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Economic and Non-economic Determinants of Environmental Sustainability in the Long Run: Evidence from G20 Economies*

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Abstract

Purpose – This paper analyzes the economic and non-economic factors that contribute to environmental sustainability by reducing CO_2 emissions, based on G20 panel data.

Design/methodology – We conduct a comparative analysis of advanced and developing economies during 1995–2016. To examine the impact, an environmental Kuznets curve (EKC) model was employed, incorporating additional explanatory variables such as internet use, renewable energy, and services trade.

Findings – The empirical findings show the existence of an inverted U-shaped EKC phenomenon between GDP per capita and CO_2 emissions in G20 economies, with the turning point at a per capita GDP level of US$ 38,340. Moreover, an inverted U-shape relation exists between internet use and CO_2 emissions, with the turning point at a 44% internet use rate. The comparative analysis show that the inverted U-shape curve only exits in advanced economies, with turning points of US$ 42,356 per capita GDP and 27% internet use rate, respectively. Renewable energy and services trade have a greater negative impact on CO_2 emissions in advanced economies than in developing economies.

Originality/value – Renewable energy and services trade have a greater negative impact on CO_2 emissions in advanced economies than in developing economies. Overall, the results suggest the role of internet use, renewable energy and services trade in sustainable development in G20 countries.

Keywords: CO_2 Emissions, Internet Use, Renewable Energy; Services Trade; Sustainable Development, The Environmental Kuznets Curve

JEL Classifications: D31, F14, O57

1. Introduction

Carbon dioxide (CO_2) is a greenhouse gas (GHG) that is known to absorb and emit thermal radiation, contributing to the "greenhouse effect." Energy-driven consumption of fossil fuels has caused expeditious growth in CO_2 emissions since the industrial revolution, disrupting the global carbon cycle and contributing to global warming. Emissions have more than doubled since the early 1970s and risen by around 40% since 2000, much of which can be linked to increased economic output.

For the environmental effect of economic factors, the most widely considered type of

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relation between environmental pollutants and economic activity, usually measured by gross domestic product (GDP), is that of an "inverse U", referred to as the "environmental Kuznets curve" (EKC). Much of the empirical evidence indicates that economic growth initially causes increased environmental damage, but once they become sufficiently rich, they become more environment friendly (Grossman and Krueger, 1991; Farhani et al., 2014; Fujii et al., 2018; Omri et al., 2019). Moreover, the effect of trade on the environment has been examined by many scholars, but there are few studies that consider services trade for realizing environmental sustainability. In particular, the Group of Twenty (G20) economies contributed more than 55% of services trade in the world in 2016 (see Table 1). Considering the rapid increase of services trade, it is important to identify the role of service trade in environmental sustainability.

For the non-economic factors, the role of internet use in CO_2 emissions reduction has drawn wide attention. Some studies have confirmed the negative impact of internet use on CO_2 emissions (Zhang and Liu, 2015; Asongu, 2018; Ozcan and Apergis, 2018; Zhang and Meng, 2019; Shabani and Shahnazi, 2019). However, other studies support its positive impact on CO_2 emissions, arguing that the use of ICT, especially internet use, has direct positive effects on electricity consumption, which also leads to a rise in energy consumption related to the production of equipment and operation of infrastructure (Lee and Brahmasrene, 2014; Salahuddin et al., 2016a; Zhou et al., 2018). In addition, due to increasing concern regarding the environmental consequences of emissions from fossil fuels, renewable energy has become an important alternative. The existing literature shows that renewable energy can help mend the climate change problem (Paramati et al., 2017; Balsalobre-Lorente et al., 2018; Dong et al., 2018; Qiao et al., 2019).

However, few studies have examined the environmental effect of economic and non-economic factors together, with a focus on the G20 economies. In particular, G20 economies accounted for about 76.9% of the world's GDP and 78.4% of the world's CO_2 emissions in 2016, making them the largest economies and CO_2 emitters (see also Table 1). Given the importance of G20 economies to the world economy and quality of the environment, examining both economic and non-economic factors that contribute to CO_2 emissions reduction in the G20 is urgent.

Table 1. CO_2 Emissions, Economic Growth, Internet Users, Renewable Energy and Services Trade for Global and G20 Economies in 1995 and 2016 (Except the European Union).

Categories	1995			2016		
	G20	Global	share(%)	G20	Global	Share(%)
CO_2 emissions (million tonnes)	17646	22803	77.4%	26886	34291	78.4%
GDP (constant 2010 billion US$)	33027	42299	78.1%	59858	77797	76.9%
Internet users (100 thousands people)	338	447	75.6%	23156	34194	67.8%
Renewable energy (Mtoe)	755	1211	62.3%	1091	1881	58.0%
Services trade (current billion US$)	1571	2632	59.7%	5450	9764	55.8%
Energy consumption (Mtoe)	6765	9215	73.4%	10120	13812	73.3%

Data sources: Enerdata, 2018; World Bank, 2019; OECD,2019; GCP, 2019.

The purpose of this paper is to examine the impact of GDP per capita, services trade, internet use, and renewable energy on CO_2 emissions, based on the EKC framework. We compare the impact in advanced economies with developing ones of the G20, which, to our best knowledge, is the first attempt to conduct such a comparative study.

This paper is organized as follows. Section 2 summarizes the existing related literature and presents the hypotheses. Section 3 describes the methodology and data, while section 4 discusses the empirical results. Finally, section 5 presents the conclusions and policy implications of this study.

