the income level is low, the priority is given to the environment due to food and shelter and with the rise in income level, people will become more sensitive to the environment (Kaypak, 2011: 30). The hypothesis is that in its first stages of economic growth, environmental deterioration will rise due to the attention given to increasing production and per capita income while ignoring environmental problems; however, as the economy grow more and more environmental sensitivity increases and environmental conditions improve (Aslanidis, 2009: 5). According to Grossman and Krueger (1991: 3-4), there are four main strong effects behind the EKC hypothesis: (i) The effect of scale: if emissions rise by a greater scale of economic growth it means the rise in revenue has a negative impact on ecological damage, (ii) the effect of the output: from basic production to structured production, that is, shifting to more advanced value-added actions which would lead to reduced emissions per output unit, replacing old technology with cleaner technologies, (iii) the effect of materials: where materials causing emissions are replaced by the ones that are less harmful to the environment, decreasing emissions per unit, (iv) the effect of technology: to have features that enable new technologies to be used in the manufacturing processes to improve the methods of production and distribution. While the effect of the scale is seen in the primary phases of economic growth, the rest is seen in the latter stages (European e-Business Report, 2010: 33). The EKC hypothesis has been tested by various studies throughout the years by using (a) different econometric techniques, (b) different explanatory variables, (c) a set of countries or a unique country (d) for various ecologically hazardous substances. Empirical studies have contradictory findings. Certain studies support the EKC hypothesis (Zhang & Cheng, 2009; Jalil & Mahmud, 2009; Rehman, 2011; Wang et al., 2011; Farhani & Rejeb, 2012; Saboori & Sulaiman, 2013; Baek, 2015; Apergis & Ozturk, 2015; Shahbaz et al., 2015; Shahbaz et al., 2016; Alam et al., 2016; Sinha et al., 2018) while others do not consider it valid (Soytaş & Sarı, 2007; Sinha & Mehta, 2014; Adu & Denkyirah, 2017). Jalil and Mahmud (2009), using the data between 1975-2005 in China, analyze the long-term connection between energy consumption, foreign trade, CO_2 emissions and income. Despite siding with the EKC hypothesis, they concluded that the effects of carbon emissions, energy consumption and income level were found to be significant, but the effect of trade was not. Zhang and Cheng (2009) explored the connection among the variables CO_2 emissions, economic growth and energy consumption between 1960-2007. They found a causal relationship among GDP, energy consumption and CO_2. Nasir and Rehman (2011) analyzed the relationship among energy consumption, foreign trade, CO_2 emissions and income between 1972-2008 in Pakistan. Income and CO_2 emissions were found to have a long-term relationship. Wang et al. (2011) explored the causal relationship among energy consumption, CO_2 emissions and real economic output for the years 1995-2007. The outcomes pointed out a long-term bi-directional relationship among economic growth and carbon emissions. Also, Farhani and Rejeb (2012) conducted empirical research concerning the relationship between CO_2 emissions, energy consumption and GDP using the data from 1973-2008 of 15 countries in the MENA region. The results point out that GDP also leads to energy consumption and CO_2 emissions. In their study, Saboori and Sulaiman (2013) used the data form 1971-2009 and revealed the existence of significant nonlinear relationship between economic growth and carbon emissions in Singapore and Thailand, supporting the EKC hypothesis. Baek (2015) evaluated the per capita income related to CO_2 consumption in the Arctic countries by including the role of energy consumption. The results show that economic growth has favorable effects on the environment only in certain polar countries and that the EKC hypothesis is feasible for the Arctic countries. Apergis and Ozturk (2015) analyzed the Environmental Prediction Curve hypothesis for the years 1990–2011. The findings support the EKC hypothesis and inverted U-shaped relationship between income and per capita emissions. Shahbaz et al. (2015) studied the non-linear relationship between the environmental degradation and FDI (foreign direct investments) in high, middle, and lower-income countries. Long-term results show that the EKC and pollution haven hypothesis (PHH) exist and that foreign direct investments increase environmental deterioration. Shahbaz et al. (2016) conducted a study for the years 1970-2013 on recently industrialized countries such as South Africa, Brazil, China, and India. The results show that liberalization of trade in recently industrialized economies leads to higher energy depletion and CO_2 emissions which, again, confirms the EKC hypothesis. Alam et al. (2016) investigated the role of energy expenditure and population growth on CO_2 emissions using annual data for China, Brazil, Indonesia and India for the years 1970-2012. The results indicate that CO_2 emissions in Indonesia, China, and Brazil will decrease. Sinha et al. (2018) analyzed CO_2 emissions in India between 1971-2015 and the effect of renewable energy on EKC. The findings confirm EKC for CO_2 emissions. In their study conducted on Turkey for the period between 1960-2000 with Granger causality analysis, Soytaş and Sarı (2007) revealed that there is no causality between income and long-term emissions. Similarly, Ozturk and Acaravcı (2010) conducted their empirical study on the economic growth of Turkey between 1968-2005, CO_2 emissions and the connection between employment and energy consumption. They used a linear logarithmic model causal analysis framework and concluded that the EKC hypothesis is applicable to Turkey. Adu and Denkyirah (2017) analyzed the link between the real GDP and CO_2 emissions for the years 1971 and 2011 in distinct income groups in a total of 106 countries. In the analysis they found that the ongoing growth period worsened CO_2 emissions. They could not find any proof that developed countries are free of environmental pollution. Sinha and Mehta (2014) focused on CO_2 emissions and GDP growth throughout the 1960-2010. So far, there has been a bi-directional causality among GDP growth and increase in CO_2 emissions. Any of these two aspects of this causal relationship have already been demonstrated in some literature, but the bi-directional causality relationship is a new finding. Causality from the rising in CO_2 emissions to GDP growth is important in terms of the EKC hypothesis. The inconsistent results on the EKC hypothesis in the literature can be explained by the different variables that were used (Amri, 2018).

