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Internet usage, renewable energy, electricity consumption and economic growth : Evidence from developed countries

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Abstract

Using a dataset of 31 developed countries over the period of 1990-2015 we empirically investigate the relationship between Internet usage, renewable energy, electricity consumption and economic growth. Panel autoregressive distributed lag method (ARDL) and Dynamic Ordinary Least Squares method (DOLS) are applied to test this relation. Results from ARDL estimates reveal that Internet usage and economic growth have a positive and significant long-run effect on electric power consumption. Results, also indicate that renewable energy has a negative and significant effect on electricity consumption. Otherwise, only economic growth has positive and significant effect on electricity consumption in the short-run. This paper supports the view that developed countries still dependent to nonrenewable energy use to support their economic growth and to meet the increasing electricity demand from Internet usage. Moreover, by supporting investment in renewable energy and green IT developed countries can increase renewable electricity production and mitigate pollution.

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1 Introduction

In the 1990s, Internet has emerged as a tool that has improved communication consistently, but has since transformed into a ubiquitous technology that supports the real economy. It has fueled the growth of businesses in technology centers and has changed the way a wide range of businesses operate. By improving access to relevant markets information, facilitating trade operations and by creating new business opportunities, the Internet can enhance firm's performance (Kaushik and Singh (2004);Aker and Mbiti (2010)). However, at the end of 2014, the Internet had about 3 billion users, many of whom use it on a daily basis. Whether it is powering smartphones, tablets, PCs or servers, the energy requirements are enormous. Fettweis and Zimmermann (2008) expected that in 25 years, the consumption of 500 billion devices connected to the Web equal to that of humanity in 2008. This may exerts pressure on energy use and increases the electricity consumption (Moyer and Hughes (2012); Salahuddin and Alam (2015)). Moreover, Internet users data are stored and managed by data centers which consume huge amounts of electrical energy, contributing to high operational costs and carbon footprints to the environment (Koomey (2011),Beloglazov et al. (2012)). Besides, cloud hosting decreases the proportion of use-stage electricity by consumer devices which is transferred to the networks and data centers. However, electricity efficiency of wireless access networks and fixed access networks (data centers) still not enough improved . Therefore, the Communication Technology (CT) could use as much as 51% of global electricity in 2030 (Andrae and Edler (2015)).

While, several empirical studies have been conducted on the relationship between Internet usage, electricity consumption and economic growth, relatively little attention has been given to the nexus between Internet usage, renewable energy, electricity consumption and economic growth. For instance,Salahuddin and Alam (2015) used an ARDL bounds test for cointegration and Granger causality test to investigate a causal link between Intenet usage, electricity consumption and economic growth in Australia over the period 1985-2012. Their results indicate that the Internet use and economic growth stimulate electricity consumption in the long-run. By performing a structural unit root test and Johansen and ARDL cointegration tests, Salahuddin and Gow (2016) examined the long-run relationship between Internet usage, financial development, trade openness and economic growth in South Africa over the period 1991-2013.They found a positive and significant long run relationship between variables. Afzal and Gow (2016) investigated the impact of ICT on electricity consumption in the next eleven (N-11) emerging economies over the period 1990-2014 by using mean group (MG) and pool mean group (PMG) methods. Findings indicate an increase in ICT, measured using Internet connections, mobile phone subscriptions or ICT goods imported, increases the demand for electricity in the N-11 emerging economies. Moreover, results show that effect of ICT on electricity consumption is actually greater than the effect of income growth on electricity consumption. Saidi et al. (2015) used a dynamic panel data model to analyze the impact of ICT and economic growth on electricity consumption for a global panel consisting of 67 countries. Their main results show that Internet connections and mobile phone subscriptions increase the demand for electricity in 69 countries. Sadorsky (2012) examines the impact of information communication technology (ICT) on electricity consumption in emerging economies using a dynamic panel method. The result reveals a positive and statistically significant relationship between ICT measured using internet connections and electricity consumption.Using a logistic growth model, Cho et al. (2007) investigated the effects of ICT investment and energy price on electricity consumption in South Koreas industries. Their results indicate that ICT investment increases electricity consumption in manufacturing sectors and service sector.

