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Will Information and Communication Technology Developments Keep up with the Global Goals of Reducing Carbon Emissions?

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Introdução

Research suggests that ICTs can help tackle the challenges of global warming. But ICTs also pollute throughout their lifecycle. These two-way impacts lead to what is called the ICT paradox. Studies investigate the balance between these impacts and suggest there is a threshold in the overall carbon emission curve where ICTs start contributing to reducing pollution, which occurs after a country achieves a mature state of ICT infrastructure and economy. This phenomenon is known as the inverted U-shaped relationship between ICTs and CO2 emissions and is founded on the EKC theory.

Problema de Pesquisa e Objetivo

What also has an inverted U-shape curve is the current global goal of reducing the total CO2 emissions by 76% by 2030 before global warming reaches a point where no mitigation measures will produce significant effects anymore. This restriction poses challenges to ICT developments, which leads us to raise the following question: can the inverted U-shaped relationship between ICTs and CO2 emissions keep up with the current global goal of reducing carbon emissions?

Fundamentação Teórica

The reasoning behind the EKC theory is that accelerating economic growth will achieve higher world output and better ways of protecting the environment. In other words, some damage to the environment is necessary before achieving sustainable growth. Therefore, according to this theory, at some point in time, environmental degradation will stop increasing and start decreasing due to advancements in technology and income. Research suggests this theory holds for ICT development as well.

Metodologia

We developed an ICT index consisting of the percentage of a few ITU’s indicators. The index reflected the overall percentage of the spread of ICTs. Next, we used panel data from institutions such as the World Bank and the UNECE to estimate a mathematical model associating ICT with CO2 emissions, thus finding the threshold. Then, we estimated the global annual rate of ICT development and forecasted when countries will reach the threshold. We compared both curves to see whether the current pace of ICTs developments worldwide keeps up with, forges ahead of, or lags, the UN's goals.

Análise dos Resultados

Global ICT development advances 2.3% annually but at the country level it can range from as small as .1% to as large as 7.2%. If countries’ ICT development advances at global pace, their current ICT index must be .27, considering the best-case scenario in which the threshold between CO2 emissions and ICT development is at .46. Based on our data, global levels of ICT development can keep up with the Global Goals and most of the developed countries have already reached it. Developing countries need to progress at a higher pace than the global pace or they will not reach the peak by 2030.

Conclusão

Previous estimates in the literature suggested that countries achieve the threshold level between ICT and CO2 emissions when the percentage of the spread of ICT is about .30. Here we have found that the threshold does not occur before .49. Experts on the EKC of ICT claim the curve is inverted U-shaped but our study suggests that it may perhaps be N-shaped. The world average annual rate of ICT development is 2.3% but varies largely across countries. At this pace, not every country will be able to reach the threshold by 2030.

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Palavras Chave

Sustainable Development Goals, ICT development, Carbon emission

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WILL INFORMATION AND COMMUNICATION TECHNOLOGY DEVELOPMENTS KEEP UP WITH THE GLOBAL GOALS OF REDUCING CARBON EMISSIONS?

INTRODUCTION

Global warming has pushed the world into coming up with alternatives to the way that societies are organized. Changes in lifestyles, production systems, water, energy and food consumption, to name just a few, are required if we want the average increase in global temperature to remain below 2°C (Peters et al., 2013; United Nations [UN], 2015; Williams et al., 2021). Scholars of all disciplines, the information systems (IS) field included, have been discussing such alternatives and proposing solutions. Most have argued that information and communication technologies (ICTs) play a key role in helping tackle the challenges involved in such necessary and urgent changes (Watson et al., 2021).

Indeed, there is empirical evidence that ICTs help reduce carbon emissions (Chen et al., 2019; Ulucak et al., 2020). However, it is also true that ICTs contribute to carbon emissions throughout their lifecycle (Hilty & Bieser, 2017; Malmodin & Lundén, 2018). These two-way impacts lead to what is called the ICT paradox (Qureshi, 2019). Therefore, scholars currently investigate the balance between these impacts and studies suggest there is a threshold in the carbon emission curve where ICTs stop contributing to pollution and start contributing to reducing it, which occurs after a country achieves a mature, developed country-like state of ICT infrastructure and economy (Higón et al., 2017).

This phenomenon is known as the inverted U-shaped relationship between ICTs and carbon dioxide (CO_2) emissions and is founded on the environmental Kuznets curve (EKC). The evidence of this relationship has been reported in several studies (Higón et al., 2017; Shahnazi & Shabani, 2019; Ulucak et al., 2020). However, what also has an inverted U-shape curve is the current global goal of reducing the total CO_2 emissions by 76% by 2030 before global warming reaches a point where no mitigation measures will produce significant effects anymore (Friedlingstein et al., 2011; UN, 2020, 2021).