2.2. ICT and CO_2 Emission

Economic growth leads to increased need for ICT goods and services, which would mean more electricity usage and CO_2 emissions (Lee & Brahmasrene, 2014). Considering that ICT affects almost all sectors of the economy, its effects on how sustainable development is viewed is important (Plepys, 2002: 510). According to Kohler and Erdmann (2004), the main aim is to establish a conceptual link to environmental indicators resulting from the usage of ICT in a number of economic sectors. ICT environmental interaction has three levels of impact on economic structures and lifestyles, from the most direct to the most indirect: (1) Primary impacts; arising from the physical presence of ICT, (2) secondary impacts; indirect environmental impacts from ICT, (3) tertiary impacts; environmental impacts arising from medium or long period action adaptation. The primary impact points to the lineal effect of the ICT sector on CO_2 emissions and potential of the ICT industry to enhance significant growth and energy consumption, which would jeopardize the targets of reducing CO_2 emissions (Zhang & Liu, 2015: 13). These effects refer to the impacts of the physical presence of ICT, such as environmental influences, the manufacture, usage, recycling and selling of ICT equipment (Hilty et al., 2006: 1620). A series of studies on primary impacts also address problems caused by illegal recycling and environmental problems in developing countries (Erdmann & Hilty, 2010: 230). Secondary impacts, emphasized by the indirect environmental impacts created by ICT's power to influence production or transportation operations, refer to a change (decrease or increase) in its environmental impacts. (Kohler & Erdmann, 2004: 834). This impact contains dematerialization decarbonization, and demobilization (Salahuddin et al., 2016). Virtualization of all products have positive effects such as the transition from CDs to mp3s, digitization of information catalogs to web sites, teleconferencing together with the dematerialization of transportation, reduction of warehouses or office spaces and shortening of supply chain processes (Yi & Thomas, 2007: 841-842). Virtual services such as e-mail, teleworking, tele-conferencing are taking the place of physical services (Vereecken et al., 2010). Some examples for this could be writing letters, reading e-books rather than physical books, GPS and control cameras used in transportation applications and intelligent transport systems. Other examples are the use of e-applications in banking, commerce and governmental affairs to decrease the necessity of physical presence and mobility (which shows that e-commerce causes more production and consumption and therefore more environmental impacts).

In other words, internet marketing encourages people to buy more with one click thanks to the relative convenience it provides (Rivera, 2014: 4). Increasing the possibilities of organizing virtual trainings and virtual meetings via the usage of wireless networks decreases the requirement for business trips (Shabani & Shahnazi, 2018: 2). And lastly, the tertiary impacts are the result of integration into medium or long period action or economic structures because of the advantages of ICT such as services and stable usability (Hilty et al., 2006: 1620). However, a number of studies indicated that ICT has greater potential for indirect facilitation and that it has potentially significant and positive effects. Climate Group established the basis for potential impacts that will ensure global greenhouse gas emissions reductions that are nine times larger than the carbon footprint of ICT (SMART 2030). Tertiary ICT impacts represent the revolution of ICT in the form of communication, which is difficult to quantify (Erdmann & Hilty, 2010: 230). This radical change can influence all social systems from a company to a global community. This attitude would help sustainable development in businesses. Erdmann and Hilty explained that the way that ICT is changing the way of communication can affect social systems from companies to global communities.

One of the optimistic studies observing that ICT decreases CO_2, Zhang and Liu (2015) investigated the effect of the ICT sector on CO_2 emissions at national and regional levels by using the STIRPAT model for the 2000-2010 time period, taking the regional differences in China into account. The findings reveal that ICT helps the reduction of CO_2 emissions in China. It indicates that the effect of the ICT industry is significant in the center than in the east and is insignificant in the west. Again, Stewart (2015) used a case approach using the Latis model. He discovered that carbon emissions were reduced by ICT measures implemented by the Scottish government to improve bus travel times. The research sets out which ICT measures in Scotland lead to a reduction in the number of vehicles used and consequently a reduction in CO_2 emissions. Salahuddin et al. (2016) conducted a study for the period between 1991-2012 in OECD countries. The aim was to not only increase existing measures to combat CO_2 emissions and to reduce the carbon footprint of OECD countries, but also to decrease emissions, such as energy, transport, agriculture and service sectors, also to draw attention to the necessity of using ICT equipment. Higon et al. (2017) stated that as various developed countries reach the level of developed ICT, their CO_2 emissions decrease. Parallel to the above studies, it verifies the relationship between the two variables is an inverted U-shape. Khan et al. (2018) researched the relationship among economic growth, CO_2 emissions and ICT using a correlation matrix for the 1990-2015 time period in developing economies. They conclude that ICT significantly affects CO_2 emissions, but the interactive relation between ICT and GDP reduces pollution. Lu (2018), also emphasizes the significant adverse effect of ICT on CO_2 emissions, thus making ICT one of the major strategies for reducing CO_2 emissions for a variety of countries. According to Lu, the aim of ICT should be to reduce CO_2 emissions, rather than to harm the environment. Tsaurai and Chimbo (2019) investigated the effect of ICT on CO_2 emission with annual secondary data dating back to 1994 by panel methods. The results indicate that ICT decreases CO_2 emissions in emerging markets. Shabani and Shahnazi (2019) also explored the short and long term causal relationship among the variables; energy consumption, GDP, CO_2 emissions and ICT, in Iran for 2002 and 2013. Their findings support the presence of the Kuznets curve in all sectors. The results approved the positive impact of ICT on CO_2 and its negative impact on the transport and service sectors. Also, Raheem et al. (2019) conducted a questionnaire on G7 countries for the period 1990-2014 and the findings confirm that the positive long-term impact of ICT on both CO_2 emissions and financial development is a low indicative of carbon emissions. There are different opinions regarding the direct effects of ICT on sectors. These opinions are based on how the industry perceives ICT and the extent of ICT-connected energy use.

