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Information and Communication Technology, electricity consumption and economic growth in OECD countries: A panel data analysis

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Abstract

This study estimates the short- and long-run effects of Information and Communication Technology (ICT) use and economic growth on electricity consumption using OECD panel data for the period of 1985 to 2012. The study employs a panel unit root test accounting for the presence of cross-sectional dependence, a panel cointegration test, the Pooled Mean Group regression technique and Dumitrescu-Hurlin causality test. The results confirm that both ICT use and economic growth stimulate electricity consumption in both the short- and the long run. Causality results suggest that electricity consumption causes economic growth. Both mobile and Internet use cause electricity consumption and economic growth. The findings imply that OECD countries have yet to achieve energy efficiency gains from ICT expansion. Effective coordination between energy efficiency from ICT policy and existing emissions reduction policies have the potential to enable OECD countries reduce environmental hazards arising from electricity consumption for ICT products and services. Introducing green IT and IT for green are also recommended as potential solutions to curb electricity consumption from ICT use especially in the data centers.

Keywords: Economic growth, electricity consumption, internet usage, OECD, panel data, Pooled Mean Group Regression

JEL classifications: O4, O13, Q4, Q42, Q43

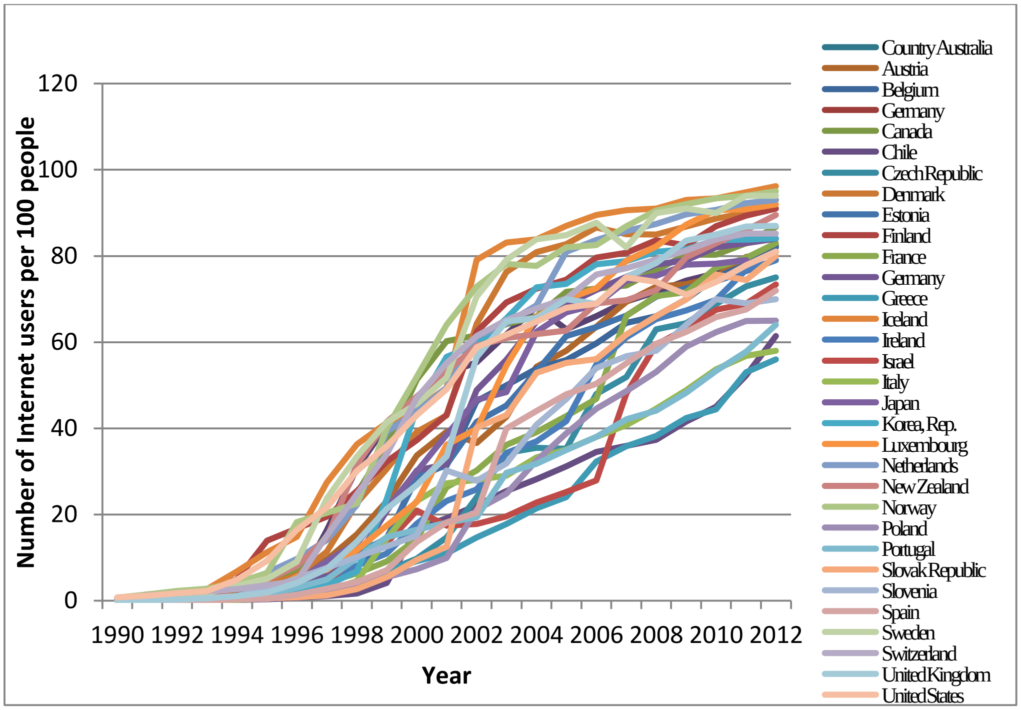
1. Introduction

Information and Communication Technologies (ICTs) have a wide array of effects on key global systems such as energy and economic systems (Moyer and Hughes, 2012). The rapid use and expansion of these technologies have a number of economic consequences ranging from increasing productivity, boosting economic growth (Shahiduzzaman and Alam, 2014) to reducing corruption (Goel et al., 2012). As a result the world is rapidly moving from offline to online. The United Nations Development Program (UNDP, 2001) acknowledged that the Internet improves market efficiency, creates economic opportunities, enhances productivity and promotes political participation. Because of its increasingly important role in human activities, United Nations (The United Nations, 2009) declared that access to the Internet is one of the basic human rights in the contemporary society. According to Greenpeace International report (2014), the global online population will increase from 2.3 billion in 2012 to 3.6 billion in 2017.

The OECD governments are funding rollouts worth billions of dollars for further expansion of the ICT use (The OECD Internet Outlook, 2013). ICT use especially the Internet use has been transforming the economies of the OECD countries since the last two decades (Zhang, 2013).

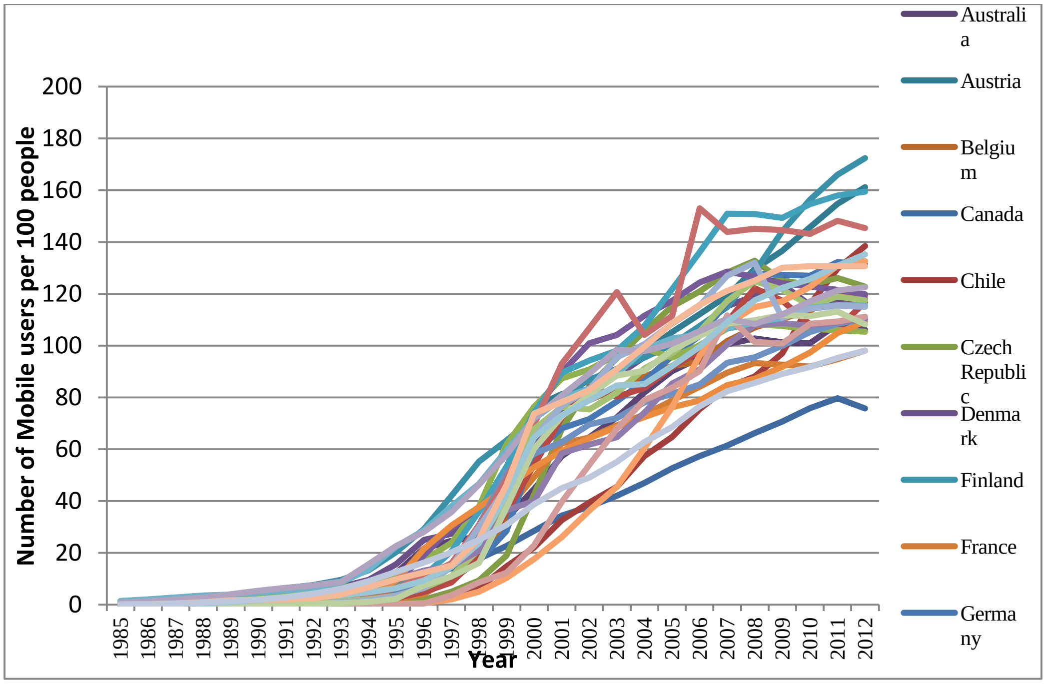
ICT use especially the Internet use and the use of mobile cellular phone have been expanding in the OECD countries at a phenomenal speed. The trends of change in these variables (The World Bank, 2013) during the last two decades are depicted in Figure 1 and Figure 2.