Otherwise,Raza et al. (2016) examine the effect of electricity consumption on economic growth of four South Asian countries over the period 1980-2010. Their findings indicate a long-run relationship between electricity consumption and economic growth in South Asia. Their results support also an unidirectional causal relationship running from electricity consumption to economic growth. Gokten and Karatepe (2016) analyze the relationship between electricity consumption and economic growth in Turkey. The author reported that there is an unidirectional causal relationship running from electricity consumption to GDP. Findings show also that there is a bidirectional causality running from import-based electricity to current account deficit.Similarly, Dogan (2015) by applying the ARDL approach to cointegration, the Johansen cointegration test and the GregoryHansen cointegration test with structural break, analyzes the casual relationship between economic growth, electricity consumption from renewable sources and electricity consumption from non-renewable sources for Turkey. The results show that there is a long-run and casual relationship between variables.The study further suggests that Turkish government should continue to reduce the share of electricity consumption from renewable sources and encourage the usage of electricity from non-renewable sources to have sustainable long run growth rates.

Despite that studies on the indirect effect of the relationship Internet usage, economic growth on electricity consumption are plentiful; there are few studies that investigated the direct relationship between Internet usage and electricity consumption. Baliga et al. (2007) present a network-based model that estimates Internet power consumption including the core, metro and access network. There results show that the power consumption of the Internet is 1% of electricity consumption in broadband enabled countries. Moreover, there findings indicate that this percentage could increase to over 4% as the access rate increases. Hinton et al. (2011) presented a network-based model of power consumption in Internet infrastructure. There model shows that the access network dominates the Internet's electric power consumption and, as access speeds grow, the core network routers will dominate power consumption. Similarly, Lambert et al. (2012) studied the use phase electricity consumption in communication networks, consisting of telecoms operator networks, customer premises equipment and office networks. There results show that the total worldwide electricity consumption in communication networks will exceed 350 Terawatt-hours (TWh) in 2012.

The purpose of this paper is to empirically investigate the link between Internet usage, renewable energy, electricity consumption and economic growth for the developed countries. Reviewing the existing literature, we observe two shortcomings:First, most empirical studies on the electricity consumption effects of increased Internet usage have only been studied in time series settings. Second, most frequently empirical evidence is based on first generation panel unit roots and panel cointegration tests which assume that the individual time series in a panel are cross-sectionally independently distributed. However, cross-sectional independence does not occur in real-world scenarios (Pesaran (2006); Hoang and McNown (2006)).

To fill these shortcomings we reexamine the issue with the following key features: First, we use a panel dataset of 31 developed countries over the period of 1990-2015. Second, we conduct second generation panel unit roots and cointegrations tests for cross-sectional dependence.

The remainder of this paper is structured as follows. Section 2 presents the data and the model specification. Section 3 shows the model estimation and results and section 4 concludes.

2 Data and model specification

In this study, we used a balanced annual data of 806 observations for 31 developed countries. The period of the study spans from 1990 to 2015. Variables are collected from the U.S. Energy Information Administration and the World Bank Development Indicators (WDI) database. The countries used in the sample include Australia, Austria, Belgium, Canada, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Latvia, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Slovak Republic, Slovenia, Switzerland, Sweden, United States, United Kingdom, South Korea.

In this study four macroeconomic variables are used. They include the electric power consumption from nonrenewable energy (kWh per capita), Internet users per 100 people, Renewable energy consumption (net geothermal, solar, wind and biomass energy) measured in millions of kilo watt hours (MkWh) and real GDP per capita measured in millions of constant 2010 U.S dollars.All variables meet the international standard definition.

Following earlier studies (Narayan et al. (2010),Sadorsky (2012) andSalahuddin and Alam (2015)), we estimate an econometric model in which electric power consumption is assumed to be a function of Internet usage, renewable energy and economic growth. Our function is defined by:

$$ep_t = f(A, intr_t, re_t, y_t) = A intr_t^{\beta_1} re_t^{\beta_2} y_t^{\beta_3} \tag{1}$$

Where ep_t refers to the electric power consumption. $intr_t$, re_t, and ly_t denote the Internet usage, renewable energy and economic growth respectively. The $(\beta_1, ..., \beta_3)$ represent the output elasticities of Internet usage, renewable energy and economic growth, respectively.

We apply the natural logarithm to the equation (1), than we can write our model as,

$$lep_{it} = \alpha_i + \delta_{it} + \beta_{1t} lintr_{it} + \beta_{2t} lre_{it} + \beta_{3t} ly_{it} + \varepsilon_{it} \tag{2}$$

Where α_i is the country fixed effects and ε_{it} is the error term.