Contrary to these arguments, in the literature some studies have found that ICT increases carbon emissions; Sadorsky (2012), also claims that a positive significance relationship exists between ICT and electricity consumption according to the results of dynamic panel models. According to Lee and Brahmasrene's (2014) study, ICT development has a substantial effect on CO_2 emissions and growth. The level of economic growth and ICT development are major determinants for each country. Unlike most studies in the literature, Gelenbe and Caseau (2015) reported that the role of ICT on CO_2 emissions relates the sectors included. However, the overall conclusion is that ICT does not disregard the energy costs and that ICT may actually cause a decrease in total energy use. Contrary to these arguments, there are studies that found that ICT increases carbon emissions. Similarly, the results of Malmodin and Lunden's (2018) study show that there is an annual, nearly linear tendency to increase in electricity consumption and carbon emissions. Recently, various international organizations and universities have carried out studies on the interaction of ICT with the environment. In addition to being responsible for a major part of environmental problems around the world, ICT has started to be seen as an effective solution tool in reducing and solving environmental issues.

3. Model Specification

The connection between the ICT exports and CO_2 emissions was analyzed in selected countries by two distinct models for the years 1993-2014. Austria, Canada, Finland, China, Indonesia, Germany, the

Netherlands, France, Israel, Italy, Portugal, Norway, the United Kingdom, and South Korea are the 15 selected countries. The countries were selected based on the market constituent of the information and communication technologies. Information technologies services, hardware and software are included under the market components of information and communication technologies. The selected countries were the leading countries in the information technologies service export criterion among the market components. The study uses two models; in the first model, dependent variable is CO_2 emission (metric tons per capita) and CO_2 emission from electricity and heat generation (metric tons per capita). While in the second model, independent variables are GDP per capita (2010 US$ constant), ICT service exports (% of service exports), individual internet usage (% of population) and trade openness (% of GDP). The data of CO_2, CO_{2H}, GDP per capita, trade openness, Internet usage were acquired from the 2015 data of the World Development Indicators. Models of the study are formed as follows:

$$InCO2_{i,t} = \alpha_0 + \alpha_1 InIU_{i,t} + \alpha_2 InICT_{i,t} + \alpha_3 InY_{i,t} + \alpha_4 InTR_{i,t} + \varepsilon_{i,t} \qquad (1)$$

$$InCO2H_{i,t} = \alpha_0 + \alpha_1 InIU_{i,t} + \alpha_2 InICT_{i,t} + \alpha_3 InY_{i,t} + \alpha_4 InTR_{i,t} + \varepsilon_{i,t} \qquad (2)$$

According the model, t, i and $\varepsilon_{i,t}$ point out time period, cross section, residual term respectively. Furthermore, $InCO_{2i,t}$ is natural logarithm of CO_2, Inc $CO_{2Hi,t}$ is natural logarithm of CO_{2H}, $InIU_{i,t}$is natural logarithm of individuals using the Internet, $InY_{i,t}$is natural logarithm of GDP per capita and $InTR_{i,t}$is natural logarithm of (% of GDP) trade openness. Standard panel data analysis relies on the assumption that there is no cross-sectional dependency among the units that make up the panel. And the shocks that occur in the units do not influence another unit. On the other hand, the lack of interaction between units may not always apply. In order to make the results more statistically significant, this condition called cross-sectional dependency should be analyzed and if there is dependence, the tests used should take the dependence into account. Considering all these causes, this study used the Pesaran et al. (2008), Cross-sectional Dependency Lagrange Multiplier (CDLM) test. After determining the cross-sectional dependency, long term relationship among the variables was estimated via CIPS unit root analysis, Westerlund Cointegration and Pedroni Cointegration analyses. The Pedroni cointegration test ignores cross-sectional dependency. The primary reason this study uses this method is to see the comparative results between cointegration tests. In the last phase of the analysis, cointegration parameter estimates were made by using the CCE method. This paper initially analyzes cross-sectional Dependency with the CDLM test. In panel data analysis, it was confirmed that fractures and modifications formed in the panel units are independent from each other and the units do not influence each other. Nevertheless, it is improbable that the units whose panel is created will not affect each other. Therefore, in panel data analysis, the dependency between units should be investigated first. The dependency among the units of the panel entitled cross-sectional dependency were predicted by the tests developed by Breush Pagan (1980) and Pesaran et al. (2008). Pesaran (2004) improved Breush Pagan's (1980) test in the case of when time dimension is smaller than the cross-section dimension and when the time dimension is greater than the cross-section dimension. This test is biased when the average group is zero, but the average individual is different from zero. Pesaran et al. (2008) adjusted this deviation by adding the variance and the average to the test statistics. Therefore, it is called the bias-adjusted LM test (LMadj).

The CDLM test developed by Pesaran et al. (2008) is formulated as below:

$$LM_{adj} = \left(\frac{2}{N(N-1)}\right)^{1/2} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \rho_{ij}^2 \left(\frac{(T-K-1)\rho_{ij}^2 - \mu_{Tij}}{\upsilon_{Tij}}\right) \qquad (3)$$

Where $\hat{\mu}_{Tij}$ represents the average, υ_{Tij} represents the variance. The test statistics to be obtained here show a standard normal distribution as asymptotic (Pesaran et al., 2008).