Figure 1 Trends in the Internet usage in OEDC countries during 1990-2012



Source: The World Development Indicators Database, The World Bank, 2013.

Figure 2: Trends in the Mobile usage in OEDC countries during 1985-2012



Source: The World Development Indicators Database, The World Bank, 2013.

But all these expansions and the increasingly important role of ICT in the OECD economies are not expected to be without opportunity cost. The expansion of the ICTs has important environmental implications. As such, the studies investigating the energy impacts of ICTs have been profoundly researched in a macro framework (Sadorsky, 2012). Although the rapid expansion of ICT usage is believed to improve productivity and energy efficiency, there is no consensus as yet on its effect on the environment. Some of the studies support the positive role of ICT in mitigating greenhouse gas emissions while others conclude that ICT use causes GHG emissions through the increased use of electricity which is one of the major sources of global CO_2 emissions (Hamdi et al. 2014; Moyer and Hudges, 2012; IEA, 2006). According to some estimates (The Greenpeace International, 2014), ICT industry is responsible for 2% of global CO_2 emissions.

The OECD economies are characterized by the highest level of energy consumption in the world and electricity is one of the key sources of this huge energy supply (Shafiei and Salim, 2014). The same authors argue that 80% of the power generation in the region is still sourced from non-renewable fossil fuels such as coal and gas in these countries. As a result, there has been a sharp increase in CO_2 emissions. Nevertheless, the rapid expansion of ICT use in the region is likely to have significant energy impacts as ICT products and services cannot be operated without electricity. Since no work has so far investigated this impact before, this study is the first ever attempt to examine the short- and long-run effects of ICT use on electricity consumption in a panel of OECD countries.

The current study also includes economic growth as an independent variable in the study. The reason for including economic growth is that usually simple bivariate models may fail to appropriately capture empirical relationship between the series (Karanfil, 2009; Barleet and Gounder, 2010). Also, since the mid-eighties and following the second oil shock, enormous literature investigating the relationship between economic growth and electricity consumption evolved (Hamdi et al. 2014). Therefore, assessing the impact of economic growth on electricity consumption has been an important area that has drawn special attention in research since long. Nevertheless, there is no recent literature investigating this relationship in the context of OECD countries. Thus, the inclusion of economic growth in our study is justified.

There are a number of expected contributions of this study to the existing energy, ICT and growth literature. First, it is believed that following Sadorsky (2012), this is only the second study that involves panel data to investigate the empirical relationship between ICT use and electricity consumption. The rationale for using panel data instead of time series data is quite obvious. In panel data estimations, the existence of unobservable factors that potentially affect electricity consumption and are country specific can be acknowledged and taken into account in the estimation (Ravallion, 1995). Panel data also allows one to control for unobserved time invariant country specific effects resulting from omitted variable bias (Hsiao, 1986). Second, the most important contribution of the current study is that the ICT use-electricity consumption relationship is being investigated for the first time ever for the OECD countries which house majority of the data centers in the world as a consequence of rapid expansion of ICT use since the last two decades. Third, although literature on the electricity-growth relationship is abundant, the economic growth-led electricity consumption hypothesis has not yet been examined for this region. Fourth, the current study uses the most recent data for its investigation thus expecting to offer time-befitting policy-oriented discussion. Fifth, it also makes a methodological contribution by employing a sophisticated and a potentially suitable panel data econometric technique, the Pooled Mean Group Regression (PMG) that has never been used before in ICT and energy economics literature. The novelty of this technique is that it simultaneously estimates the short- and the long-run relationship between the concerned variables controlling for endogeneity and small sample bias and sixth, unlike other studies, the findings of the study are expected to provide important implications at a time for ICT policy, energy policy and growth policy for the region of investigation.

The rest of the paper is structured as follows: Section 2 discusses literature review, and methodology is presented in Section 3. Section 4 presents estimation results and finally the paper ends in Section 5 with conclusions and policy implications.

2. Literature Review

2.1 Energy impacts of ICT

ICT use may potentially impact the environmental basically in two different ways. First of all, during the production of IT products, a number of toxic and non-renewable resources such as lead and mercury are used which are very harmful and dangerous elements for the environment. Waste disposal from the electrical and electronic IT goods also contribute towards environmental pollution. Second, the widespread expansion of ICTs has caused dramatic rise in the demand for electricity over the last two decades. ICT related electricity consumption has increased significantly both in the workplaces and households (IEA, 2009). The combined electricity consumption related to ICT equipments such as communication networks, personal computers and data centers is growing at a rate of nearly 7% per year (Heddeghem et al., 2014). The relative share of these ICT products and services in the global electricity consumption has increased from about 3.9% in 2007 to 4.6% in 2012 (Heddeghem et al., 2014).

The residential electricity consumption related to ICT also increased significantly during the 1990s and this trend is expected to continue further. The International Energy Agency (IEA, 2009) state that the global residential electricity consumption by ICT equipment rose by nearly 7% per annum between 1990 and 2008 and consumption from electronics is set to increase by 250% by the year 2030. From these developments, ICT is viewed as a new round of electrification and thus has the potential to increase GHG emissions in an economy. A significant percentage of domestic electricity consumption in Europe is linked to the use of ICT products and services (Faucheux and Nicolai, 2011).

A recent development in ICT service, cloud computing which refers to as the interaction between telecommunications network and the data centers and involves the transfer of vast amount of data from the devices to the data centers require relatively higher level of electricity consumption. According to a recent report of the Greenpeace International (2014), data centers will be the fastest growing part of IT sector energy footprint and its electricity demand is expected to rise by 81% by the year 2020. The aggregate electricity demand of the cloud was 684 billion kWh in 2011 and is forecasted to increase by 63% in 2020 (SMARTer2020 report). It also suggests that global carbon footprint of data centers and telecommunications networks would increase carbon emissions on average between 5% - 7% each year up to 2020. But if energy efficiency could be achieved leading to energy saving gains, the positive effect of energy efficiency might outweigh the negative effect of increased electricity consumption.

The environmental implications of ICT use has not drawn any attention from researchers until the early 1990s. Since the early 1990s, researchers started focusing first of all on the energy impacts of ICT use. Ever since, such impacts have been extensively examined in macro studies. One strand of literature directly studied the direct impact of ICT equipment on electricity consumption not least in relation to standby electricity use.

Another strand of literature focuses on the environmental impacts of the application of ICT in various economic domains. Firstly, it emphasizes the role of ICT in improving the environment. In the early 1990s, the potential of ICT to improve the environment was generally recognized. This followed profound researches in the area. Erdman and Hilty (2010) identify two 'green ICT waves' of empirical studies. The first one motivated by the rising Internet economy and the second one focused on the potentials of ICT in reducing GHG emissions. It is argued that ICT can play a significant role to mitigate global climate change through its ability to improve energy efficiency and reduce renewable energy costs (Moyer and Hughes, 2012).