The econometric approach is based on three steps. In the first one, the stationarity of each variable is examined by performing the second-generation panel unit root tests proposed by Pesaran (2007). In the second one, we apply the autoregressive distributed lag method (ARDL) developed by Pesaran (1997) and Pesaran et al. (2001) to estimate the long-run relationship between the variables. Finlay, we apply the dynamic OLS as a robustness check of the ARDL long-run estimates.

The dynamic specification form of the ARDL(p,q$_1$,...,q$_k$) is

$$\mathrm{y}_{it}= \sum_{j=1}^{p} \lambda_{ij} \mathrm{y}_{i,t-j} + \sum_{j=0}^{q} \delta'_{ij} \mathrm{X}_{i,t-j} + \mu_i + \varepsilon_{it} \tag{3}$$

where the number of groups i=1,2,...,N; the number of periods t = 1, 2, . . . ,T;X$_{it}$ is a kx1 vector of explanatory variables; δ'_{ij} are kx1 coefficient vector; λ_{ij} are scalars; and μ_i is the group-specic effect. T must be large enough such that the model can be fitted for each group separately. Time trends and other fixed regressors may be included.

We specified our long-run model as:

$$\mathrm{lep}_{it}=\alpha_{0t}+\alpha_{1t}\mathrm{lintr}_{it}+\alpha_{2t}\mathrm{lre}_{it}+\alpha_{3t}\mathrm{ly}_{it}+\mu_{it}+\varepsilon_{it} \tag{4}$$

where the number of nations i=1,2,...,N; the number of periods t=1,2,...,T; lep$_{it}$ is electric power; lintr$_{it}$ the Internet usage;$_{it}$ is the renewable energy consumption ; ly$_{it}$ is the economic growth. If there are I(1) and cointegrated, then the error term is I(0) for all i. The ARDL(1,1,1) dynamic specification of (4) is

$$\mathrm{lep}_{it}=\delta_{10i}\mathrm{lintr}_{it}+\delta_{11i}\mathrm{lintr}_{i,t-1}+\delta_{20t}\mathrm{lre}_{it}+\delta_{21t}\mathrm{lre}_{i,t-1}+\delta_{30}\mathrm{ly}_{it}+\delta_{31}\mathrm{ly}_{i,t-1}+\lambda_i\mathrm{lep}_{i,t-1}\mu_i+\varepsilon_{it} \tag{5}$$

The error correction reparameterization of (5) is

$$\Delta\mathrm{lep}_{it}=\mathit{\Phi}_i(\mathrm{lep}_{i,t-1}\text{-}\alpha_{0i}\text{-}\alpha_{1i}\mathrm{lintr}_{it}\text{-}\alpha_{2i}\mathrm{lre}_{it}\text{-}\alpha_{3i}\mathrm{ly}_{it})+\delta_{11i}\Delta\mathrm{lintr}_{it}+\delta_{21i}\Delta\mathrm{lre}_{it}+\delta_{31i}\Delta\mathrm{ly}_{it}+\varepsilon_{it} \tag{6}$$

where $\mathit{\Phi}_i$=-(1-λ_i), $\alpha_{0i}=\dfrac{\mu_i}{1-\lambda_i}$, $\alpha_{1i}=\dfrac{\delta_{10i}-\delta_{11i}}{1-\lambda_i}$, $\alpha_{2i}=\dfrac{\delta_{20i}-\delta_{21i}}{1-\lambda_i}$, $\alpha_{3i}=\dfrac{\delta_{30i}-\delta_{31i}}{1-\lambda_i}$.

The error-correction speed of adjustment parameter, $\mathit{\Phi}_i$, and the long-run coefficient α_{1i}, α_{2i} and α_{3i}, are of primary interest. With the inclusion of α_{0i} a nonzero mean of the cointegrating relationship is allowed. One would expect $\mathit{\Phi}_i$ to be negative variables exhibit a return to long-run equilibrium.

One advantage of using this method is that the error correction representation in the ARDL provides information about the contemporaneous impacts and the speed of adjustment towards equilibrium following a shock. Furthermore, while the long-run coefficients are assumed to be homogeneous (that is, identical across panels), the short-run coefficients are allowed to be heterogeneous (that is, country-specific). Alternatively, we use the mean group (MG) estimator which essentially allows the long-run parameters to change. The poolability assumption of the pooled mean-group (PMG) estimator is thus tested using the Hausman test.

3 Model estimation and results

3.1 Panel unit root tests

The Pesaran's cross-sectional dependence test (CD) Pesaran (2004) reported in Table 1 rejects the null hypothesis of no cross-sectional dependence.