The formulation of the cross-sectional *ADF (CADF)* regression is represented below:

$$\Delta y_{it} = \alpha_i + p_i y_{it-1} + \beta_i \bar{y}_{t-1} + \sum_{j-0}^{k} y_{ij}\, \Delta \bar{y}_{it-1} + \sum_{j=0}^{k} \delta_{ij}\, y_{it-1} + \varepsilon_{it} \quad (4)$$

α_i is the deterministic term, k is the lag order, $\overline{y}_i$ is the cross-sectional mean of time. After the above equation, t-statistics are acquired by calculating individual ADF statistics and CIPS is retrieved from the mean of CADF statistic for each "i " in the following equation:

$$CIP = \left(\frac{1}{N}\right) \sum_{i=1}^{N} t_i\,(N,T) \quad (5)$$

Critical values are given by Pesaran for different deterministic terms of CIPS (2007). In this study, Westerlund (2007) cointegration analysis was used to define the long-term relationship between the factors. This method includes the heterogeneity between the units that make up the panel, which is the main reason for using this analysis. The Westerlund (2007) cointegration test allows structural fractures under cross-sectional dependency. The test is on the error correction model in equations 6, 7, and 8.

$$\Delta E_{i,t} = \alpha_i^E + \lambda_i^E\left(E_{i,t-1} - \beta_i^E Y_{i,t-1} - \gamma_i^E T_{i,t-1}\right) + \sum_{j=1}^{n} \theta_{i,j}^E\, \Delta E_{i,t-j} + \sum_{j=1}^{p} \phi_{i,j}^E\, \Delta T_{i,t-j} + \sum_{j=1}^{m} \delta_{i,j}^E\, \Delta Y_{i,t-j} + u_{i,t} \quad (6)$$

$$\Delta Y_{i,t} = \alpha_i^Y + \lambda_i^Y\left(Y_{i,t-1} - \beta_i^Y E_{i,t-1} - \gamma_i^Y T_{i,t-1}\right) + \sum_{j=1}^{n} \delta_{i,j}^Y\, \Delta Y_{i,t-j} + \sum_{j=1}^{m} \theta_{i,j}^Y\, \Delta E_{i,t-j} + \sum_{j=1}^{p} \phi_{i,j}^Y\, \Delta T_{i,t-j} + \varepsilon_{i,t} \quad (7)$$

$$\Delta T_{i,t} = \alpha_i^T + \lambda_i^T\left(T_{i,t-1} - \beta_i^T Y_{i,t-1} - \gamma_i^T E_{i,t-1}\right) + \sum_{j=1}^{p} \phi_{i,j}^T\, \Delta T_{i,t-j} + \sum_{j=1}^{m} \delta_{i,j}^T\, \Delta Y_{i,t-j} + \sum_{j=1}^{n} \theta_{i,j}^T\, \Delta E_{i,t-j} + e_{i,t} \quad (8)$$

The parameters in the equation λ_i^k, $k \in \{E, Y, T\}$ indicate the error correction terms to forecast the error correction rate of a unit in the panel.

There was no cointegration null hypothesis in the Westerlund (2007), cointegration analysis, and the alternative hypothesis was created as two different tests: as the mean group and panel test. Thus, four cointegration test statistics $(G_\alpha, G_t, P_\alpha, P_t)$ were created based on the error correction model. Group statistics based on the weighted sum of the value of λ_i^k are estimated separately for each unit forming the panel. Test statistics (G_t, P_t) generated by calculating the standard errors of the λ_i^k value were estimated as standard. Newey and West (1994), calculated test statistics (G_α, P_α)based on the standard error of varying variance and values independent from autocorrelation. According to the analysis, the variables should be stationary in I. As a result, the model is estimated as follows:

$$G_\tau = \frac{1}{N} \sum_{j=1}^{N} \frac{\xi j}{SE\left(\hat{\xi}_j\right)},\ G_\alpha = \frac{1}{N} \sum_{j=1}^{N} \frac{T\hat{\xi}_j}{\hat{a}_j(1)} \quad (9)$$

$$P_\tau = \frac{\hat{\xi}}{SE\left(\hat{\xi}\right)},\ P_a = T\hat{\xi} \quad (10)$$

If $\lambda_i^k \langle 0$ there is error correction and there is a cointegration relationship between $Y_{i,t}, E_{i,t}$ and$T_{i,t}$. If $\lambda_i^k = 0$ There is no cointegration relationship between error correction and variables (Cialani, 2013: 6).

In the study, the long-term cointegration vector under the presence of heterogeneity, cross-section dependence and cointegration relationship was estimated with the help of common correlated effects (CCE), which was introduced by Pesaran (2006). This model provides that the regression coefficients estimated for cross-section units by various methods in panel data analysis are obtained for each cross-section unit one by one.

4. Results and Discussion

In order to analyze the relationship between ICT exports and CO_2 emissions, Breush Pagan (1980) and Pesaran et al. (2008) tests were used in the study. Table 1 presents the findings for Model 1 and Model 2.

Table 1. CDLM Test Results for Model 1 and Model 2

Breusch-Pagan (1980) Test Results for Variables						
	CO_2	**CO_2h**	**ICT**	**GDP**	**IU**	**TR**
LM Test	913.42 (0.000)	620.28 (0.000)	810.94 (0.000)	1460.35 (0.000)	1990.48 (0.000)	912.49 (0.000)
Pesaran et al. (2008) Results for Variables						
	CO_2	**CO_2H**	**ICT**	**GDP**	**IU**	**TR**
LM_{adj} Test	55.79 (0.000)	35.56 (0.000)	48.71 (0.000)	93.53 (0.000)	130.11 (0.000)	55.72 (0.000)
Breusch-Pagan (1980) Test Results for Model 1 and Model 2						
		Model 1			**Model 2**	
LM Test		1326.92 (0.000)			535.56 (0.000))	
Pesaran et al. (2008) Results for Model 1 and 2						
		Model 1			**Model 2**	
LM_{adj} Test		84.35 (0.000)			29.71 (0.000)	

According to the results of eight tests conducted to understand whether the variables and models covered in the analysis include cross-sectional dependence, it was concluded that there is a cross-sectional dependence between the variables. According to this test result, it was concluded that a second generation unit root test should be performed in order to understand the level at which the variables are stationary. However, another problem at this point is to determine which second generation unit root test is appropriate. For this, homogeneity test should also be applied to the variables.