Ever since, it is believed that the Internet economy has the potential to fundamentally alter the historic relationship-allowing faster growth with less energy. Romm (2002) label this as the 'new energy economy'. Recently, scholars have attempted to combine ICT and sustainable development as they recognize these two factors to be closely intertwined. This perception eventually led to two recent concepts what are known as 'green ICT' and 'ICT for green'. ICT is said to be green when ICT sector itself can achieve environmental efficiency. ICT for green means when the use of ICT products and services can enhance the energy efficiency in other sectors. It is argued that green ICT can lead to sustainable development only when ICT themselves are green. ICTs are said to be green when they make eco-innovating contributions to ecological economics. According to Schumpeter (1934), 'an eco-innovation is an innovation that is able to reduce environmental burdens and contributes to improving a situation according to given sustainable targets'. Despite tremendous potentials of ICT use in economies, its energy impact is mixed and no consensus has yet been realized.

2.2 ICT and electricity consumption

ICT- electricity consumption nexus is relatively an under-investigated area of research despite its potential implications for environmental sustainability. Most of the studies that have so far been conducted for developed economies are at the country level time series studies or at industry level cross-sectional studies (Sadorsky, 2012).

Romm (2002) in a study on the US economy shows that the Internet does not cause increase in electricity demand rather it seems to enhance energy efficiency. Schefer et al. (2003) show that the share of total energy consumption of German mobile telephone sector is only 7% when it did not include electricity use for charging of the handsets. When charging of the handsets is accounted for, the share stands at 45%. Takasi and Murota (2004) examine the effects of ICT investment on energy consumption and CO_2 emissions in Japan and USA. They find that ICT use boosts energy efficiency recommending energy conservation for Japan while for the USA, ICT investment is found to increase energy use.

Cho et al. (2007) in a study employ logistic growth model to examine the effects of ICT investment on energy consumption and show that in the service sector and most of the manufacturing sectors, ICT investment increases electricity consumption. However, overall findings of the study support the hypothesis that increased use of ICT leads to increased efficiency. The European Commission e-Business Watch (2008) conducts a comprehensive study on the effects of ICT on electricity in Austria, Germany, Denmark, Finland, France, Italy, Spain and the UK. It also conducts a number of case studies at firm level. The findings indicate that at the aggregate level, ICT use increases electricity consumption while at the micro level, it enhances energy efficiency. Heddeghem et al. (2014) in a study examine the trend in worldwide electricity consumption and show that the absolute electricity consumption of three key ICT categories, namely, communication networks, personal computers and data centers, has increased in 2012 from its level in 2007.

In arguably the first empirical exercise on the direct association between Internet usage and electricity consumption, Salahuddin and Alam (2015) examine the short- and long-run effects of the Internet usage and economic growth on electricity consumption using annual time series data for Australia for the period 1985-2012. The study finds that Internet usage and economic growth cause a rise in electricity consumption in the long-run. A unidirectional causality is observed running from Internet usage to economic growth and electricity consumption.

There is so far none but one panel study (Sadorsky, 2012) which estimated the empirical relationship between ICT investment and electricity consumption in emerging economies. Using a dynamic panel model, it employed the Generalized Methods of Moments (GMM) technique to investigate the link between the ICT and electricity consumption for a sample of emerging economies. The study found that ICT use increases electricity consumption in these countries. One limitation of homogeneous panel data approaches such as the GMM technique that was employed in this study is that it allows the intercept to differ while constraining all other parameters to be the same thus still imposing a high degree of homogeneity ignoring the potential cross-sectional heterogeneity in the panel. Such method of homogeneity has the potential risk of producing biased results. The current study overcomes this limitation by employing a panel estimation technique that allows for cross-country heterogeneity.

Moyer and Hughes (2012) use International Futures (IFs) integrated assessment system to explore the dynamic impacts of ICT on economic and energy systems including its impact on carbon emissions. They argue that ICT has the potential to reduce overall carbon emissions across a 50-year time horizon. However, they further caution that the net effect might be limited. The study recommends that global carbon pricing should be in place with ICT expansion.

From the above discussion, it is evident that literature on ICT- electricity consumption nexus is very inadequate although this nexus has significant implications for the environmental sustainability of countries and regions. The available scanty literature mostly dealt with time series country level data. Since, ICT use has rapidly expanded in the OECD countries and that these countries are homes to the majority of the world's data centers (Farnandez-Montes et al. 2015) for the last two decades, environmental threats arising from this expansion cannot be ruled out. The current study is believed to be the first ever attempt to investigate the empirical link between ICT use and electricity consumption in the OECD countries within a dynamic panel framework.

2.3 Electricity consumption and economic growth

Literature investigating the relationship between electricity consumption and economic growth is enormous. Since the pioneering work of Kraft and Kraft (1978) that examined this relationship in the USA, plenty of literature in the area have emerged. Basically four main streams of literature evolved that investigated this relationship: (i) the electricity consumption-led growth hypothesis (growth hypothesis), (ii) the growth-led electricity consumption hypothesis (conservation hypothesis), (iii) feedback hypothesis, and (iv) neutrality hypothesis.

Most of the empirical studies tested the growth hypothesis and supported its validity (Hamdi et al., 2014). Literature testing conservation hypothesis dealt with both time series and panel data. Different time series techniques such as Error Correction Model (ECM), Autoregressive Distributed Lag (ARDL), Variance Auto Regression (VAR), Dynamic Ordinary Least Squares

(DOLS), Fully Modified Ordinary Least Squares (FMOLS) and panel techniques such as Panel cointegration, panel Granger causality and panel Vector Error Correction Model (VECM) were used to test the hypothesis.

Yoo (2006) investigates the causal link between real GDP and electricity consumption in four ASEAN countries, namely Indonesia, Malaysia, Singapore and Thailand over the period 1971-2002. Findings indicate a bi-directional relationship for Malaysia and Singapore and a unidirectional relationship in Indonesia and Thailand. Wolde-Rufael (2006) examines the causality between electricity consumption and GDP for 17 African countries over 1971-2001. He employed Toda-Yamamoto Granger causality and found that GDP per capita Granger causes electricity consumption for six countries. His findings indicate that electricity consumption Granger causes GDP for three countries and a bi-directional relationship also for three countries. For the rest four countries, he found no causal relationship.

Squalli (2007) conducts causality testing for 11 OPEC countries using time series data for the period of 1980-2003 and found mixed results. Chen et al. (2007) examine the causal relationship for 10 Asian countries. They employ panel causality tests based on the error correction model over the period of 1971-2001. They find a unidirectional short-run causality running from economic growth to electricity consumption and a bi-directional long-run causality between the variables. Narayan and Prasad (2008) examined the causal effects between electricity consumption and real

GDP for 30 OECD countries. They employ a bootstrapped causal testing method and find that electricity consumption causes real GDP in Australia, Iceland, Italy, the Slovak Republic, Korea, Portugal and the UK. For the rest of the countries, they conclude that electricity conservation policy will not affect real GDP.

Narayan et al. (2010) investigate the long-run causality between electricity consumption and real GDP for seven panels consisting of a total of 93 countries. They conduct Canning and Pedroni long-run causality test for the first time in energy literature. They find long-run bi-directional causality for all panels except where only GDP Granger causes electricity consumption. There exist positive relationship between these variables in all the significant panels except in the then G6 countries which means that an increase in electricity consumption will reduce GDP.

