Smartphones and Environmental Sustainability: A Country-Level Analysis

Namchul Shin
Pace University, nshin@pace.edu

Jason Dedrick
Syracuse University, jdedrick@syr.edu

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SMARTPHONES AND ENVIRONMENTAL SUSTAINABILITY: A COUNTRY-LEVEL ANALYSIS

Research Paper

Namchul Shin, Pace University, New York, USA, nshin@pace.edu
Jason Dedrick, Syracuse University, New York, USA, jdedrick@syr.edu

Abstract

Research suggests that information and communication technologies (ICTs) have a nonlinear relationship with CO2 emissions, specifically an inverted U-shaped curve similar to the environmental Kuznets curve (EKC). While extant research has investigated the relationship using an ICT index, there has been no research looking at smartphones, which have been closely associated with the explosive growth in the use of mobile apps and a build-out of large information systems to support their use. To address this gap, this research examines the relationship of ICTs and smartphones with CO2 emissions by employing a country-level data set for the period from 2009 to 2014. Our results show that the relationship of ICTs with CO2 emissions takes an inverted U-shaped curve form, consistent with the EKC hypothesis. Our OLS results also show that CO2 emissions increase with spending on smartphones but decrease as smartphone spending increases further; however, these results are not consistent in fixed effects models. These findings imply that carbon emissions go up with the penetration of ICTs in poorer countries but in wealthier countries ICT penetration and smartphone spending is related to lower CO2 emissions. The results should not be taken as evidence that ICTs cannot lead to greater sustainability in poorer countries, but should be seen as a call for the IS community to help all countries apply existing knowledge and develop new knowledge to use ICTs to reduce emissions in response to the immediate challenge of climate change.

Keywords: ICT, Smartphones, CO2 emissions, Environment Kuznets Curve

1 Introduction

Concerns about the environmental sustainability of economic development have grown in recent years as the impacts of climate change have become more apparent. In 2015, the United Nations (UN) General Assembly launched the Sustainable Development Goals (SDGs) as a universal call to action to protect the planet and ensure a better and more sustainable future for all. One of the SDGs, “Climate Action,” is designed to slow global warming. According to the UN, global carbon dioxide (CO2) emissions have increased by almost 50 percent since 1990 and grew more quickly between 2000 and 2010 than in each of the three previous decades.

The relationship of information and communication technologies (ICTs) to environmental sustainability has been recognized as an important issue in information systems research for over a decade (Melville, 2010; Watson et al., 2010). Possibly the biggest concern is how ICTs impact greenhouse gas emissions (GHG) that cause climate change. Researchers have argued that the production and use of ICTs can be a source of greenhouse gas emissions, but that information systems are also a tool for reducing emissions across the economy as a whole, e.g., through smarter
management of transportation systems, buildings, electricity distribution and supply chain logistics (Dedrick, 2010).

There has been limited empirical research on the relationship of ICTs to emissions, especially at the country and cross-country levels. Some studies have found that ICT use leads to higher emissions (Lee and Brahmasrene, 2014; Khan et al., 2018), while others have found an inverse relationship with ICTs related to lower emissions (Ozcan & Apergis, 2018). Drawing on the Environmental Kuznets Curve, which states that pollution levels increase with national income levels up to a certain point, at which they start to fall, Higon et al. (2017) found evidence that the relationship takes an inverted U-shaped curve: while ICT penetration is associated with higher CO2 emissions in the early stages of ICT adoption, the curve turns downward at higher ICT penetration levels.

These studies use measures of ICT use or penetration, such as an ICT index or Internet penetration, to model impacts of ICTs. There has been no research we are aware of that focuses on smartphones, which have only been widely used since the mid-2000s, with the introduction of the iPhone and Android phones and the availability of 3G and 4G cellular networks and WiFi networks. The total number of smartphones sold worldwide grew more than tenfold, from 123 million units in 2007 to 1,471 million in 2016 (Dedrick & Kraemer, 2017).

Why might smartphones be a special case worth examining? It is partly because smartphones have put a combination of computing power and cheap mobile communications in the hands of billions of consumers, workers, and small businesses, a far greater share of the world’s population than have ever owned any kind of personal computer. The app revolution enabled by smartphones has given those individuals access to sophisticated tools supported by cloud computing, high-speed networking, and real-time data analysis. These tools inform and educate the users and intervene in their behaviors, which may lead to a reduction in energy consumption and CO2 emissions. For instance, using mapping applications lets people plot faster routes in response to traffic conditions, saving gasoline that would be consumed idling in traffic. Ride sharing apps make more efficient use of vehicles and reduce the need for urban parking space.