This restriction poses challenges to ICT developments. On the one hand, ICT artifacts should continue to spread because of their potential to promote individuals, societies, and economies. On the other hand, efforts must be put to diminish substantially not only the CO_2 emissions caused by the ICTs themselves – which are currently estimated to be about 3–3.6% of the global carbon emissions (Belkhir & Elmeligi, 2018) – but also the overall emissions.

Given that the Global-Goals curve has a strict deadline whereas the ICTs- CO_2 curve has only conceptual definitions that are highly dependent on investments, government actions, and public policies, in addition to having no deadline, we raise the following question: can the inverted U-shaped relationship between ICTs and CO_2 emissions keep up with the current global goal of reducing carbon emissions?

To answer this question, in this study we used panel data from the International Telecommunication Union (ITU, 2022) and the World Bank (2022) to estimate mathematical models and compare both curves to investigate whether the current pace of ICT developments worldwide keeps up with, forges ahead of, or lags, the UN's goal. In the latter case, we then estimated how much the pace should be so that countries reach the threshold faster. The results can offer valuable contributions to the understanding of the EKC dynamics in the ICT field, in addition to having practical implications for industries designing sustainable ICTs and targeting potential markets, and for governments promulgating regulations, promoting economic growth, and designing public policies.

THEORETICAL FRAMEWORK

Global warming, climate change, and the UN's Global Goals

Global warming is caused by increased levels of pollutants in the atmosphere, namely, greenhouse gases (GHG). Lovelock (2010) said in his controversial book that the evidence of global warming is threefold: (i) the sea-level rise (Rahmstorf, 2007), because water expands on heating; (ii) the melting of Arctic ice, which had its area reduced by 60% in less than three decades; and (iii) the decline of marine algae population caused by the increase in the barren area of the ocean (Polovina et al., 2008).

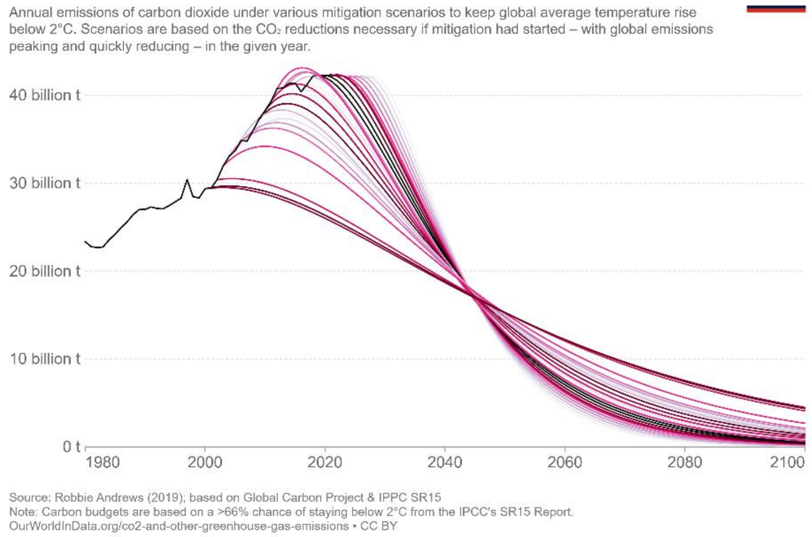
Since the discovery of the Ozone hole in the 1980s caused by the emissions of chlorofluorocarbons (CFCs), the international community has debated the human impacts on the environment and has presented several proposals to mitigate these impacts. The initiatives led to many International Environmental Agreements known as the UNFCCC (Framework Convention on Climate Change), such as the conference held in Rio de Janeiro in 1992, the Kyoto Protocol set in 1997, and the Paris Agreement reached in 2015 and signed by 197 countries (European Commission, 2021).

The Intergovernmental Panel on Climate Change (IPCC) has been the main body responsible for reporting scientific information on climate change. Without losing sight of the fact that their climate estimates are considered by the scientific community to be very conservative, the IPCC claims that, in order to avoid serious consequences of global warming, global temperature rise must be kept below 2°C throughout this century (UN, 2015, 2021) and the most important way of doing so is by reducing carbon emissions.

Fig. 1 shows the limits of CO_2 emissions needed to keep global temperature rise below 2°C. The turning point must be reached in this decade, which makes the decade decisive for achieving the goal, considering a >66% chance of falling below 2°C (Knutti & Hegerl, 2008; UN, 2021). Ironically, ten years ago Friedlingstein et al. (2011) estimated that considerable efforts would be necessary to reduce CO_2 emissions by 5% p.a. if mitigations started at that time. History shows that, four years later, what occurred was that the mitigation rate had to be readjusted to the current 7.6% p.a.