As a result of the Pesaran and Yamagata (2008) homogeneity test performed for Model 1 and Model 2, it was seen that the p values were less than 0.05.

Tablo 2. Homogeneity Test

Model 1		**Model 2**	
Delta	**p-value**	**Delta**	**p-value**
11.577	**0.0001**	**10.559**	**0.0001**

In line with these results, a unit root test that defends the heterogeneity under cross-section dependence should be performed and the level at which the variables are stationary should be determined.

In the study, the CADF test developed by Pesaran (2007), which takes into account the cross-sectional dependence and was developed by Pesaran, was used in order to clearly determine the level at which the series is stationary under the cross-sectional dependence in the two models defined for 15 selected countries.

Tablo 3. Pesaran CADF Test Results

Variables	CADF prob. (level)	Result
CO_2	0.6446	I(1)
CO_{2H}	0.1296	I(1)
ICTS	0.7627	I(1)
GDP	0.0080	I(0)
Trade	0.0000	I(0)
IU	1.0000	I(1)

The stationarity of the variables was analyzed prior to the cointegration test. With this aim in mind, CIPS test was made. The variables were analyzed according to the delay values used in the CD test. The findings acquired are represented in Table 4.

Table 4. CIPS Test Results

Variables	CIPS	Critical values (%5)	Result
CO_2	-0.986	-2.25	I(1)
CO_{2H}	-2.144	-2.25	I(1)
ICTS	-1.858	-2.25	I(1)
GDP	-1.335	-2.25	I(1)
Trade	-1.988	-2.25	I(1)
IU	-1.824	-2.25	I(1)

According to the results of the Peseran (2007) analysis, it was concluded that all variables are not stationary. Afterwards, the Westerlund test, which is one of the 2nd generation co-integration tests, was performed. The results obtained as a result of the analysis made as follows: Since the slope coefficients are heterogeneous, $G\alpha$ and $G\tau$ statistics were used in the evaluation of all variables.

In the study, Westerlund (2007), cointegration analysis was used to define the long-term relationship among the variables. The main reason behind using this method is that the tests consider the heterogeneity between the units that make up the panel.

Table 5. Panel Cointegration Tests Results

Statistic	Value	Z-value	P-value	Robust
Model 1				
$G\tau$	-1.938	2.059	0.980	0.405
$G\alpha$	-3.196	4.934	1.000	0.805
Model 2				
$G\tau$	-2.164	1.143	0.873	0.190
$G\alpha$	-4.034	4.510	1.000	0.450

In accordance with the results in Table 5, there is no cointegration null hypothesis. Therefore, as per the findings of this test, there is no cointegration relationship among the variables.

Therefore, CCE or AMG estimators should be used in the study. In this study, the CCE estimator was preferred. It is shown in Table 6 as for Model 1 and Model 2.

Table 6. CCE Estimators for Model 1 and Model 2

CO_2	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
ICTS	-0.033359	0.0195635	-1.71	0.088	-0.0717027	0.0049848
GDP	0.0001354	0.000101	1.34	0.180	-0.0000626	0.0003334
Trade	-0.009926	0.0147083	-0.67	0.500	-0.0387538	0.0189018
IU	0.002344	0.0207042	0.11	0.910	-0.0382356	0.0429235
Constant	-1.156.439	1.408.764	-0.82	0.412	-3.917.566	1.604.688
CCE Estimators for Model 2						
CO_{2H}	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
ICTS	-0.2551748	0.1087841	-2.35	0.019	-0.4683877	-0.0419618
GDP	0.0001084	0.0003216	0.34	0.736	-0.000522	0.0007387
Trade	-0.0384675	0.0565389	-0.68	0.496	-0.1492817	0.0723468
IU	0.005584	0.0308804	0.18	0.857	-0.0549405	0.0661086
Constant	9.763.427	1.230.959	0.79	0.428	-1.436.293	3.388.978

The collected data indicates a negative and statistically significant relationship between the two variables in Model 2. As the table suggests, in Model 2, ICTS has a significant effect on CO_2 emissions from electricity and heat generation. Accordingly, a 1% increase in ICT service exports leads to a 25% decrease in CO_2 emissions from electricity and heat generation. While in Model 1, variables have no significant effect on CO_2 emissions.

Ultimately, the causality relationship among the variables was analyzed using the Granger causality method developed by Dumitrescu and Hurlin (2012). The main advantages of this method are as follows; "*cross-sectional dependency between the countries that make up the panel can be used when the time dimension (T) is larger than the cross-sectional dependency (N) or smaller and can produce effective results in unstable panel data sets*" (Dumitrescu & Hurlin, 2012: 1457).