On the other hand, the availability of smartphone apps may have a boomerang effect, encouraging people to drive more often, knowing they can more easily avoid traffic. They also may encourage inefficient shopping patterns such as making many small online orders rather than consolidating (“free delivery”). Ride sharing apps may increase traffic as drivers circle waiting for riders to appear.

The data centers that support smartphone apps create significant demand for electricity, potentially increasing emissions. But in the past decade, their energy use has stabilized even as demand for computing, storage and networking has grown exponentially, thanks to the shift to highly efficient cloud-based data centers (Masanet et al., 2020).

A key question we raise for this research is, “What relationships do ICT penetration and smartphone spending have with the levels of CO2 emissions across countries?” In order to address this question, we examine the relationship between ICTs, smartphones, and CO2 emissions by employing a country-level data set for the period from 2009 to 2014. We examine whether there are different relationships for ICT penetration and smartphone spending and what form they take across different levels of wealth.
2 Theoretical Background

2.1 Environmental Kuznets Curve

The Kuznets Curve hypothesizes that as an economy develops, income inequality first increases and then decreases with income (Kuznets, 1955). The Environmental Kuznets Curve (EKC) model postulates a similar relationship for economic growth and pollution: pollution per capita initially worsens as an economy develops but then turns downward at a certain level of national income. The logic is that economic growth tends to involve environmentally harmful industrialization in the initial stages, but over time, economies shift to less-polluting services, and new technologies and more sophisticated production methods may reduce pollution levels (Dinda, 2004; Stern, 2004, Ghosh and Yamarik, 2006; Aslanidis, 2009; Selhofer et al., 2010). The empirical evidence for the EKC is mixed, with some researchers finding evidence to support the hypothesis and others finding no evidence. Results for multi-country studies differ depending on the sample of countries and years covered, the type of emission being studied, and econometric methods used to model the relationship (Hove & Tursoy, 2019).

2.2 ICTs, Smartphones, and Environmental Sustainability

In recent years, there has been interest in studying the impacts of ICTs on the environment. In a study of 142 countries over 15 years, Higon et al. (2017) found that the relationship of ICT use to CO2 emissions takes an inverted U-shaped curve, increasing at lower levels of ICT adoption, then decreasing at higher levels. This finding is consistent with the EKC, with an index of ICT penetration replacing national income level as the key factor in the model. The results hold up even with GDP per capita included as a control variable, so the authors do not just see the impacts of differences in income levels. In a smaller study of 20 developing countries, Ozcan and Apergis (2018) found a negative relationship of Internet use with CO2 emissions, while a study of 23 European Union countries found Internet use had a positive relationship with CO2 emissions, lowering environmental quality (Park et al., 2018). Given the limited availability of studies on ICTs and CO2 emissions, there is still a need for additional empirical research on different measures of ICT adoption and emissions.

Among the various types of ICTs, smartphones are now the primary computing device for most people and can be seen as potentially responsible for increasing CO2 emissions related to ICTs, including massive data centers that support mobile computing (Suckling and Lee, 2015; Kuntsman and Rattle, 2019; Masanet et al., 2020). However, as economies advance, more environmentally friendly production methods and inputs can reduce emissions. More efficient resource management enabled by ICTs, e.g., eco-efficiency of energy consumption and cloud computing, can also make a greater reduction in emissions (Suckling and Lee, 2015; Kuntsman and Rattle, 2019).

Research shows that smartphones allow users to monitor and control energy consumption (Weiss et al., 2012) and drivers to receive eco-driving feedback, which may change their driving styles to improve fuel efficiency (Tulusan et al., 2012; Hermsen et al., 2016). Brauer et al. (2016) argue that smartphone apps can contribute to environmental sustainability by improving efficiency and reducing CO2 emissions. The higher penetration of smartphones has contributed to ubiquitous access to information and enabled various tools that can intervene users’ behaviors to help sustain the environment (Tulusan et al., 2012; Brauer et al., 2016; Hermsen et al., 2016).

Based on the EKC hypotheses and the previous research on ICTs and environmental sustainability, we might expect that CO2 emissions increase with ICT and smartphone penetration, but CO2 emissions would eventually fall at higher levels of penetration. In other words, the relationship takes an inverted U-shaped form. We model the relationship of ICT to CO2 emissions, and smartphones to emissions independently and then in a single model. We control for a number of factors found to influence CO2
emissions in other studies (e.g., Higon et al., 2017), such as income levels, industrialization, education, oil reserves, and effective governance.