Figure 1

CO_2 reductions needed to keep global temperature rise below 2°C



Annual emissions of carbon dioxide under various mitigation scenarios to keep global average temperature rise below 2°C. Scenarios are based on the CO_2 reductions necessary if mitigation had started – with global emissions peaking and quickly reducing – in the given year.

Source: Robbie Andrews (2019); based on Global Carbon Project & IPPC SR15
Note: Carbon budgets are based on a >66% chance of staying below 2°C from the IPCC's SR15 Report.
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions • CC BY

Source: Our World in Data (2022).

Carbon emissions are also associated with economic growth (Grossman & Krueger, 1995). Hence, not only countries will need to cut carbon emissions to keep the Earth system stable (Steffen et al., 2015) but they will also need to look for alternative and sustainable energy sources to support their growth. This poses greater challenges mainly to low-income economies, which do not have the same resources and conditions that developed economies do. That is why the UN and the Paris Agreement also bring to the discussion the inequality of carbon emissions per capita. According to the UN's Emissions Gap Report (UN, 2020), the richest countries in the world (which represents only 1% of the total) need to reduce their current emissions thirtyfold or so by 2030 while the poorest 50% can rather increase their current levels threefold during the same period.

This means that there is still room for underdeveloped and developing countries to grow and develop in all spheres of economy, production, and society, as long as the goal of reducing global carbon emissions is kept on track and the turning point is reached by 2030. Among these developments, the ICT development field is of particular interest to this study, given the relevance that ICTs have to all spheres.

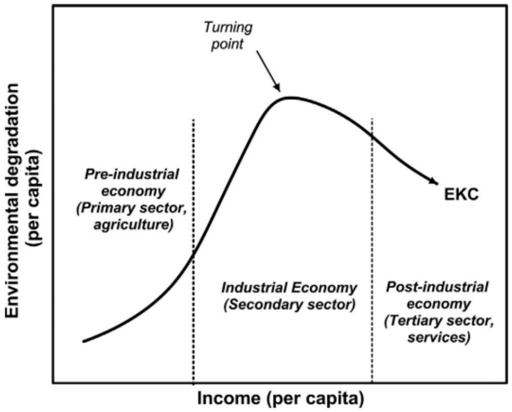
The EKC theory in the ICT context

Although conceived in 1955 by Simon Kuznets (1955), the EKC theory became popular in the 1990s from the discussion of the negative effects of economic growth on the environment. From that onward, economic discussions changed from 'the exhaustion of natural resources and environmental degradation to issues concerning the necessity of economic growth to overcome environmental deterioration and pollution' (Kaika & Zervas, 2013, p. 1392).

The reasoning behind the EKC theory is that accelerating economic growth will achieve higher world output and better ways of protecting the environment (Ekins, 1993; Kaika & Zervas, 2013). In other words, some damage to the environment is necessary before achieving sustainable growth. Therefore, according to this theory, at some point in time environmental degradation will stop increasing and start decreasing due to advancements in technology and income. When plotting this progression on a chart, one obtains the inverted U-shape curve depicted in Fig. 2.

Figure 2

An environmental Kuznets curve



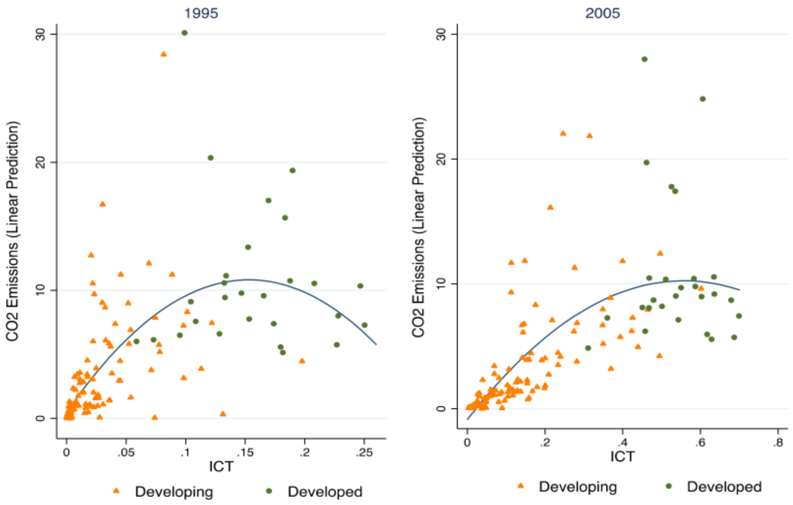
Source: Kaika and Zervas (2013, p. 1394).