Acaravci and Ozturk (2010) examine the long-run relationship and causality issues for a panel of 15 transition economies. Their findings do not indicate any cointegrating relationship between electricity consumption and economic growth implying that policies aiming to reduce electricity consumption would have no effect on real GDP in these countries. Ozturk (2010) provides a comprehensive survey of the empirical studies on electricity-growth nexus up to the year 2009. The survey highlights the methodologies used in these studies and focused on the conflicting results from these empirical exercises. The study concludes that application of new approaches and new methodologies would reduce the variation in results that will eventually lead to sound and consistent policy discussions.

Yoo and Kwak (2010) investigate the causal relationship between electricity consumption and economic growth for seven South American countries for the period of 1975-2006. They find unidirectional, bi-directional and no causal link for different countries across the region. Ciaretta and Zarraga (2010) use annual data to investigate the long-run and causal relationship between electricity consumption and real GDP for a panel of 12 European countries for the period of 1970-2007. They estimate a trivariate VECM by GMM. The results show evidence of a long-run equilibrium and a negative short-run relationship between the variables. The findings further confirm bi-directional causality between energy prices and GDP and between electricity consumption and energy prices.

Apergis and Payne (2011) undertake a study using a multivariate panel of 88 countries categorized into four panels based on the World Bank income classifications (i.e. high, upper-middle, lower-middle and low income) over the period of 1990-2006. The results reveal long-run equilibrium relationship between real GDP, coal consumption, real gross fixed capital formation and the labor force for the high, upper-middle and lower-middle income country panels. They also find bi-directional causal relationship for high-income and the upper middle-income country panels in both the short- and the long-run. Their findings further indicate unidirectional causal link in the short-run and bi-directional causal link for the lower middle-income country panel and unidirectional causality from electricity consumption to economic growth for the low-income country panel.

Bildirici and Kayikci (2012) in a study of 11 Commonwealth Independent States (CIS) employ panel ARDL and the FMOLS methods to examine the causal relationship. They divide the panel of CIS countries into three sub-panels based on income levels. Their empirical findings confirm a cointegrating relationship between the variables in all groups. The results further indicate a unidirectional causal link running from electricity consumption to economic growth for all groups in the long-run. FMOLS and ARDL estimations show that the effect of electricity consumption on GDP is negative for the second group of countries while it is positive for the first group of countries supporting the growth hypothesis. Acaravci and Ozturk (2012) performs an empirical exercise to determine the short- and long-run causality between electricity consumption and economic growth in Turkey during the period 1968-2006. The study finds evidence in support of the Growth hypothesis. The role of electricity in stimulating economic growth is also highlighted.

Cowan et al. (2014) in a study on BRICS (Brazil, Russia, India, China and South Africa) find support for no causal link between electricity consumption and economic growth in Brazil, India and China. However there is unidirectional causal relationship from electricity consumption to economic growth in Russia and South Africa.

Bouoiyour et al. (2014) provides a meta-analysis of the empirical results of 43 studies investigating electricity-growth nexus and published during the period 1996-2013. They suggest mixed findings from these studies. The study attribute these inconclusive findings to different country samples, econometric methodologies etc. Using different approaches and introducing other relevant variables in the model in future studies are recommended to reduce the disparity in findings.

Salahuddin et al. (2015) investigate the causal linkages among economic growth, electricity consumption, carbon dioxide emissions and financial development using panel data for the Gulf Cooperation Council Countries (GCC) for the period 1980-2012. Their findings indicate significant long-run relationship between economic growth, electricity consumption and financial development with carbon dioxide emissions.

Ozturk and Acaravci (2015) address the short- and long-run causality issues between electricity consumption and economic growth in selected 11 Middle East and North Africa (MENA) countries using annual data for the period 1971-2006. The study did not find any evidence in support of the positive relationship between electricity consumption and economic growth for most of these countries.

From the above review, it is evident that electricity consumption and economic growth relationship has important implications for energy policy. Despite this importance, such studies involving the OECD countries is almost absent. Only one study (Narayan and Prasad, 2008) attempted to address this issue for the region so far. However, their study analyzed data up to the period of 2002 and as such, the findings of this work has little policy relevance in the present context. This study is expected to fill this gap by using the most recently available dataset (up to 2012).

3. Methods

3.1 Data

A dynamic panel dataset is constructed with 26 OECD countries. We deal with an unbalanced panel as some of the data for some countries are missing. Electricity consumption per capita, real GDP per capita and mobile cellular subscription data were obtained for the period of 1985-2012 while data for internet user per 100 people was available for the period of 1990-2012. A few missing values were observed in the Internet users per 100 people and mobile cellular users per 100 people series which were replaced by 3-year moving average values. Also, six OECD countries were dropped from our dataset for having too many missing values. All data were obtained from the The World Data Bank, 2013 (previously, The World Development Indicators database (The World Bank, 2013). The variable per capita electricity consumption (EC) is measured by electric power consumption (kWh per capita), real GDP per capita (GDPPC) is measured at constant 2000 US$ and two measures of ICT usage, namely, the number of internet users per 100 people (ICTINTERNET) and the number of mobile cellular subscription per 100 people (ICTMOB) are considered for the study. All variables are expressed in natural logs.

Table 1 presents the descriptive statistics of all the variables. It reveals from the standard deviations that the data for all the series are fairly dispersed around the mean. This allows us to proceed with the data for further estimation.

Table 2 presents the correlation matrix. The correlation coefficients between all variables are moderate except between the number of the Internet users per 100 people and mobile cellular subscription per 100 people. However the high coefficient of 0.78 between these two variables do not pose any multi collinearity threat as these two variables are considered in two separate models as indicators of ICT use.

Table 1: Descriptive statistics

Variables	Obs	Mean	Std. Dev.	Min	Max
L Electric Power Use (per capita)	784	8.894	0.621	6.906	11.023
L GDP(per capita)	784	10.127	0.626	8.084	11.381
L Mobile Cellular Subscription	784	13.498	4.494	0	19.552
L Internet Use (per 100 people)	784	1.228	3.438	-13.778	4.564

Table 2: Correlation matrix

Variables	L GDP(per capita)	L Electric Power Use (per capita)	L Internet Use (per 100 people)	L Mobile Cellular Subscription
L GDP(per capita)	1.000			
L Electric Power Use (per capita)	0.755	1.000		
L Internet Use (per 100 people)	0.389	0.399	1.000	
L Mobile Cellular Subscription	0.374	0.264	0.789	1.000

3.2 Methodology

3.2.1 The model

Following Sadorsky (2012) and Narayan et al. (2010), we propose and estimate an econometric model where electricity consumption is assumed to be a function of ICT use and economic growth in OECD countries. Therefore, the functional form of the model is:

EC= F(A, ICT, GDPPC)--1

or

$EC_{it}= A. (ICT_{it})^{\beta 1} (GDPPC_{it})^{\beta 2}$ --2

Log-linearizing both sides of the equation, we obtain:

$1/E \ln E= \beta_0+ \beta_1 ICTINTER_{it} + \beta_2 GDPPC_{it} + \varepsilon_{it}$ --3

or, $\Psi \ln E= \beta_0+ \beta_1 ICTINTER_{it} + \beta_2 GDPPC_{it} + \varepsilon_{it}$ --4

When we measure the Internet with the number of mobile subscribers per 100 people, our model takes the form of:

$\Omega \ln E= \beta_0+ \beta_1 ICTMOB_{it} + \beta_2 GDPPC_{it} + \varepsilon_{it}$ --5

The subscripts *i*, and *t* represent the country and time period, respectively.