3 Data Sources

This research employs two main data sources: 1) World Development Indicators (WDI), World Bank’s cross-country data on development and 2) International Data Corporation (IDC) mobile phone shipments data. The IDC data contains mobile phone shipments data for 86 countries, including smartphones. The data used for this research include 79 countries, splitting into 39 developed countries and 40 developing countries for the six years from 2009 to 2014. From the WDI, the following data are obtained: data on CO2 emissions (metric tons per capita), GDP per capita in purchasing power parity (PPP) at constant 2011 international dollars, population density, the share of value-added from industry, school enrollment, as well as ICT data, such as the number of fixed telephone subscriptions per 100 people, percentage of individuals using the Internet, and fixed broadband subscriptions per 100 people. An ICT index is constructed by taking the average scores of the three ICT indicators.¹

We also obtain data on oil reserves from the U.S. Energy Information Administration. We obtain governance data from the Worldwide Governance Indicators, such as government effectiveness, the rule of law, control of corruption, political stability, regulatory quality, and voice and accountability. We use the principal component analysis technique to construct a governance (or institutional) index from these six indicators. As a measure of smartphone spending, we use the value of total shipments for smartphones (revenue paid to vendors including channel mark-ups) per capita in U.S. dollars. We use market rates rather than PPP since smartphones are traded internationally, and there is no need to make adjustments for PPP (Shih, Dedrick, and Kraemer, 2007). The variables included in the analysis are shown in Table 1.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>Carbon dioxide (CO₂) emissions in metric tons per capita</td>
<td>WDI (World Bank)</td>
</tr>
<tr>
<td>ICT</td>
<td>Three components were used to construct the ICT index: the number of fixed telephone subscriptions per 100 people, percentage of individuals using the Internet, and fixed broadband subscriptions per 100 people</td>
<td>WDI (World Bank)</td>
</tr>
<tr>
<td>Smartphone</td>
<td>Value of shipments per capita (in USD Million)</td>
<td>IDC</td>
</tr>
<tr>
<td>GDP</td>
<td>GDP per capita, PPP (constant 2011 international S)</td>
<td>WDI (World Bank)</td>
</tr>
<tr>
<td>Industry Share</td>
<td>Share of value added from the industry (% of GDP)</td>
<td>WDI (World Bank)</td>
</tr>
<tr>
<td>Population Density</td>
<td>Population per square km of land area</td>
<td>WDI (World Bank)</td>
</tr>
<tr>
<td>Sch. Enroll, Primary</td>
<td>School enrollment, primary (% gross)</td>
<td>WDI (World Bank)</td>
</tr>
<tr>
<td>Sch. Enroll, Secondary</td>
<td>School enrollment, secondary (% gross)</td>
<td>WDI (World Bank)</td>
</tr>
<tr>
<td>Sch. Enroll, Tertiary</td>
<td>School enrollment, tertiary (% gross)</td>
<td>WDI (World Bank)</td>
</tr>
<tr>
<td>Oil Reserves</td>
<td>Crude oil reserves (Billion Barrels)</td>
<td>U.S. Energy Information Administration</td>
</tr>
<tr>
<td>Governance</td>
<td>Six components were used to construct the governance index: government effectiveness, rule of law, control of corruption, political stability, regulatory quality, and voice and accountability</td>
<td>Worldwide Governance Indicators (WGI)</td>
</tr>
</tbody>
</table>

¹ The ICT (penetration) index does not include mobile cellular phone subscriptions per 100 people (WDI) since the study employs the smartphone shipments variable separately. It is different from a previous ICT index used by Higon et al. (2017), which included mobile cellular phone subscriptions per 100 people. The indicator of PC owners per 100 inhabitants is also not incorporated into the ICT index since its data are not available from WDI any longer.
Notes: ICT index is the average of three components; The governance index is derived from the principal component analysis of six components; School enrollment is % gross (regardless of ages); Industry share is % of GDP.