Table 7. Dumitrescu and Hurlin Causality Test Results Model 1

Null Hypothesis:	Zbar-Stat.	Prob.
InICT does not cause homogeneously $InCO_2$	2.30171	0.0214
$InICO_2$ does not cause homogeneously InICT	3.8957	0.0001
InIU does not cause homogeneously $InCO_2$	2.22901	0.0258
$InCO_2$ does not cause homogeneously InIU	1.67430	0.0941
InTR does not cause homogeneously $InCO_2$	10.2048	0.0000
$InCO_2$ does not cause homogeneously InTR	0.52173	0.6019
InY does not cause homogeneously $InCO_2$	5.08030	0.0000
$InCO_2$ does not cause homogeneously InY	1.95142	0.0510

As can be seen Table 7, according to Dumitrescu and Hurlin Causality Model 1 Test results; there is a bidirectional causality relationship CO_2 emissions and per capita income, ICT service exports, and individual internet usage while there is a unidirectional causality between trade openness and CO_2.

Table 8. Dumitrescu and Hurlin Causality Test Results Model 2

Null Hypothesis:	Zbar-Stat.	Prob.
InICT does not cause homogeneously $InCO_{2H}$	1.96909	0.0489
$INCO_{2H}$ does not cause homogeneously InICT	1.99652	0.0459
InIU does not cause homogeneously $InCO_{2H}$	5.36723	0.0000
$InCO_{2H}$ does not cause homogeneously InIU	0.23798	0.8119
InTR does not cause homogeneously $InCO_{2H}$	2.39730	0.0165
$InCO_{2H}$ does not cause homogeneously InTR	- 0.24746	0.8046
InY does not cause homogeneously $InCO_{2H}$	5.01214	0.0000
$InCO_{2H}$ does not cause homogeneously InY	- 0.13468	0.8929

According to Dumitrescu and Hurlin Causality Model 2 Test results that take part in Table 8 there is a bidirectional causal relationship between ICT service exports and CO_2; however, there is a unidirectional causal relationship between national income per capita, individual internet use, trade openness and CO_2 emissions.

5. Conclusion and Remarks

When the share of ICT carbon emissions is evaluated together with the potential to reduce global carbon emissions in the framework of sustainable development, it is seen that ICT is both responsible and a solution for global environmental problems. However, the role of ICT in sustainable development is still not completely understood. The spread of ICT enough to be useful for society and the economy is still at an early stage (Mohamed et al., 2010: 745). Recently, there has been a growing awareness of what ICT can do in the energy system. Although there are many views suggesting that ICT directly increases consumption as energy usage increases, there are many studies suggesting that ICT may also indirectly reduce energy demand (Martiskainen & Coburn, 2011: 210). This paper investigates the impact of ICT on CO_2 emissions from electricity and heat generation. The findings of this study suggest that in Model 2 CO_2 emissions from electricity and heat generation affect per capita national income the most. As stated by Aslanidis (2009), this situation can be explained by the scale effect of economic growth. ICT is expanded through the scale effect as a part of the growth process and this causes more emissions (Higon, 2017: 87). Both models of the study found that while national income per capita, individual internet usage and ICT service exports increased CO_2 emissions, trade openness index had no significant effect. The results of Jalil and Mahmud's (2009) study are in parallel with these results. However, it can be justified that the net impact of trade over pollution may depend on the strength of many opposing variables and the absence of trade openness. The results of the study point to a bidirectional causality between ICT service exports and CO_2 in Model 2. Additionally, the impact of individual internet usage and ICT service exports on CO_2 emissions from electricity and heat generation was found to be higher than overall CO_2 emissions.

According to Salahuddin (2016), this situation is explained as follows, the need for electricity for operation of ICT products and services and increased pressure on electricity consumption leading to increased CO_2 emissions. Although ICT related electricity consumption is a relatively a less studied field, it has significant potential impacts on environmental sustainability (DTI, 2007). The utilization of ICT, such as smart meters and real-time indicators to decrease energy demand, could be a potential way to better manage energy. Gelenbe (2015) also emphasized that ICT can contribute to reducing the effect of CO_2 on other sectors such as transportation, smart buildings, virtual business and education. ICT poses great solutions for sustainable production. Low-cost measurements and communication systems, smart meters, virtualization, smart transportation systems, smart buildings, smart networks and energy sector applications such as intelligent production systems provide solutions for decreasing CO_2 emissions. All these results are consistent with the behavioral effect hypothesis of ICT environment interaction on the systemic (tertiary) interaction level. This hypothesis refers to the changes in human behavior in the long term with the usage of ICT in economic and social fields. According to the Information Technologies and Communication Committee Report, 60% of ICT-based CO_2 emissions originate from end-user products, indicating the importance of public policies, incentives and sanctions in order to direct and disseminate these behavioral changes. Again, the said report states that the behavior of ICT users at the corporate and individual levels in terms of energy efficiency and saving, recycling and waste has become even more important. Higon (2017) emphasized that various industrialized countries have reached a level of ICT, where CO_2 emissions decrease as the ICT development level increases.

In conclusion, countries should create policies in order to ensure the place of ICT in sustainable development as it is one of the major aspects of global economy with its role in economic growth and social development, especially for developed and developing countries. The limitation of this study is that it was not able to reach different types of data that were not available in every region. There should also be macro studies where all the sectoral effects of ICT are investigated in order to understand the global effects of ICT better. A cooperation between Energy Management Systems and the Electronics sector is thought to be beneficial to create an economy based on sustainable energy within the scope of ICT. “Sustainable ICT” surely requires further research that would contribute to the literature.

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References

Adu, D. T., & Denkyirah, E. K. (2017). Economic growth and environmental pollution in West Africa: Testing the environmental Kuznets curve hypothesis. *Kasetsart Journal of Social Sciences*, (30), 1-8.

Alam, M. M., Murad, M. W, Noman, A. H. M., & Ozturk, I. (2016). Relationships among carbon emissions, economic growth, energy consumption and population growth: Testing environmental Kuznets curve hypothesis for Brazil, China, India and Indonesia. *Ecological Indicators,* (70), 466-479.