The EKC hypothesis has been tested in varied studies, such as oil exploitation (Esmaeili & Abdollahzadeh, 2009), income inequality (Grunewald et al., 2017), electricity production and consumption (Jiang et al., 2021), economic complexity (Pata, 2021), e-waste (Boubellouta & Kusch-Brandt, 2020), and ICT development (Ulucak et al., 2020). In Fig. 3 we see Higón et al.'s

(2017) EKC projection for ICTs. The *x*-axis represents the ICT index, which consists of the combination of two stages of ICT development: ICT readiness and ICT use and intensity.

Figure 3

CO_2 emissions and ICT in developing and developed countries



Note. The *x*-axis represents the ICT Index and was constructed by combining: (i) the number of fixed telephone subscribers per 100 inhabitants lines, (ii) mobile cell phone subscribers per 100 inhabitants, (iii) PC owners per 100 inhabitants, (iv) percentage of individuals using internet and (v) fixed-broadband subscribers per 100 inhabitants. Source: Higón et al. (2017, p. 90).

In the IS field, the inverted U-shaped relationship between ICT and CO_2 emissions has been widely confirmed (Chen et al., 2019; Shahnazi & Shabani, 2019; Ulucak et al., 2020), although it does not seem to hold across all levels of ICT consumption. For example, Park et al. (2018) found that the EKC hypothesis does not apply to Internet use, at least in the European Union (EU) context. Notwithstanding these limitations and some inconsistence, by and large the conclusions are that ICT does play a key role in countries' development and pays off its environmental degradation as time goes by.

At this point it is important to distinguish research that investigates the relationship between ICTs and the overall CO_2 emissions from research on the CO_2 emissions of ICTs specifically (e.g., Andrae & Edler, 2015; Belkhir & Elmeligi, 2018; Malmodin & Lundén, 2018). The latter is concerned with the environmental impact of ICTs throughout their life cycle, regardless of whether they contribute or not to mitigating CO_2 emissions.

Still, there are some insights from that field of research that are worth considering, notably the argumentation about the importance of covariates in the estimation models to assure robustness (Torras & Boyce, 1998) and the warning that the composition of what can be understood as ICT artifacts and ICT-related pollutants is equally important because, otherwise, conclusions can be misleading. For example, Belkhir and Elmeligi (2018) claim that the carbon emissions of smartphones have been nearly completely neglected in the literature even though they comprise 11% of the total ICT contribution to GHG emissions, which the authors estimate to be around 2,000 metric tonnes of carbon dioxide equivalent (Mt- CO_2-eq).

To conclude, the ICT-EKC literature indicates that countries achieve a turning point in carbon emissions after they become developed, which Higón et al. (2017) predicted to be at an ICT development index of about 0.30. However, despite the large number of studies investigating the

EKC between ICT and CO_2 emissions, the concern with a deadline for reaching the turning point has not been emphasized. We of course acknowledge that setting a deadline for ICT development is not simple because many countries, especially the least developed ones, face several difficulties of all matters, such as low human development index (HDI), social inequalities, violence, poor infrastructure, and political issues. These restrictions not only severely prevent them from focusing on one dimension or another but also force them to fight on many fronts simultaneously.

Nevertheless, this does not change the fact that a race against time is going on and a bold goal needs to be achieved. Therefore, beyond estimating the relationship between ICT and carbon emission, it is necessary to estimate what pace each country is at and how long it will take for a given country to reach the turning point considering its pace.

The hypothesis here is that not all countries can meet the global carbon emission reduction deadline, and, as far as we can tell, this hypothesis has not been tested yet. One way of testing it could be by comparing the curves shown in Fig. 1 and 2. At first glance, because the horizontal axes of the figures are not on the same scale, comparisons cannot be made. However, this can be overcome by converting the ICT index into an annual rate of progress and estimating such an annual rate with historical data, for example, the ITU's or World Bank's. That is precisely what this study does.

RESEARCH METHOD

CO_2 emission as pollution indicator

Carbon dioxide emission has become a common metric for macroeconomic studies addressing sustainability, both inside and outside of the ICT field, and is recommended when associating ICTs with the environment (Higón et al., 2017; Melville, 2010). The metric is so common that experts and international organizations such as the Organisation for Economic and Co-operation Development (OECD) and the IPCC have developed indicators that convert GHG emissions into carbon dioxide equivalent.