**Table 1. Variables.**

Table 2 shows sample statistics for the full sample, developed countries, and developing countries.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Full Sample</th>
<th>Developed Countries</th>
<th>Developing Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean(^1) (St. Dev.)</td>
<td>Obs.(^2)</td>
<td>Mean (St. Dev.)</td>
</tr>
<tr>
<td>CO(_2) per capita</td>
<td>6.97 (6.87)</td>
<td>462</td>
<td>10.90 (7.55)</td>
</tr>
<tr>
<td>ICT index</td>
<td>32.40 (17.18)</td>
<td>695</td>
<td>46.38 (10.41)</td>
</tr>
<tr>
<td>Smartphone values per capita</td>
<td>83.85 (95.89)</td>
<td>644</td>
<td>134.18 (105.18)</td>
</tr>
<tr>
<td>GDP per capita</td>
<td>27,152.09 (20,950.63)</td>
<td>772</td>
<td>43,361.19 (18,223.38)</td>
</tr>
<tr>
<td>Industry Share</td>
<td>29.40 (10.88)</td>
<td>757</td>
<td>29.57 (13.89)</td>
</tr>
<tr>
<td>Population Density</td>
<td>352.10 (1,147.57)</td>
<td>780</td>
<td>569.13 (1,604.67)</td>
</tr>
<tr>
<td>Sch. Enroll, Primary</td>
<td>103.59 (6.93)</td>
<td>614</td>
<td>102.05 (5.15)</td>
</tr>
<tr>
<td>Sch. Enroll, Secondary</td>
<td>95.41 (21.72)</td>
<td>559</td>
<td>107.18 (16.68)</td>
</tr>
<tr>
<td>Sch. Enroll, Tertiary</td>
<td>52.95 (25.14)</td>
<td>523</td>
<td>67.73 (19.67)</td>
</tr>
<tr>
<td>Oil Reserves</td>
<td>15.48 (48.01)</td>
<td>769</td>
<td>19.32 (54.24)</td>
</tr>
<tr>
<td>Governance (normalized)</td>
<td>.50 (.20)</td>
<td>780</td>
<td>.66 (.15)</td>
</tr>
</tbody>
</table>

\(^1\) The average of all observation for 2009-2014.

\(^2\) The number of observations varies due to the availability of data for the sample countries.

**Table 2. Sample Statistics (2009-2014).**

### 3.1 Data Exploration

Before presenting an analytical model incorporating the inverted U-shaped form, we explore the data to see if such a functional form is evident for both ICT and smartphones. We employ locally estimated scatter plot smoothing (LOESS) for the analysis. Our exploratory analysis shows that the relationship of both ICT index and smartphones to CO\(_2\) emissions takes the inverted U-shaped curve form over income levels (GDP), consistent with the EKC hypothesis. These findings suggest that CO\(_2\) emissions increase with ICT penetration and smartphone use, along with economic growth, but the levels of CO\(_2\) emissions are eventually lowered as ICT penetration and smartphone use increases further.

Figure 1 shows the relationship between smartphone (total shipment values per capita) and CO\(_2\) emissions (metric tons per capita) across developed and developing countries (a sample of 79 countries) in the periods of 2009-2014. The figure illustrates that smartphone investment increases with carbon emissions in developing countries, but emissions start to decrease once smartphone investment has reached a threshold level in developed countries. Overall, the figure shows that carbon
emissions increase first and then decrease as smartphone investment increases. The relationship between ICT index and CO2 emissions shows a similar pattern (Figure 2). What is notable is that the uphill slope of the inverted U-shaped curve for smartphones is steeper than the curve for the ICT index. This pattern implies that the rate of growing carbon emissions is faster in the early stages of smartphone development, compared to the rate of decreasing carbon emissions in the later stages.

Figure 1.  
CO2 emissions per capita and smartphone values per capita in developing (in blue) and developed countries (in red): Curve generated with Locally Estimated Scatterplot Smoothing (LOESS) (2009-2014).
4 Methodology and Model

Our regression model analyzes the relationship of CO2 emissions to smartphones and ICT and their squared terms. The model also includes GDP per capita and its squared term as well as other control variables. We apply log transformation on CO2 emissions, smartphones, GDP, and oil reserves since the data scales of these variables are different from the other variables, which are measured in ratios or indexes. We conduct both ordinary least-squares (OLS) and fixed effects (FE) regressions since OLS yields biased results in the presence of unobserved heterogeneity. Either a random-effects model or fixed-effects model could be used to obtain consistent results. However, if country-specific effects are correlated with the explanatory variables, the estimates of the random effects will be biased and inconsistent. The appropriateness of the fixed effects model is tested using the Hausman test.