Table 1: Pesaran's test of cross sectional independence

CD=4.461	Prob=0.0000
average absolute correlation = 0.660	

Results of second-generation panel unit root tests proposed by Pesaran (2007) are introduced in Table 2 . From this table it can be noted that the null hypothesis of the unit root cannot be rejected at the 5% and 1% level of significance for renewable energy consumption (lre) and respectively for Internet usage (lintr). However, by testing for the unit root in the first difference, all panel unit root tests reject the null hypothesis at the 1% level of significance.

Table 2: Second-generation panel unit-root

Variables	Levels CIPS	First differences CIPS
lep	0.813	0.000***
lre	0.027**	0.000***
lintr	0.000 ***	0.000***
ly	1.000	0.000***

Signif. codes: 0 (***) 0.001 (**) 0.01 (*) 0.05 (.) 0.1 ( ) 1

3.2 Panel cointegration test

The panel unit root tests confirm that the order of integration of variables is mixed (I(0) and I(1)), then we test for evidence of a long-run relationship.The Westerlund cointegration test (Westerlund (2007)) is used to test the null hypothesis of the nonexistence of cointegration against the alternative of cointegration. The results represented in Table 3 provide strong evidence for panel cointegration among the variables.

Table 3: Westerlund panel cointegration test

Statistic	Value	Z-value	P-value	Robust P-value
Gt	-4.666	-14.135	0.000***	0.200
Ga	-14.361	-2.643	0.004***	0.000***
Pt	-27.305	-15.883	0.000***	0.000***
Pa	-15.421	-6.649	0.000***	0.000***

Notes: Optimal lag and lead length determined by Akaike Information Criterion with maximum lag and lead length of 2. We allow for a constant and deterministic trend in the cointegration relationship. Number of bootstraps to obtain bootstrapped p-values which are robust against cross-sectional dependencies set to 100. Results for H0: No-cointegration. The Bartlett kernel window width set according to $4(T/100)^{2/9}$.Signif. codes: 0 (***) 0.001 (**) 0.01 (*) 0.05 (.) 0.1 ( ) 1

3.3 Panel ARDL estimates

Given the evidence of panel cointegration among variables, we perform the autoregressive distributed lag method (ARDL). The results of the PMG and the MG are reported in the Table 4

Table 4: PMG and MG estimations, 1990-2015

	pmg		mg	
	Long-run coefficients			
Variable	Coefficients	P-value	Coefficients	P-value
lintr	.009751	0.000***	.0331351	0.120
lre	-.0983785	0.000***	.0033076	0.995
ly	.4443937	0.000***	.2299524	0.465
	Short-run coefficients			
ec	-.28157	0.000***	-.635481	0.000***
D.lintr	-.0053152	0.202	-.0100927	0.055*
D.lre	.060539	0.378	.0728502	0.307
D.ly	.5098759	0.000***	.3167318	0.000***
Const	.5454976	0.000***	1.223106	0.000 ***
Hausman Test	1.68 (0.6406)			

Notes: ***, **, * indicate statistical significance at 1, 5 and 10 percent level of significance, respectively.

According to the Hausman test, the null hypothesis is not rejected and the selected estimation method is the pooled mean group (PMG). The PMG long-run results show that all the coefficients are significant at 1% significance level, the coefficients can be interpreted as elasticity estimates. Results indicate that 1 percent increase in Internet usage increases Electric power consumption by 0.9%. This means that Internet usage simulate electricity consumption in the long-run. The energy consumption of Internet infrastructure especially data centers and content distribution networks increases as the network access speeds grow. This energy consumption is dominated by the electricity consumption of data storage for materials that are frequently downloaded and by transporting data for hardware.

Results indicate also a negative and significant relationship between renewable energy and electricity consumption. An increase of 1 percent of renewable energy decreases electricity consumption by 9%. Indeed, most of developed countries have set voluntary targets for the reduction of pollution and global warming and attract wide attention to toward developing alternative energy sources. With the quest for environmental sustainability, electricity generation from renewable resources are becoming increasingly significant alternatives. Besides, economic growth is associated positively and significantly at 1% with the dependent variable. Specifically, an increase of 1 percent of economic growth increases electricity consumption by 44%. This suggests that the two variables are in a long-run equilibrium relationship and that economic growth leads to electricity consumption in the developed countries. It means that electric power represents one of the most important inputs for industry and production.