The OECD (2020a) claims that data on GHG emissions are more comparable across countries. However, data on CO_2 emissions are more consistent in the overall databases because the data are available from a larger number of countries and cover more uninterrupted years, usually from 1990 onward. Besides, each gas that contributes to global warming has a CO_2 equivalent (Melville, 2010). Therefore, we use metric tonnes of CO_2 emission per capita as our dependent variable.

ICT index

For the purposes of this study we stem from Higón et al.'s (2017) work in terms of considering the spread of ICT as a factor that contributes (or not) to reducing CO_2 emissions. In this sense, we use some of the ITU's (2021) indicators of ICT access and usage. These indicators consist of the percentage of ICT access and usage by individuals from nearly 200 nations.

We then estimate the ICT index by averaging the percentages of (i) internet users, (ii) fixed-telephone subscriptions per 100 inhabitants, (iii) mobile-cellular subscriptions per 100 inhabitants, and (iv) fixed-broadband subscriptions per 100 inhabitants, from 2007-2020.

Data acquisition and mathematical models

This study used the most recent datasets available on the ITU (2022), the OECD (2020b), the World Bank (2021, 2022), the United Nations Economic Commission for Europe (UNECE, 2022), NationMaster (2019), and BP Statistical World Energy (2021) websites regarding global carbon emission by country plus variables and covariates that participate in CO_2 emissions, such as population density (Grunewald et al., 2017), income per capita (Grossman & Krueger, 1995), oil reserves (Esmaeili & Abdollahzadeh, 2009), electricity consumption (Belkhir & Elmeligi, 2018; Jiang et al., 2021) and the number of passenger cars per 1,000 inhabitants (Higón et al., 2017).

Besides, throughout the years many countries have changed their environmental policies, faced emissions reductions obligations, and adopted mitigation measures such as the ones set by the Kyoto Protocol (UN, 1997) and the Paris Agreement (UN, 2016). These measures can be more or less effective in reducing CO_2 emissions depending on the quality of countries' governance (Gani, 2012). Higón et al. (2017) called these facts country-specific measures and confirmed that they contribute to reducing CO_2 emissions. Additionally, to capture exogenous advances in carbon saving technology, they controlled for time by creating year-specific dummies. Hence, we also included these circumstances as control variables in our regression models.

And since the datasets contain longitudinal data, we employed panel analysis to estimate the mathematical models, as expressed in (1):

$$C_{it} = \alpha_i + \beta_1 I_{it} + \beta_2 I_{it}^2 + \beta_3 GDP_{it} + \beta_4 GDP_{it}^2 + \beta_n Z_{it}' + \mu_i + \upsilon_t + \varepsilon_{it} \qquad (1)$$

where C_{it} is Mt-CO_2 emission per capita – i.e., the environmental indicator, I_{it} and its squared term are the ICT index of country i at time t, GDP_{it} and its squared term are the GDP per capita of country i at time t, Z stands for covariates, μ_i is country-specific effects, υ_t represents year-specific dummies, and ε_{it} is the error term. Note that the inverted U-shaped relationship is confirmed if $\beta_1 > 0$ and $\beta_2 < 0$.

To estimate countries' rate of ICT development, we calculated the ICT index as a function of time as in (2):

$$I_{it} = \alpha_i + \beta_1 T_{it} + \varepsilon_{it} \qquad (2)$$

where T_{it} is time expressed in years.

Put simply, in this study we estimated whether the current pace of ICT developments worldwide can keep up with the UN's Global Goals. To achieve this objective, we estimated longitudinal regression models associating the percentage of ICT access and usage with CO_2 emissions per capita. Following the guidelines of previous research, we used covariates in the analyses to assure robustness. We checked whether the EKC theory holds true in the context of ICT development and estimated how close or how far countries are to reaching the threshold in CO_2 emissions from the perspective of the spread of ICT.

Deciding on the estimators

A Breusch & Pagan (1980) Lagrangian multiplier (LM) test was done to check for the presence of heteroscedasticity in the data and to assess the feasibility of using panel data modelling. Next, three tests were carried out to decide on the appropriate estimators. The Hausman (1978) test and the Baum et al. (2003) test were to choose between random and fixed effects estimator, and the Wooldridge (1991) test was to check for autocorrelation in the panel data, which would impact the standard errors of the parameter estimates. Upon the results of the tests, a decision was made to estimate fixed effects models with Driscoll and Kraay (1998) standard errors. All statistical analyses were performed in Stata/MP 16.0 (©1985-2019 StataCorp LLC).

RESULTS

As outlined in methods, the data were obtained from a few public databases and refer to the most relevant variables that participate in CO_2 emissions. The data sources and variables description are in Table 1. The data are from 2007 to 2020, arranged in strongly balanced panel, and are summarized in Table 2. The sample comprises 191 nations. The current OECD members are considered developed countries (n = 38).