We also conduct the Pesaran (2004) test for cross-sectional dependence and reject the null hypothesis of cross-sectionally independent residuals for all the explanatory variables estimated with standard fixed effects. Cross-sectional dependence may be important because the behavior of all other countries is likely to influence a single country’s behavior in terms of CO2 emissions. Such dependence will usually not affect the consistency of the parameter estimates but will affect the standard errors used for inference (Eberhardt, 2009). We, therefore, estimate the model with Driscoll and Kraay (1998) standard errors, which are heteroscedasticity-consistent and robust to any general form of cross-sectional and temporal dependence (Hoechle, 2007). The following is our main regression model.

\[
\ln C_t = \beta_0 + \beta_1 \text{ICT}_t + \beta_2 \text{ICT}^2_t + \beta_3 \ln \text{SP}_t + \beta_4 (\ln \text{SP})^2_t + \beta_5 \ln \text{GDP}_t + \beta_6 (\ln \text{GDP})^2_t + \alpha X_t + \mu_i + \gamma_t + \varepsilon_t
\]

where the subscripts i and t refer to country and year respectively.
\[ \text{LnC}_i: \text{log transformation of CO2 emissions per capita} \]
\[ \text{ICT}_{it}: \text{ICT index} \]
\[ \text{ICT}^2_{it}: \text{a square term of ICT index} \]
\[ \text{LnSP}_{it}: \text{log transformation of smartphone value per capita} \]
\[ (\text{LnSP})^2_{it}: \text{a square term of LnSP} \]
\[ \text{LnGDP}_{it}: \text{log transformation of GDP per capita} \]
\[ (\text{LnGDP})^2_{it}: \text{a square term of LnGDP} \]
\[ X_i: \text{a vector of other covariates} \]
\[ \mu_i: \text{country-specific effects} \]
\[ \gamma_t: \text{year-specific effects} \]
\[ \varepsilon: \text{error term} \]

C stands for CO2 emissions per capita. ICT and ICT\(^2\) stand for an ICT index and its square term. SP and SP\(^2\) stand for smartphone value per capita and its square term. GDP and GDP\(^2\) stand for GDP per capita and its square term. X refers to a vector of other covariates\(^2\), such as school enrollments (tertiary, secondary, and primary), the share of industry value-added, population density, oil reserves, and governance. In order to control for the country- and year-specific effects, dummy variables for each country (\(\mu\)) and year (\(\gamma\)) are included.

Based on the inverted U-shape relationship between the variables, we expect \(\beta_1 > 0\), \(\beta_2 < 0\), \(\beta_3 > 0\), and \(\beta_4 < 0\): CO2 emissions increase as ICT and smartphone investments increase, but after a certain threshold level of ICT and smartphone investments, CO2 emissions may decline. We also expect \(\beta_5 > 0\) and \(\beta_6 < 0\): The EKC model depicts that CO2 emissions increase with economic development up to a certain level, but they decrease as the economy further develops beyond the threshold level.

5 Results

Our OLS regression results (Table 3) confirm the hypothesis for ICT: its relationship with CO2 emissions has an inverted U-shape form. The estimated turning points for ICT are 39.90-51.95, which is above the average level of ICT for the full sample, 32.40. These results imply that countries attaining this level of ICT development may experience reduced CO2 emissions by additional advances in ICT. The OLS regressions for smartphones show similar results (Model 2): smartphones and CO2 emissions have an inverted U-shaped relationship. The estimated turning points for smartphones are 98.52, which is also above the averages of smartphone values per capita, 83.85. However, the FE regressions do not show significant results for smartphones. These findings suggest that the OLS results might be driven by some underlying country-specific fixed effects that are controlled in the FE. However, the small sample size might be the reason for the smartphone results since it could influence the power and precision of the FE regression analysis (Pandey and Bright, 2008; Walker, 1940). The sample data period (2009-2014) may not be long enough as a substantial amount of smartphone investment had not been made to have a significant impact on emissions.

\(^2\) Unlike the previous model (Higon et al., 2017), our model does not include the number of passenger cars per 1000 inhabitants since there are many missing data for countries. It also doesn’t include the Kyoto Protocol since it was ratified in 1997; most countries were ratified in the early years, but it appears its impact is not significant any longer.
Looking at control variables, tertiary education appears to be positively associated with CO2 emissions in all FE models, while primary education is negatively related to CO2 emissions. Governance is negatively associated with CO2 emissions in OLS models, suggesting that effective governance is vital to achieving lower emissions and may be a necessary condition for ICTs and smartphones to have a significant impact on emissions.

\[ \text{Table 3. OLS and Fixed Effects Regression Results for CO2 Emissions.} \]
Our findings are consistent with the data exploration results illustrated in Figure 1: carbon emissions start to decrease once ICT penetration has reached threshold levels. Below those levels, the relationship is the opposite: ICT penetration is associated with higher levels of emissions. In other words, carbon emissions go up with ICT use in poorer countries, as they are also probably moving towards industrialization, while in richer countries that are more service-oriented, ICT and smartphone use are associated with greater energy efficiency and emission reduction.