3.2.2 Estimation procedures

The estimation of our model proceeds as follows: (i) a cross-sectional dependence (CD) test is conducted to assess the presence of cross-sectional dependence across the panel; (ii) as the presence of cross-sectional dependence is detected, an appropriate panel unit root test (i.e., CIPS) is carried out to determine the stationarity properties of all the series; (iii) to see whether the variables have a cointegrating relationship between them, the Pedroni cointegration test is implemented and (iv) a PMG estimation is employed to estimate the short-run and long-run relationships among the variables.

3.2.3 Tests for cross sectional dependence and unit roots

It is extremely likely that there will be cross-sectional dependence among the OECD countries due to shocks such as global financial crisis or oil price shock, which affects all countries but with varying magnitude. To verify the existence of such dependence in the panel, the cross-sectional dependence (CD) test developed by Pesaran (2004) is conducted. Pesaran (2004) defines CD statistic as:

$$\mathrm{CD} = \left[\frac{TN(N-1)}{2}\right]^{1/2}\bar{\hat{\rho}},$$

where

$$\bar{\hat{\rho}} = \left(\frac{2}{N(N-1)}\right)\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}$$

in which $\hat{\rho}_{ij}$ is the pair-wise cross-sectional correlation coefficients of residuals from the conventional Augmented Dickey Fuller (ADF) regression and T and N are sample and panel sizes, respectively.

Having found the presence of cross-sectional dependence in the panel, an appropriate unit root test referred to as the cross-sectionally augmented IPS (CIPS) test was performed (Pesaran, 2007). The test statistic provided by Pesaran (2007) is given by:

$$\mathrm{CIPS}(N,T) = N^{-1}\sum_{i=1}^{N} t_i(N,T)$$

where t_i (N, T) is the t statistic of β_i in equation (2). The critical values of CIPS (N, T) are available in Table II(c) of Pesaran (2007).

3.2.4 Panel cointegration test

The presence of the unit root in the series enforce us to conduct Pedroni test (1997, 1999) which involves several panel cointegration tests for both models. Pedroni test is justified for this study as it controls for country size and heterogeneity allowing for multiple regressors (as in our case). Pedroni (1997) provides seven panel cointegration statistics for seven tests. Four of these are based on the within-dimension tests, and the other three are based on the between-dimension or group statistics approach.

The next step is the calculation of the Pedroni cointegration test statistics using the following expressions.

Panel–ρ statistic

$$T\sqrt{N}Z_{\hat{\rho}N,T-1} \equiv T\sqrt{N}\left(\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}\hat{e}_{i,t-1}^{2}\right)^{-1}\sum_{i}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}(\hat{e}_{i,t-1}\Delta\hat{e}_{i,t}-\hat{\lambda}_i$$

Panel–t statistic

$$Z_{tN,T}^{*} \equiv \left(\tilde{s}_{N,T}^{*2} \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^{2} \right)^{-1/2} \sum_{i}^{N} \sum_{t=1}^{T} \hat{L}_{11i}^{-2} (\hat{e}_{i,t-1} \Delta \hat{e}_{i,t}$$

Group–ρ statistic

$$TN^{-1/2} \tilde{Z}_{\hat{\rho}N,T-1} \equiv TN^{-1/2} \sum_{i=1}^{N} \left(\sum_{t=1}^{T} \hat{e}_{i,t-1}^{2} \right)^{-1} \sum_{t=1}^{T} (\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_{i})$$

Group–t statistic

$$N^{-1/2} \hat{Z}_{tN,T}^{*} \equiv TN^{-1/2} \sum_{i=1}^{N} \left(\sum_{t=1}^{T} \hat{s}_{i}^{*2} \hat{e}_{i,t-1}^{2} \right)^{-1/2} \sum_{t=1}^{T} \hat{e}_{i,t-1} \Delta \hat{e}_{i,t}$$

Lastly, we apply the appropriate mean and variance adjustment terms to each panel cointegration test statistic so that the test statistics are standard normally distributed:

$$\frac{\chi_{N,T} - \mu \sqrt{N}}{\sqrt{v}} => N(0,1)$$

where $\chi_{N,T}$ is the appropriately standardized form of the test statistic and the functions of moments of the underlying Brownian motion functionals. The appropriate mean and variance adjustment terms for the various number of regressors (*m* is the number of regressors without taking the intercept into account) and the various panel cointegration test statistics are given in Table 2 in Pedroni (1999).

3.2.5 Pooled Mean Group Regression

One major weakness of the Pedroni tests is that these tests do not estimate the short-run relationship or the speed of adjustment of the short-run disequilibrium towards the long-run equilibrium relationship (Murthy, 2007). To overcome this limitation, this study employs the pooled mean group estimator (PMG) technique, which is expected to provide us the most consistent and efficient estimates for both models for our panel of OECD countries. The justification for employing this technique is that we expect electricity consumption in OECD countries to be affected by the long-run homogeneous conditions and for the short-run adjustment to depend on country-specific characteristics such as vulnerability to domestic and external shocks.

Pesaran and Smith (1995), Pesaran (1997) and Pesaran and Shin (1999) show that PMG can render consistent and efficient estimates of the parameters in a long-run relationship even in case of mixed order of integration of variables. To eliminate the influence of the common factors, we allow for time-specific effects in the estimated regression. To comply with the requirements of standard estimation and inference, the long-run regression equations (equation 4 and equation 5) are incorporated into an ARDL (*p*, *q*) model. In error correction form, this can be written as follows:

$$\Delta(E_i)_t = \sum_{j=1}^{p-1} \gamma^i_j \Delta(E_i)_{t-j} + \sum_{j=0}^{q-1} \delta^i_j \Delta(x_i)_{t-j} + \varphi^i \left[(E_i)_{t-1} - \beta^i_1 (X_i)_{t-1}\right\}] + \beta^i_0 + \mu_t + \varepsilon_{it} \text{ ---------------6}$$

where γ^i_j and δ^i_j are short run coefficients, φ^i is the error correction adjustment speed, β^i_1 are the long-run coefficients, β^i_0, μ_t and ε_{it} are the country-specific fixed effects, time-specific effects and stochastic error term, respectively.

3.2.6 Dumetrescu -Hurlin (DH) causality test

Assessing the causal link between variables helps with a discussion of better policy implications of findings (Shahbaz et al., 2013). Taking into cognizance this fact, the current study employs a recently introduced Dumetrescu -Hurlin (DH) causality test which has two advantages over the traditional Granger (1969) causality test. In addition to considering fixed coefficients like Granger causality test, the DH test considers two dimensions of heterogeneity: the heterogeneity of the regression model used to test the Granger causality and the heterogeneity of the causal relationship.

4. Empirical results and discussion

The CD test and unit root test results are demonstrated in Table 3. The CD results demonstrate that there is cross-sectional dependence in all the series considered in our study. This kind of dependencies usually arise from the presence of multiple unobserved common shocks that different countries respond in different ways. There may be strong factors such as oil price shocks or the global financial crisis and weak factors like local spill-over effects that contribute to such error dependencies. The CIPS unit root results confirm that all the variables are first-difference stationary, i.e. I(1), even in the presence of cross-sectional dependence.