Table 1

Variables description and data sources

Variable	Description	Source
CO_2 per capita	Carbon dioxide emissions in Mt-CO_2 per capita. The emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring.	World Bank (2022)
GDP per capita	Gross domestic product per capita in current U.S. dollars.	World Bank (2022)
Population density	People per square kilometer of land area.	World Bank (2022)
Oil proved reserves	Proved reserves in thousand million barrels.	BP Statistical World Energy (2021)
Electric power consumption	Electric power consumption in KWh per capita. It consists of the production of power plants and combined heat and power plants less transmission, distribution, and transformation losses and own use by heat and power plants.	World Bank (2022)
Industry share	Industry share is the value added from the industry, given in percentage of GDP.	World Bank (2022)
ICT index	The percentage of ICT access and usage by individuals, as measured by the ITU.	ITU (2022)
Passenger cars	Passenger cars per 1,000 people. Passenger cars refer to road motor vehicles, other than two-wheelers, intended for the carriage of passengers and designed to seat no more than nine people.	NationMaster (2019), World Bank (2022) and UNECE (2022)
Control of corruption	Perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as capture of the state by elites and private interests.	World Bank (2021)
Political stability	Perceptions of the likelihood of political instability and/or politically motivated violence, including terrorism.	World Bank (2021)
Rule of law	Perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and courts, as well as the likelihood of crime and violence.	World Bank (2021)
Kyoto Protocol	A dummy variable that is equal to one from 1997 onward for the 39 countries that were parties in the Kyoto Protocol, and zero otherwise.	UN (1997)
Paris Agreement	A dummy variable that is equal to one from 2016 onward for countries that signed the Paris Agreement treaty, and zero otherwise.	UN (2016)

Table 2

Descriptive statistics (2007-2020)

Variable	Total		Developed Countries		Developing Countries	
	Mean	SD	Mean	SD	Mean	SD
$MtCO_2$ per capita	4.36	(5.20)	7.84	(4.09)	3.49	(5.08)
ICT index	0.39	(0.24)	0.65	(0.15)	0.33	(0.21)
GDP per capita	14077.92	(21630.37)	37809.42	(23934.82)	8094.44	(16241.11)
ln Population density	4.26	(1.36)	4.29	(1.30)	4.25	(1.37)
Oil proved reserves	14.46	(71.60)	8.66	(37.61)	15.92	(77.76)
Electricity consumption (KWh per capita)	4174.87	(5876.81)	8669.60	(8345.96)	2466.88	(3264.19)
Passenger cars	212.75	(201.01)	438.68	(147.91)	119.87	(135.66)
Industry share	25.92	(11.28)	23.95	(5.61)	26.46	(12.34)
Control of corruption	-0.74	(0.99)	1.17	(0.82)	-0.39	(0.77)
Political stability	-0.08	(0.99)	0.61	(0.70)	-0.26	(0.98)
Rule of law	-0.08	(0.99)	1.21	(0.67)	-0.40	(0.77)
# of countries	191		38		153	
Observations (n *x* T)	2674		532		2142	

Note. Population density is provided in a logarithmic scale because the original scale is highly positively skewed. Oil proved reserves refer to thousand million barrels. Some missing data in GDP (6.3%) and Passenger cars (7%) were linearly interpolated, but the latter is still unavailable for several countries in the sample.

Before estimating the models, we ran the statistical tests as described in methods. The residuals variance was found to be heterogeneous ($\chi^2(1, N = 2245) = 9494.26$, $p < 0.001$, Breusch-Pagan test), hence the panel data approach provides a more consistent estimator. As for which panel data modelling (fixed or random effects) was more appropriate for the data, the difference in coefficients of the random effects model was found to be systematic (χ^2(12, N = 2245) = 137.25, p < 0.001, Hausman test), therefore the predictive power of a random effects model would be inconsistent. This was also confirmed by the Schaffer and Stillman test (χ^2(14, N = 2245) = 1665.01, p < 0.001, Sargan-Hansen statistic).

Yet, the fixed effects model could still provide an inconsistent estimator in case of groupwise heteroscedasticity. A modified Wald test indicated the existence of serial correlation in the errors, meaning they were not independent (χ^2(188, N = 2245) = 5,100,000, p < 0.001, Wooldridge test) and thus requiring a robust approach to estimate the standard errors. The definitive model was therefore estimated with fixed effects and Driscoll-Kraay standard errors.

Because the data on electric power consumption, passenger cars, and industry share are not available for all countries in the sample, we also ran the models without them. Table 3 reports the results of the regressions estimated by robust fixed effects (FE) and Driscoll-Kraay fixed effects (DK-FE). Note that the inverted U-shaped relationship is confirmed in all specifications.