Amri, F. (2018). Carbon dioxide emissions, total factor productivity, ICT, trade, financial development, and energy consumption: Testing Environmental Kuznets curve hypothesis for Tunisia. *Environmental Science and Pollution Research*, 25(3), 33691-33701.

Apergis, N., & Ozturk, I. (2015). Testing environmental Kuznets curve hypothesis in Asian countries. *Ecological Indicators*, (52), 16-22.

Aslanidis, N. (2009). Environmental Kuznets Curves for carbon emissions: A critical survey. Working Paper No 51, University of Teramo.

Baek, J. (2015). Environmental Kuznets curve for CO_2 emissions: The case of Arctic countries. *Energy Economics*, (50), 13-17.

Baller, S., Dutta, S., & Lanvin, B. (2016). *Global information technology report 2016*. Geneva: Ouranos.

Breusch, T. S., & Pagan, A. R. (1980). The Lagrange multiplier test and its applications to model specification in econometrics. *The Review of Economic Studies*, 47(1), 239-253.

Cialani, C. (2013). CO_2 emissions, GDP and trade: A panel cointegration approach. Working Papers in Transport, Tourism, Information Technology and Microdata Analysis.

Cole, M. A. (2004). Trade, the pollution haven hypothesis and the environmental Kuznets curve: Examining the linkages. *Ecological Economics,* (48), 71-81.

Climate Group (2008). SMART 2020: Enabling the low carbon economy in the information age. Belgium: Global e-Sustainability Initiative (GeSI).

Climate Group (2015). SMARTer 2030, ICT Solutions for 21st Century Challenges. Belgium: Global e-Sustainability Initiative (GeSI).

Dinda, S. (2004). Environmental Kuznets curve hypothesis: A survey. *Ecological Economics, (*49), 431-455.

DTI-Department of Trade, (2007). Meeting the energy challenge: A white paper on energy (7124). The Stationery Office.

Dumitrescu, E. I., & Hurlin, C. (2012). Testing for Granger non-causality in heterogeneous panels. *Economic Modelling*, 29(4), 1450-1460.

Erdmann, L., & Hilty, L. M. (2010). Scenario analysis: Exploring the macroeconomic impacts of information and communication technologies on greenhouse gas emissions. *Journal of Industrial Ecology*, 14(5), 826-843.

European e-Business Report, (2010). ICT and e-Business for an Innovative and Sustainable Economy. http://ec.europa.eu/enterprise/archives/e-businesswatch/index.htm (Access Date: 09.10.2019).

European Commission, (2008). Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions: Addressing the challenge of energy efficiency through Information and Communication Technologies. Brussels.

Farhani, S., & Rejeb, J. B. (2012). Energy consumption, economic growth and CO_2 emissions: Evidence from panel data for MENA region. *International Journal of Energy Economics and Policy*, 2(2), 71-81.

Gelenbe, E., & Caseau, Y. (2015). The impact of information technology on energy consumption and carbon emissions. Association for Computing Machinery Publication.

Grossman, G. M., & A. Krueger (1991). Environmental impacts of a North American free trade agreement. NBER Research Working Paper, No. 3194, Cambridge.

Grossman, G. M., & Krueger A. (1995). Economic growth and the environment. *Quarterly Journal of Economics*, 110(2), 353-377.

Hernnäs, H. (2018). What is the impact of ICT on CO_2 emissions? A macro perspective. Dissertation PSME, Universite Paris 1 Pantheon-Sorbonne.

Higon, A. D., Gholami, R., & Shirazi, F. (2017). ICT and environmental sustainability: A global perspective. *Telematics and Informatics*, 34(2), 85-95.

Hilty, L. M., Arnfalk, P., Erdmann, L., Goodman, J., Lehmann, M., & Wager, P. A. (2006). The relevance of information and communication technologies for environmental sustainability. A prospective simulation study. *Environmental Modelling & Software,* (21), 1618-1629.

IEA-International Energy Agency, (2012). World Energy Outlook 2012. http://ec.europa.eu/enterprise/archives/e-businesswatch/index.htm (Access Date: 04.09.2019).

IEA-International Energy Agency, (2016). World Energy Outlook 2016, Www.iea.org (Access Date: 09.10.2019).

Jalil, A., & Mahmud, S. F. (2009). Environment Kuznets Curve for CO_2 emissions: A cointegration analysis for China. *Energy Policy*, 37(12), 5167-5172.

Kaypak, Ş. (2011). Küreselleşme sürecinde sürdürülebilir bir kalkınma için sürdürülebilir bir çevre. *KMÜ Sosyal ve Ekonomik Araştırmalar Dergisi*, 13(20), 19-33.

Khan, D. N., Baloch, M. A., Saud, S., & Fatima, T. (2018). The effect of ICT on CO_2 emissions in emerging economies: Does the level of income matters? *Environmental Science and Pollution Research*, 25(23), 22850-22860.

Kohler, A., & Erdmann, L. (2004). Expected environmental impacts of pervasive computing. *Human and Ecological Risk Assessment*, 10(5), 831-852.

Lee, J., & W, Brahmasrene, T. (2014). ICT, CO_2 emissions and economic growth: Evidence from a panel of ASEAN. *Global Economic Review*, 43(2), 93-109.

Lu, W. C. (2018). The impacts of information and communication technology, energy consumption, financial development, and economic growth on carbon dioxide emissions in 12 Asian countries. *Mitigation and Adaptation Strategies for Global Change*, 23(8), 1351-1365.

Malmodin, J., & Lunden, D. (2018). The Electricity consumption and operational carbon emissions of ICT network operators 2010- 2015. Report from the KTH Centre for Sustainable Communications Stockholm.