Table 3: Panel unit root test results

Variables	$\hat{\rho}$	CD	Levels CIPS	First differences CIPS
L GDP(per capita)	0.930	95.66***	-1.699	-2.592***
L Electric Power Use (per capita)	0.728	70.52***	-1.243	-2.579***
L Internet Use (per 100 people)	0.988	101.68***	-2.640***	-3.288***
L Mobile Cellular Subscription	0.934	96.11***	-3.318***	-3.333***

Notes:, **, *** denote 10%, 5% and 1% respectively*

Table 4(A) and 4(B) present the results of the Pedroni panel cointegration test for model A and model B, respectively. All Pedroni test statistics except the v statistic have a critical value of -1.64. The v statistic has a critical value of 1.64. Table 4A shows that four out of seven test statistics support the presence of cointegration among the variables in model A. It is evident from Table 4B that the statistical values of six out of the seven tests are greater than the critical values (-1.64) which indicate that the null hypothesis of no cointegration is rejected. Nevertheless, among the seven test statistics, the group rho statistic has the best power (Gutierrez, 2003), which is also greater than the critical value. Thus, it can be concluded that there is a long-run cointegrating relationship among the variables in model B. The presence of the cointegrating relationship between the variables in both models allow us to proceed with further investigation of the short- and the long-run relationship among them.

Table 4A: Panel cointegration test results (Pedroni Residual Cointegration Test) for model A

Alternative hypothesis: common AR coefs. (within-dimension)

			Weighted	
	Statistic	Prob.	Statistic	Prob.
Panel v-Statistic	1.330477	0.0917	2.073177	0.0191
Panel rho-Statistic	0.724972	0.7658	-1.789434	0.0368
Panel PP-Statistic	1.051950	0.8536	-3.333802	0.0004
Panel ADF-Statistic	-0.529274	0.2983	-3.486336	0.0002

Alternative hypothesis: individual AR coefs. (between-dimension)

	Statistic	Prob.
Group rho-Statistic	-0.855397	0.1962
Group PP-Statistic	-3.589833	0.0002
Group ADF-Statistic	-4.608395	0.0000

Table 4B: Panel cointegration test results (Pedroni Residual Cointegration Test) for model B

Alternative hypothesis: common AR coefs. (within-dimension)

			Weighted	
	Statistic	Prob.	Statistic	Prob.
Panel v-Statistic	1.044619	0.1481	1.946064	0.0258
Panel rho-Statistic	1.649529	0.9505	-0.797989	0.2124
Panel PP-Statistic	2.965696	0.9985	-2.111578	0.0174
Panel ADF-Statistic	1.644944	0.9500	-2.177232	0.0147

Alternative hypothesis: individual AR coefs. (between-dimension)

	Statistic	Prob.
Group rho-Statistic	0.521711	0.6991
Group PP-Statistic	-2.323784	0.0101
Group ADF-Statistic	-2.559930	0.0052

Table 5(A) and 5(B) present the results from the PMG estimations for both models A and B, respectively. The findings indicate that for both measures of ICT use, the estimated coefficients are positive, persistent and significant at 1% level of significance. In model A, the long-run estimated coefficient of the variable, the number of the Internet users per 100 people is .026 which means that a 1% increase in the number of the Internet users per 100 people increases per capita electricity consumption by .026%. In model B, the estimated long-run coefficient of the number of mobile cellular users per 100 people is 0.010, meaning a 1% rise in the number of mobile cellular users per 100 people causes 0.010% increase in per capita electricity consumption. These findings are consistent with the expected energy impact of ICT use. In other words, ICT use stimulate electricity consumption meaning increased use of ICT leads to increased demand for electricity eventually leading to its increased consumption. Thus the findings are also robust across different measures of ICT use.

There is also highly significant positive short-run and the long-run relationship between economic growth and electricity consumption in both models. The estimated long-run coefficient of economic growth rate (log of GDP per capita) is 0.25 in model A. This means that a 1% economic growth rate will cause .25% increase in per capita electricity consumption. The estimated coefficient of economic growth varies in model B from model A. The long-run coefficient of economic growth in model B is 0.130 which means a 1% growth rate will cause a 0.13% increase in per capita electricity consumption. This finding supports the argument that economic growth is always accompanied by increased demand for electricity use. This is quite expected as economic growth leads to increased economic activities and consumption for electronic appliances is expected to rise resulting in a rise in electricity consumption. Overall, these are expected findings as most of the empirical literature suggest that economic growth is accompanied by increase in domestic energy demand and in particular, electricity demand.

Table 5A: Results from PMG estimation for model A

Dependent variable: Electric Power Consumption	Pooled Mean Group	
Variable	Coefficient.	Standard Error
Long-Run Coefficients		
LGDPC	0.252***	0.053
Net Use (Per 100 People)	0.026***	0.002
Error correction Coefficient	-0.176***	0.049
Δ LGDPC	0.566***	0.051
Δ Net Use (Per 100 People)	0.008***	0.005
Intercept	1.124	0.320

Notes:, **, *** denote 10%, 5% and 1% respectively*

Table 5B: Results from PMG estimation for model B

Dependent variable: Electric Power Consumption	Pooled Mean Group	
Variable	Coefficient	Standard Error
Long-Run Coefficients		
LGDPC	0.130***	0.032
L Mobile Cellular	0.0104***	0.001
Error correction Coefficient	-0.174***	0.042
Δ LGDPC	0.528***	0.050

Δ L Mobile Cellular	0.0012***	0.005
Intercept	1.357***	0.340

Notes:, **, *** denote 10%, 5% and 1% respectively*

Dumitresco-Hurlin (DH) causality results as reported in table 6 suggest that electricity consumption causes economic growth. There is unidirectional causal link running from mobile and Internet use to electricity consumption and economic growth in the OECD countries.

Table 6: Pairwise Dumitrescu Hurlin Panel Causality Tests

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.
LGDPC does not homogeneously cause LEC	3.85804	8.85025	0.0000
LEC does not homogeneously cause LGDPC	2.60799	4.85215	1.E-06
MOB does not homogeneously cause LEC	2.75485	5.30600	1.E-07
LEC does not homogeneously cause MOB	8.52791	23.7292	0.0000
NET does not homogeneously cause LEC	3.64957	7.70658	1.E-14
LEC does not homogeneously cause NET	3.94185	8.59689	0.0000
MOB does not homogeneously cause LGDPC	2.46452	4.37949	1.E-05
LGDPC does not homogeneously cause MOB	13.7760	40.4773	0.0000
NET does not homogeneously cause LGDPC	4.90493	11.5305	1.E-.27
LGDPC does not homogeneously cause NET	6.16437	15.3668	0.0000
NET does not homogeneously cause MOB	5.12691	12.2067	0.0000
MOB does not homogeneously cause NET	8.55127	22.6374	0.0000

5. Conclusions and Policy Implications

This study uses panel data to examine for the first time ever the short- and long-run effects of ICT use and economic growth on electricity consumption in OECD countries for the period of 1985-2012. It employs a battery of powerful econometric techniques including non-conventional panel unit root test that accounts for the presence of cross-sectional dependence, panel cointegration test, the Pooled Mean Group regression (PMG) method and recently introduced Dumetrescu-Hurlin (DH) causality test. The panel unit root test confirms that all the series in the study are first-difference stationary even in the presence of cross-sectional dependence indicating cointegrating relationship between the variables. Panel Pedroni cointegration test results confirm the cointegrating relationship between the variables in both models using two different indicators of ICT use. Estimation results suggest a highly positive significant relationship between ICT use and electricity consumption and between electricity consumption and economic growth both in the short- and the long-run. The findings are robust across both models. Also causality results suggest that electricity consumption causes economic growth. Both mobile and Internet use cause electricity consumption and economic growth.