Considering the short-run analysis, the results of error correction show that a 1 percent increase in economic growth increases electric power consumption by 50%, at 1% level of significance. As expected, the coefficient of lagged error correction term (ec_{t-1}) is found to be negative with the value of (-0.28 < 1) and statistically significant at the 1% level of significance. It means that the error correction model is stable and confirms the presence of cointegration among the variables. In addition, the coefficient of ec_{t-1} shows that deviations from the long-run equilibrium are corrected by 28% every year. Results from DOLS estimates are reported in Table 5 which confirm the robustness of the findings of ARDL long-run estimates.

Table 5: Dynamic OLS estimation. 1990-2015

Variable	Coefficient	Prob.
LRE	-0.063053	0.0001***
LINTR	0.021621	0.0000***
LY	0.447110	0.0000***
R-squared	0.995943	

Notes: ***, **, * indicate statistical significance at 1, 5 and 10 percent level of significance, respectively.

To determinate the causal relationship between the variables, we apply the Dumitrescu-Hurlin (DH) causality test and the results are represented in the Table 6.

Table 6: Pairwise Dumitrescu Hurlin Panel Causality Tests

Sample: 1990 2015
Lags: 1

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.
LINTR does not homogeneously cause LEP	3.75130	8.42692	0.0000
LEP does not homogeneously cause LINTR	1.43254	1.00163	0.3165
LRE does not homogeneously cause LEP	4.40560	10.5730	0.0000
LEP does not homogeneously cause LRE	2.93565	5.84610	$5.E-09$
LY does not homogeneously cause LEP	2.58054	4.72392	$2.E-06$
LEP does not homogeneously cause LY	2.82058	5.49801	$4.E-08$
LRE does not homogeneously cause LINTR	2.10741	3.09625	0.0020
LINTR does not homogeneously cause LRE	2.37460	3.94054	$8.E-05$
LY does not homogeneously cause LINTR	2.50244	4.56394	$5.E-06$
LINTR does not homogeneously cause LY	6.76457	18.5068	0.0000
LY does not homogeneously cause LRE	3.69999	8.20855	$2.E-16$
LRE does not homogeneously cause LY	3.49643	7.56016	$4.E-14$

Considering the estimations from DH causality test, there is a unidirectional causality running from Intenet usage to electricity consumption. This can be interpreted that the growing number of Internet users increases energy demand especially on electricity which powering most of new technological devices. Internet usage has a bidirectional causal link with renewable energy consumption and economic growth.This imply that Internet usage increases the share of renewable energy relative to nonrenewable energy resources. Likewise, the findings show that there is a bidirectional casual relationship between renewable energy consumption, economic growth and electricity consumption, thus suggesting the presence of the feedback effect. This indicates that renewable energy consumption can play a crucial role to reduce electricity consumption from nonrenewable energy and to enhance economic growth.

4 Conclusion

Using panel data for 31 developed countries over the period 1990-2015 and performing panel autoregressive distributed lag method, we have attempt to explore the relationship between,Internet usage, renewable energy, electricity consumption and economic growth. Results from the ARDL estimates reveal that the Internet usage and economic growth have a positive and significant long-run effect on electric power consumption. Results, also suggest that renewable energy has a negative and significant effect on electricity consumption. Otherwise, only economic growth has positive and significant effect on electricity consumption in the short-run. These findings are supported by results from the Dynamic Ordinary Least Squares method (DOLS) which confirm the long-run relationship between the variables. Moreover, Dumitrescu Hurlin causality results indicates that there is a unidirectional causality running from Internet usage to electricity consumption and renewable energy and a bidirectional casual relationship between electricity consumption, renewable energy consumption and economic growth.

The findings of this study assert that both Internet usage and economic growth expand electricity consumption in the long-run. Thus, electricity in developed countries still generated from nonrenewable energy which considerably degrades the environment.However, increasing electricity demand and exhaustion problem of fossil fuels and fluctuating speculated prices lead countries to use alternative energy resources (Kumar et al. (2012),Managi and Okimoto (2013)). Nevertheless, results report that renewable energy reduces electricity consumption in the long-run. Therefore, the expansion of renewable energy would also diminish the dependence on fossil fuels energy and increases renewable electricity production.

This paper have some relevant policy implications. To meet increasing electricity demand and to mitigate pollution, developed and developing countries have to decrease energy intensity, increase energy efficiency and renewable energy use. Governments need to promote renewable electricity generation and support investments in more efficient and cleaner energies.

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