Table 3

Results of the regressions for the entire sample

Variable	FE(1)	FE(2)	DK-FE(1)	DK-FE(2)
ICT	4.66** (1.57)	6.40** (2.20)	4.66** (1.37)	6.40** (1.50)
ICT2	-4.72** (1.60)	-4.48* (1.93)	-4.72* (1.62)	-4.48* (1.26)
GDP	0.00*** (0.00)	0.00** (0.00)	0.00*** (0.00)	0.00** (0.00)
GDP2	-0.00*** (0.00)	-0.00*** (0.00)	-0.00*** (0.00)	-0.00** (0.00)
ln Population density	-1.44 (1.30)	-1.52 (1.23)	-1.44* (0.63)	-1.52 (1.120)
Oil proved reserves	0.00 (0.00)	-0.00 (0.02)	0.00 (0.00)	-0.00 (0.00)
Kyoto protocol	(omitted)	(omitted)	-	-
Paris Agreement	-0.00 (0.19)	-0.19† (0.09)	-0.00 (0.12)	-0.19 (0.43)
Control of corruption	0.47** (0.17)	-0.27 (0.28)	0.47** (0.12)	-0.27† (0.14)
Political stability	-0.00 (0.09)	-0.20 (0.17)	-0.00 (0.07)	-0.20*** (0.02)
Rule of law	0.24 (0.23)	0.88* (0.39)	0.24 (0.17)	0.88** (0.21)
Electric power consumption		0.00*** (0.00)		0.00*** (0.00)
Passenger cars		0.00 (0.00)		0.00 (0.00)
Industry share		0.02 (0.02)		0.02* (0.01)
Yr.	-	-	-	-
Observations	2245	346	2245	346
# of countries	188	114	188	114
ICT turning point	0.49	0.71	0.49	0.71
R^2	0.15	0.42		
R^2 overall	0.21	0.35		
R^2 between	0.22	0.35		
R^2 within	0.15	0.42	0.15	0.42
F	-	-	13,549,115	258.74
σ_a^2	4.57	6.30		
σ_ε^2	0.77	0.29		
ρ	0.97	0.99		

Note. Standard errors are in parentheses. The estimations from FE are with robust standard errors. The models FE(2) and DK-FE(2) were estimated with all variables but their # of observations was considerably smaller. Time dummies are not reported but were included in all specifications. Kyoto protocol ended up being omitted due to collinearity. †p<.10, *p<.05, **p<.01, ***p<.001.

All variables of interest were found to be significant. A noteworthy point is that the coefficients of the ICT increased when more variables were added, suggesting that the positive relationship between ICT and CO_2 emissions does occur as ICTs spread. More importantly, the ICT turning points are dramatically different from what has been previously reported in the literature. Here the turning points can be from as small as 0.49 to as large as 0.71. This is a matter of concern that will need further analysis in the future.

The results are even more surprising when the sample is split into developed and developing countries (Table 4). In this case, not only the EKC hypothesis was not confirmed in the second model for the developed countries but also showed a U-shape curve. This may indicate that the ICT- CO_2 emission curve is rather N-shaped and developed countries have already benefitted from the potential that ICTs can offer to reduce CO_2 emissions.

However, the data are not enough to support this claim. The rate of cases to independent variable was quite small for the model and we therefore leave this question for future investigations. For now, it serves as a warning for the scientific community to look more carefully at this relationship and tell what exactly the benefits of ICTs are. As for developing countries, in the best-case scenario they reach the ICT turning point at 0.46.

Table 4

Results of the regressions for developed and developing countries separately

Variable	Developed countries DK-FE(1)	Developed countries DK-FE(2)	Developing countries DK-FE(1)	Developing countries DK-FE(2)
ICT	13.74*** (1.72)	-0.37 (2.74)	2.45† (1.23)	4.63** (1.12)
ICT2	-9.47*** (1.05)	3.19 (2.24)	-2.68† (1.45)	-2.79* (1.04)
GDP	0.00** (0.00)	0.00* (0.00)	0.00*** (0.00)	0.00 (0.00)
GDP2	-0.00* (0.00)	-0.00* (0.00)	-0.00*** (0.00)	0.00 (0.00)
ln Population density	-9.89*** (0.58)	-9.58 (4.72)	-1.52† (0.78)	-1.73 (1.28)
Oil proved reserves	0.01 (0.01)	0.05* (0.01)	0.00 (0.00)	-0.02 (0.01)
Kyoto protocol	(omitted)	(omitted)	(omitted)	(omitted)
Paris Agreement	-0.64* (0.22)	(omitted)	0.14 (0.17)	-0.13** (0.03)
Control of corruption	-0.70† (0.38)	0.16 (0.09)	0.57** (0.18)	-0.33* (0.13)
Political stability	-0.10 (0.10)	0.36 (0.14)	-0.04 (0.08)	-0.16** (0.04)
Rule of law	0.76* (0.34)	-0.75 (0.48)	0.27† (0.13)	0.57*** (0.10)
Electric power consumption		0.00† (0.00)		0.00*** (0.00)
Passenger cars		0.00 (0.00)		-0.01** (0.00)
Industry share		-0.06 (0.02)		0.03*** (0.00)
Yr.	-	-	-	-
Observations	456	111	1789	235
# of countries	38	37	150	77
ICT turning point	0.73	0.06	0.46	0.83
R^2 within	0.57	0.66	0.12	0.40
F	396422.95	2.057.678	681019.68	29.410.187