The findings of the current study in that both ICT use and economic growth stimulate electricity consumption in OECD countries in the short- and the long-run have important policy implications. The positive relationship between ICT use and electricity consumption suggest that OECD countries are yet to achieve energy efficiency gains from ICT expansion although a target was set to achieve this goal by the year 2015 for those OECD countries which are also European countries (IEA, 2009). The unidirectional causal link from electricity consumption to economic growth imply that positive relationship between economic growth and electricity consumption imply that the OECD countries can not reduce electricity generation to combat pollution effects but rather, they need to pursue policies that will improve electricity generation efficiency which will have no adverse effect on their economic growth. To achieve this, they need to focus on energy savings gains from ICT based electricity efficiency strategy. If the energy efficiency gains from ICT use could be achieved, it is likely to further promote the expansion of the ICT use in the region as this will reduce the cost of using ICT products and services which is further expected to play an important role in reducing digital divide both within and between the OECD countries.

This study also recommends that the OECD countries should further expand Carbon Capture and Storage (CCS) facilities as this appears to be an effective method to combat CO_2 emissions in the region. Also, the governments might invite the private entrepreneurs and build public-private partnership (PPP) that might play a significant role in boosting investment funds for CCS plants in the region. Integration of CCS in GHG policies also appears to be important.

Boosting nuclear energy may be another potential option for the OECD countries for power generation. Usually nuclear energy plants involve huge investment and the benefits are likely to be due only in the very long-run. Since most of the OECD economies are generally characterized by stable economies, large scale investment in nuclear energy is not very challenging for them.

Apart from strengthening the above mentioned measures which are already in place in most of the OECD countries, the Governments of these countries need to pursue energy policy that is directed towards encouraging investment to find innovative ways to make ICT products, networks and especially data centers that involve the highest level of electricity consumption among ICT products and services, more energy efficient. The data centers that exceed the requirement of certain level of electricity consumption may be monitored and regulated through appropriate means.

Also, the Governments of OECD countries need to focus more on and gradually implement two methods as advocated by the International Energy Association (IEA, 2009). That is, they need to gradually switch to more efficient technologies that represent the shortest life cycle of ICT products and the best available technologies that imply better use of equipments and components which ensure the use of power by ICT products only when it is needed. These can be achieved by reinforcing policy that would encourage data centers to continue with their energy-saving measure of turning on/off a large number of machines that operate within these data centers. A recent study (Fernandez-Montes et al. 2015) concludes that energy savings from shutting on/off policy in data centers outweigh the costs involved therein.

The study further recommends that OECD countries promote green IT and IT for green that have the potential to substantially reduce CO_2 emissions through eco-efficiency and eco-design processes (Jenkin et al. 2011). Also the policy makers in these countries must not rule out the potential that electricity sector itself provides substantial opportunities for reducing emissions if measures such as fuel switching and generation efficiency improvement initiatives are taken (Ang et al. 2011). Finally, an effective coordination among ICT policy, energy policy and growth policy is vital to address the climate change issue in the region.

Despite important and significant findings, this study suffers from a number of limitations. First of all, six of the OECD countries had to be dropped from the study due to a lack of availability of data. Thus, one should be cautious about the generalizability of our findings to the whole OECD region. Second, although the sample period covered in this study is sufficient for the application of the PMG technique, a larger sample period would have offered more reliable findings. Nevertheless, the PMG technique imposes long-run homogeneity of the parameters across the panel (as the study considers only OECD countries), but in the real world some possibly substantial degree of cross-country heterogeneity may still exist in the long-run. Also, the findings are not expected to be invariant across different econometric methodologies. Also, with the expansion of ICT use and especially with the massive roll out of the Internet infrastructure in almost all OECD countries, the electricity demand will rise as evident from the findings of this study. The increasing demand for electricity and subsequently its increasing consumption is likely to raise the level of CO_2 emissions. Therefore, assessing the direct impact of the Internet usage on CO_2 emissions in the region, could be a potential topic for further investigation. This is left for future research.

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References:

Acaravci, A., Ozturk, I., 2012, “Electricity Consumption and Economic Growth Nexus: A Multivariate Analysis for Turkey”, Amfiteatru Economic, 14, 246-257.

Acaravci, A., Ozturk, I., 2010. Electricity consumption-growth nexus: Evidence from panel data

Ang, B.W., Zhou, P., Tay, L. P., 2011. Potential for reducing global carbon emissions from electricity production-A benchmarking analysis, Energy Policy 39, 2482-2489

Apergis, N., Payne, J. E., 2011. A dynamic panel study of economic development and the electricity consumption growth nexus, Energy Economics 33, 770-781.

Bartleet, M., Gounder, R., 2010. Energy consumption and economic growth in New Zealand: results of trivariate and multivariate models, Energy Policy 38, 3505-3517.

Bildirici, M. E., Kayikci, F., 2012. Economic growth and electricity consumption in former Soviet Republics, Energy Economics 34,747-753.

Bouoiyour, J., Selmi, R., Ozturk, I. 2014. The Nexus between Electricity Consumption and Economic Growth: New Insights from Meta-Analysis, International Journal of Energy Economics and Policy 4, 621-635.

Chen, S., Kuo, H., Chen, C., 2007. The relationship between GDP and electricity consumption in 10 Asian countries, Energy Policy 35, 2611-2621.

Cho, Y., Lee, J., Kim, T. Y., 2007. The impact of ICT investment and energy price on industrial electricity demand: dynamic growth model approach, Energy Policy 35 (9), 4730-4738.

Chudik, A. & Pesaran, H. M. (2013). Common Correlated Effects Estimation of Heterogeneous Panel Data Models with Weakly Exogenous Regressors, CFS_{IFO} Working paper No. 4232. The international platform of Ludwig-Maximilan University's Center for Economic Studies and the Ifo Institute.

Ciaretta, A., Zarraga, A., 2010. Electricity consumption and economic growth in Spain, Applied Economics Letters 17, 1417-1421.

Cowan, W.N., Chang, T., Inglesi-Lotz, R., Gupta, R. 2014. The nexus of electricity consumption, economic growth and CO_2 emissions in the BRICS countries. Energy Policy 66, 359-368.

EC, E-Business Watch, 2006. The European e-Business Report: A Portrait of e-Business in 10 sectors of the EU economy. Office for Official Publications of the European Communities, Luxembourg.