Martiskainen, M., & Coburn, J. (2011). The role of information and communication technologies (ICTs) in household energy consumption prospects for the UK. *Energy Efficiency*, (4), 209-221.

Mohamed, M., Murray, A., & Mohamed M. (2010). The role of information and communication technology (ICT) in mobilization of sustainable development knowledge: A quantitative evaluation. *Journal of Knowledge Management*, 14(5), 744-758.

Nasir, M., & Rehman, F. (2011). Environmental Kuznets Curve for carbon emissions in Pakistan: An empirical investigation. *Energy Policy,* (39), 1857-1864.

Newey, W. K., & West, K. D. (1994). Automatic lag selection in covariance matrix estimation. *The Review of Economic Studies*, 61(4), 631-653.

Ozturk, I., & Acaravci, A. (2010). CO_2 emissions, energy consumption and economic growth in Turkey. *Renewable and Sustainable Energy Reviews,* 14(9), 3220-3225.

Pedroni, P. (2000). Fully modified ols for heterogeneous cointegrated panels. Department of Economics Working Papers, Williams College.

Pernici, B., Aiello, M., Brocke, J., Donnellan, Br., Gelenbe, E., & Kretsis, M. (2012). What is can do for environmental sustainability: A report from CAiSE'11 panel on green and sustainable is. *Communications of the Association for Information Systems*, 30(18), 276-292.

Pesaran, M. H. (2007). A Simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, (22), 265-312.

Pesaran, M. H. (2004). General diagnostic tests for cross section dependence in panels. IZA Discussion Paper No. 1240, Institute for the Study of Labor (IZA).

Pesaran, M. H., Ullah, A., & Yamagata, T. (2008). A bias-adjusted LM test of error cross-section independence. *The Econometrics Journal*, 11(1), 105-127.

Plepys, A. (2002). The grey side of ICT. *Environmental Impact Assessment Review,* (22), 509-523.

PWC- PricewaterhouseCoopers, (2018). Is Paris possible? The low carbon economy index. London: PWC.

Raheem, I. D., Tiwari, A. K., & Balsalobre-Lorente, D. (2019). The role of ICT and financial development on CO_2 emissions and economic growth. African Governance and Development Institute Working Paper, WP/19/058.

Rivera, M. B., Cecilia H., Asa S., & Göran F. (2014). Including second order effects in environmental assessments of ICT. *Environmental Modelling & Software,* (56), 1-11.

Saboori, B., & Sulaiman, J. (2013). CO_2 emissions, energy consumption and economic growth in association of Southeast Asian Nations (ASEAN) countries: A cointegration approach. *Energy*, (55), 813-822.

Sadorsky, P. (2012). Information communication technology and electricity consumption in emerging economies. *Energy Policy,* (48), 130-136.

Salahuddin, M., Alam, K., & Ozturk, I. (2016). The effects of Internet usage and economic growth on CO_2 emissions in OECD countries: A panel investigation. *Renewable and Sustainable Energy Reviews*, (62), 1226-1235.

Shabani, Z., & Shahnazi, R. (2019). Energy consumption, carbon dioxide emissions, information and communications technology, and gross domestic product in Iranian economic sectors: A panel causality analysis. *Energy,* 169(2019), 1064-1078.

Shahbaz, M., Nasreen, S., Abbas, F., & Anis, O. (2015). Does foreign direct investment impede environmental quality in high, middle, and low-income countries? *Energy Economics*, (51), 275-287.

Shahbaz, A. K., & Phouphet, K. P. (2016). Revisiting the emissions energy- trade nexus: Evidence from the newly industrializing countries. *Environmental Science and Pollution Research*, (23), 7676-7691.

Sinha, A., & Shahbaz, M. (2018). Estimation of Environmental Kuznets Curve for CO_2 emission: Role of renewable energy generation in India. *Renewable Energy*, (119), 703-711.

Sinha, A., & Mehta, A. (2014). Causal analysis of India's energy-led growth and CO_2 emission (1960–2010). *Indian Journal of Economics & Business*, *1*(1),81-89.

Soytaş, U., & Sarı, R. (2009). Energy consumption, economic growth ans carbon emissions: Challenged faced by an EU candidate member. *Ecological Economics*, 68(6), 1667-1675.

Stewart, K. (2015). Assessing the carbon impact of ICT measures: A case study investigation using Latis model. *International Journal of Transportation Science and Technology*, 4(2), 277-284.

Tsaurai, K., & Chimbo, B. (2019). The impact of information and communication technology on carbon emissions in emerging markets. *International Journal of Energy Economics and Policy*, 9(4), 320-326.

Vereecken, W., Heddeghem, W. V., Colle, D., Pickavet, M., & Demeester, P. (2010). Overall ICT footprint and green communication technologies. 4th International Symposium on Communications, Control and Signal Processing (ISCCSP 2010).

Wang, S., Zhou, D. Q., Zhou, P., & Wang, Q. (2011). CO_2 emissions, energy consumption and economic growth in China: A panel data analysis. *Energy Policy*, (39), 4870-4875.

Westerlund, J. (2007). Testing for error correction in panel data. *Oxford Bulletin of Economics and Statistics*, (69), 709-748.

Yi, L., & Thomas, H. R. (2007). A review of research on the environmental impact of e-business and ICT. *Environment International,* (33), 841-849.

Zhang, X., & Xiao-Mei, C. (2009). Energy consumption, carbon emissions, and economic growth in China. *Ecological Economics*, (68), 2706-2712.

Zhang, C., & Liu, C. (2015). The impact of ICT industry on CO_2 emissions: A regional analysis in China. *Renewable and Sustainable Energy Reviews,* (44), 12-19.