Note. Values in parentheses are Driscoll-Kraay standard errors. The models DK-FE's(2) were estimated with all variables but their # of observations was considerably smaller. Time dummies are not reported but were included in all specifications. Kyoto protocol and Paris Agreement ended up being omitted due to collinearity. †p<.10, *p<.05, **p<.01, ***p<.001.

Finally, we also estimated the world average annual rate of ICT development. As can be seen in Table 5 by the coefficient of the variable Year, global ICT development advances 2.3% annually. But the pace can be quite different from country to country. To have a better understanding of how each country performs, we ran the same model without grouping the countries (results not reported here) and we found that, at the country level, the annual pace can range from as small as 0.1% (like in Venezuela) to as large as 7.2% (like in the United Arab Emirates). Four countries (Antigua and Barbuda, Libya, Micronesia, and Palau) showed a downward trend in their rate of ICT development from year to year.

Table 5

Estimate for the world rate of ICT development

Regression with Driscoll-Kraay standard errors	# of observation	2674
Method: Fixed-effects regression	# of groups	191
	F(1, 13)	194,41
	Prob > F	0,000
	R^2 within	0,6696

Dependent Variable: ICT	β	Drisc/Kraay Std. Err.	t	P>t	[95% Conf. Interval]	
Year	0.023	0.002	13.94	0.000	0.019	0.027
Intercept	-0.217	0.012	17.93	0.000	-0.191	-0.243

Estimates of world ICT developments relative to the UN's Global Goals

If countries' ICT development advances at the global pace, their current ICT index must be at least 0.27, considering the best-case scenario in which the threshold between CO_2 emissions and ICT development is at 0.46. Based on the mean values described in Table 2, global levels of ICT development can keep up with the Global Goals and most developed countries have already reached it.

However, the standard deviations also from Table 2 show that the ICT index is quite scattered across countries. In the first quartile for the ICT index of developing countries there are nations falling below 0.12. These nations therefore need to progress at a higher pace than the global pace, otherwise they will not reach the peak by 2030.

In the worst-case scenario, things do not look encouraging as the ICT turning point does not occur before 0.71 at the global level (Table 3) and no earlier than 0.83 for developing countries (Table 4). Irrespective of the rate of development we estimate for this case, they all seem unreasonable.

CONCLUDING REMARKS

Previous estimates in the literature suggested that countries achieve the threshold between ICT and CO_2 emissions when the percentage of the spread of ICT is about 0.30 (Higón et al., 2017). Here we have found that the threshold does not occur before 0.49. Experts on the EKC of ICT claim the curve is inverted U-shaped (Chen et al., 2019; Ulucak et al., 2020) but our study suggests that it may perhaps be N-shaped.

As far as we can tell, no scientific works have addressed countries' ICT development pace relative to the UN's Global Goals. According to our estimates, the world average annual rate of ICT development is 2.3% but varies largely across countries. At this pace, not every country will be able to reach the threshold by 2030. This raises queries about how global institutions and richer countries can contribute to the ICT development of middle- and low-income economies as well as what actions local governments can take to develop ICT more rapidly in their countries.

In conclusion, given that even the most conservative climate projections refer to this decade as the one that will determine whether global temperature rise will or will not fall below 2°C throughout the 21st century, it is fundamental to keep track of countries' ICT development status because the clock is ticking and the world is running out of time. As of 2023, when this study is concluded, mankind has less than ten years to meet the UN's goals. In such an unequal world like this one, where not even global pollution is equally distributed, developing economies should, responsibly, take more advantage of their limits to thrive properly and at a high pace without losing sight of the Global Goals. Few would disagree with that indeed. However, the question posed in the title of this paper remains: will ICT developments keep up with the Global Goals of reducing carbon emissions?

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