Faucheux, S., Nicolai, I., 2011. IT for green and green IT: A proposed typology of eco-innovation, Ecological Economics 70, 2020-2027.

GeSI SMARTer 2020: The Role of ICT in Driving a Sustainable Future. Retrieved from http://gesi.org/SMARTer2020

Greenpeace International, 2014. Clicking Clean: How Companies are Creating the Green Internet, April, 2014.

Gutierrez, L., 2003. On the Power of Panel Cointegration Test: A Monte Carlo Comparison, Economics Letters, 80, 105-111.

Hamdi, H., Sbia, R., Shahbaz, M., 2014. The nexus between electricity consumption and economic growth in Bahrain, Economic Modelling 38, 227-237.

Heddeghem, V. W., Lambert, S., Lannoo, B., Colle, D., Pickavet, M., Demeester, P., 2014. Trends in worldwide ICT electricity consumption from 2007 to 2012, Computer Communications (2014), http:// dx.doi.org/10.1016/j.com.com.2014.02.008.

Hsiao, C.., 1986. Analysis of Panel Data, Econometric Society Monographs, No 11, Cambridge University Press.

Huaman, R. N. E., Jun, T. X., 2014. Energy related CO_2 emissions and the progress on CCS projects: A review, Renewable and Sustainable Energy Review 31, 368-385.

IEA-WEO 2012. World Energy Outlook, 2012, International Energy Agency, Paris.

IEA, 2009. Gadgets and gigabytes, Policies for Energy Efficient Electronics, OECD/IEA, International Energy Agency, Paris.

IEA-WEO 2006. World Energy Outlook, 2006, International Energy Agency, Paris.

Jenkin, T. A., Webster, J., McShane, L., 2011. An agenda for 'Green' information technology and systems research, Information and Organization 21, 17-40.

Karanfil, F., 2009. How many times again will we examine the energy-income nexus using a limited range of traditional econometric tools? Energy Policy 36, 3019-3025.

Kraft, J., Kraft, A., 1978. On the relationship between energy and GNP. Journal of Energy Development 3, 401-403.

Moyer, J. D., Hughes, B. B., 2012. ICTs: Do they contribute to increased carbon emissions? Technological Forecasting and Social Change 79, 919-931.

Murthy, N.R.V., 2007. Panel Cointegration Analysis: An Empirical Example in Cointegration for the Applied Economist, in Rao, B. (ed.) Cointegration for the Applied Economics (Second Edition): 222-256.

Narayan, P. K., Narayan, S., Popp, S., 2010. Does electricity consumption panel Granger cause GDP? A new global evidence, Applied Energy 87, 3294-3298.

Narayan, P. K., Prasad, A., 2008. Electricity consumption-real GDP causality nexus: Evidence from a bootstrapped causality test for 30 OECD countries, Energy Policy 36, 910-918.

Nelson, C., & Plosser, C., 1982. Trends and Random Walks in Macroeconomic Time Series: Some Evidence and Implications. Journal of Monetary Economics 10, 130-162.

Ozturk, I., Acaravci, A., 2011. Electricity Consumption and real GDP Causality Nexus: Evidence from ARDL Bounds Testing Approach for 11 MENA Countries, Applied Energy 88, 2885-2892.

Ozturk, I., 2010. A literature Survey on Energy-Growth Nexus, Energy Policy 38, 340-49.

Payne, J. E., 2010. A survey of the electricity consumption-growth literature, Applied Energy 87: 723-731.

Pedroni, P., 1997. Panel Cointegration; Asymptotic and Finite Sample Properties of Pooled Time Series Tests, with an Application to the PPP Hypothesis: New Results, Working paper, Indiana University, April.

Pedroni, P., 1999. Critical Values for Cointegration Tests in Heterogeneous Panels with Multiple Regressors, Oxford Bulletin of Economics and Statistics 61, 653-670.

Pesaran H., Shin, Y., & Smith, R., 1999. Pooled Mean Group Estimation of Dynamic Heterogeneous Panels, Journal of the American Statistical Association, 94, 621-634.

Pesaran, M. H., 2004. General diagnostic tests for cross section dependence in panels. In: Cambridge Working Papers in Economics No. 435. University of Cambridge, and CESifo Working Paper Series No. 1229.

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., Shin, Y., 1999. An autoregressive distributed lag modeling approach to cointegration analysis. Chapter 11 in Econometrics and Economic Theory in the 20th Century: The Ragnar Frisch Centennial Symposium, Strom S (ed.). Cambridge University Press: Cambridge.

Pesaran, M.H., Smith, R.P., 1995. Estimating long-run relationships from dynamic heterogeneous panels. Journal of Econometrics 68, 79–113.

Ravallion M., 1995. Growth and Poverty: Evidence for Developing Countries in the 1980s, Economics Letters 48, 411-417.

Romm, J., 2002. The Internet and the new energy economy, Resource, Conservation and Recycling 36, 197-210.

Ropke, I., Christensen, T. H., 2012. Energy impacts of ICT- Insights from an everyday life perspective, Telematics and Informatics 29, 348-361.

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

Saidel, M. A., Alves, S. S., 2003. Energy efficiency policies in the OECD countries, Applied Energy 76, 123-134.

Salahuddin, M., Alam, K., 2015. Internet usage, electricity consumption and economic growth in Australia: A time series evidence, Telematics and Informatics 32, 862-878.

Salahuddin, M., Gow, J., Ozturk, I., 2015. Is the long-run relationship between economic growth, electricity consumption, carbon dioxide emissions and financial development in Gulf Cooperation Council Countries robust? Renewable and Sustainable Energy Review 51, 317-326.

Shafiei, S., Salim, R. A., 2014. Non-renewable and renewable energy consumption and CO_2 emissions in OECD countries: A comparative analysis

Shahiduzzaman, M., Alam, K., 2014. Information technology and its changing roles to economic growth and productivity in Australia, Telecommunications Policy 38, 125-135.

Sqaulli, J., 2007. Electricity consumption and economic growth: bounds and causality analyses of OPEC members, Energy Economics 29, 1192-1205.

Takase, K., Murota, Y., 2004. The impact of ICT investment on energy: Japan and US comparison in 2010, Energy Policy 32, 1291-1301.

Walker, W., 1985. Information technology and the use of energy, Energy Policy 13 (5), 458-476.

Wolde-Rufael, Y., 2006. Electricity consumption and economic growth: a time series experience for 17 African countries. Energy Policy 34, 1106-1114.

World Bank, 2013. World Development Indicators, The World Bank, Washington DC, USA, available from: <http://data.worldbank.org/data-catalog/world-development-indicators/World Bank-2013>; (accessed on 03.04.2014).

Yoo, S., 2006. The causal relationship between electricity consumption and economic growth in ASEAN countries. Energy Policy 34, 3573–3582.

Yoo, S-H., Kwak, S-Y., 2010. Electricity consumption and economic growth in seven South American countries, Energy Policy 38, 181-188.

Yu, E.S.H., Choi, J.Y., 1985. The causal relationship between electricity and GNP: An international comparison, Journal of Energy and Development 10, 249–272.

Zhang, T., 2013. Income disparity and digital divide: The Internet Consumption Model and cross-country empirical research, Telecommunications Policy, 37, 515-529.