6 Conclusion

Global warming is fueled by increasing greenhouse gas concentrations and ongoing emissions and has impacted human lives and the environment. The historic Paris Agreement entered into force on November 4 in 2016, to strengthen the global response to the threat of climate change by keeping a global temperature rise in the 21st century well below 2 degrees Celsius and pursuing efforts to limit the temperature increase even further to 1.5 degrees Celsius (UN, 2020). However, the chance of reaching that goal is slipping away. The growth in CO2 levels in the atmosphere shows no signs of falling.

In recognition of the grand challenge of global climate change, this research empirically examines the impacts of ICT and smartphones on CO2 emissions. This research contributes to the literature by modeling the relationships of ICT penetration and smartphone investment with CO2 emissions and analyzing them across countries at a range of income levels for 2009-2014.

Our findings are consistent with the EKC hypothesis and previous research using a similar ICT index.3 The results show that CO2 emissions increase with the use of ICTs at lower levels, but the levels of CO2 emissions are eventually lowered with further increases in the adoption of ICTs. These findings suggest that the relationship creates an inverted U-shape across countries.

The results for ICTs are valuable in that the empirical validity of the EKC has been questioned, and the relationship of ICTs to sustainability has not been tested beyond a few studies. Finding evidence of the EKC for ICT penetration over a range of developing and developed countries is an important contribution.

From a practical point of view however, the promise that ICT investment is likely to eventually lead to reduced carbon emissions as countries reach a turning point in overall penetration is not as reassuring. The climate challenge is imminent and there is no time to simply wait for economies to evolve and ICT use to mature. If ICTs are going to achieve their potential in reducing carbon emissions, it will require intentional effort and effective policies in all countries. As poorer countries develop economically, they will need to emphasize policies and practices that support sustainability as well as growth. Fortunately, unlike even a decade ago, the cheapest energy sources today are often renewables, and there is a wealth of knowledge available in improving the carbon productivity of manufacturing, transportation, buildings, agriculture, and other sectors of the economy. These all involve effective use of ICTs (Watson et al., 2010; Dedrick 2010), and in many cases are already economically viable and practically applicable. There is no need to wait for the inverted U-curve to turn downward—ICTs can bend the curve downward across all economies now.

We recognize the challenge for environmental sustainability is that it involves not just technical but social or institutional issues. It is described as a social dilemma problem by Ostrom et al. (2002). A

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3 The present research uses a more recent data set and partially confirms the findings of Higon et al. (2017) that used a data set for 1995-2010.
preserved environment is a common good that benefits every individual. However, to achieve sustainability, cooperation is required and cooperation comes at individual costs often provoking noncooperative behavior (Spaiser et al., 2019). While people are environmentally concerned and monitor their behaviors, they do not necessarily act in ways that are environmentally friendly. Also, much of the behavior that affects carbon emissions occurs at an organizational scale. Therefore, it is crucial to make changes in institutions as well, which would influence behaviors, habits, norms, and practices of individuals and organizations.

ICTs can play a role if used to improve energy efficiency across the economy and integrate more carbon-free energy sources. Smartphones and energy-management apps can be useful in providing individuals with timely information and tools to reduce emissions, such as shifting energy use to times when more renewable energy is available or using public transportation (with the help of real-time information on schedules), or buying products with greener supply chains.

It is clear that the greatest need is in developing countries, where ICT use is associated with higher emissions. The EKC is not a physical law, nor is it a reason for inaction; rather it is the result of human decisions and actions, and thus can be changed. International agencies and socially-conscious companies could assist developing countries in applying knowledge and lessons learned in richer countries, and also provide financial resources to implement that knowledge without waiting for countries to reach higher levels of income and ICT use.

This research is not free from limitations: its sample size is small, and the sample covers relatively a short period for certain variables, such as CO2 emissions. Thus, it would be interesting for future research to replicate our research employing a data set with more recent years. With more data, it would be meaningful to do separate analyses for developed and developing countries to examine the first-order effects of ICT penetration and smartphone use in a range of economies. Endogeneity might be a problem in the regression analysis. With more data, future research may also address the endogeneity issue using an instrumental variable estimation technique.

References