2. Literature Review and Hypotheses

2.1. Economic Growth and CO_2 Emissions

The EKC hypothesis explains the existence of an inverted U-shape relation between income and pollutant emissions. In the early stages of economic growth, pollutant emissions increase until economic growth reaches a threshold level and then begin to decline (Grossman and Krueger, 1991; Shafik, 1994).

Numerous researchers have examined the validity of the EKC hypothesis; many of them support that the income-pollutant nexus presents an inverted U-shape (Farhani et al., 2014; Dong et al., 2018; Fujii et al., 2018; Omri et al., 2019).

Fujii et al. (2018), using data for 276 cities from 26 countries, explored the impact of economic growth on urban CO_2 emissions in the transport, residential and industrial, and energy sectors. The empirical results show that, for the transport and residential and industrial sectors, there is an inverted U-shape, which indicates the existence of the EKC. Omri et al. (2019) incorporated foreign direct investment (FDI), financial development, and trade openness into the EKC model. By using fully modified ordinary least squares (FMOLS), they confirmed that the EKC hypothesis is valid in Saudi Arabia.

For example, it is argued against the EKC studies that an economic growth can not always improve the environment as carbon emissions are monotonically increasing with income (Farhani and Ozturk, 2015; Fodha and Zaghdoud, 2010; Holtz-Eakin and Selden, 1995).

Adewuyi and Awodumi (2017) added that researches analyzing the tie between energy consumption and economic growth do not contribute much to the literature. In addition, given that energy consumption also has a direct impact on the level of carbon emissions to the air, examining these two strands of studies using an integrated framework is necessary.

However, Mikayilov et al. (2018) did not find any evidence of it. In their results, the effect of economic growth on CO_2 emissions was reported to be positive, and the coefficient was found to be 0.7–0.8.

This study uses panel data from G20 economies to re-examine this issue with the following hypothesis:

Hypothesis 1: An inverted U-shape relation exists between economic growth and CO_2 emissions in G20 economies. More specifically, CO_2 emissions are expected to increase with rising income levels; however, they are more likely to decline with higher income levels.

2.2. Internet Use and CO_2 Emissions

In recent decades, with the rapid penetration of ICT and internet use, arguments concerning the impact of technology on the environment seem to be increasing.

Some studies support that the diffusion of internet technology has a positive impact on CO_2 emissions (Lee and Brahmasrene, 2014; Salahuddin et al., 2016a).

Other studies argue that internet use has revolutionized economic growth and negatively affects CO_2 emissions because it has greatly changed modes of production and the ways we communicate and work (Williams, 2011). Such negative effects have been supported by the studies of Zhang and Liu (2015), Asongu (2018), Ozcan and Apergis (2018), and Zhang and Meng (2019).

Ozcan and Apergis (2018), in their study of 20 emerging economies, reported that an improvement in internet use reduces CO_2 emissions by 0.02–0.04%; the causality relationship is unidirectional, from internet use to CO_2 emissions.

Shabani and Shahnazi (2019), using data for Iran from 2002 to 2013, compared the impacts of ICT, GDP, and energy consumption on CO_2 emissions across economic sectors. Their results show that, in the industrial sector, the ICT variable increases CO_2 emissions, while for the transportation and services sector, the ICT impact lowers CO_2 emissions.

In particular, Zhang and Meng (2019), using data from 115 countries, investigated how internet use affects the link between income and emissions and compared the impact of internet use on CO_2 reduction in 1996–2005 to that of 2006–2014, revealing that by increasing internet penetration, the level of actual income beyond which pollution begins to decline can be reduced. Their comparative tests show that internet penetration has a growing negative impact on emissions reduction over time.

In addition to the linear relations, Higón et al. (2017) examined the non-linear association between these two variables. In their study, ICT is introduced as a part of the growth process in firms through scale, input, output, and technology effects, which produce an inverted U-shape relation between ICT and emissions. First, in term of the scale effect, it helps companies to expand, while such ICT may exist in large numbers in computers and software, which increases emissions. Once the basic ICT capital is placed, marginal ICT can be used to optimize the processes of production and to improve energy efficiency, which can reduce emission intensity through technology effects. By using panel data from 142 economies, they confirmed the inverted U-shape connection.

To examine the non-linear relationship between internet use and CO_2 emissions in G20 economies, we employed the following hypothesis:

Hypothesis 2: An inverted U-shape relationship exists between internet use and CO_2 emissions in G20 economies. More specifically, CO_2 emissions are expected to increase with rising internet use rate; however, they are more likely to decline with higher levels of internet use rate.

2.3. Renewable Energy and CO_2 Emissions

A growing number of studies have investigated the nexus of renewable energy-environment at the country level and region level. Most of them confirm the role that renewable energy plays in environmental sustainability (Paramati et al., 2017; Ito, 2017; Bekhet and Othman, 2018; Mohlin et al., 2018; Dong et al., 2018; Qiao et al., 2019).

At the country level, Mohlin et al. (2018), in their studies on the United States, employed the decomposition method and provided evidence in favor of renewable energy having an equally significant effect on CO_2 reduction from 2007 to 2017 as natural gas; the reduction in CO_2 emissions by renewables was found to be 2.3–3.3%. In the case of the G20, Qiao et al. (2019) studied its impact on emissions using the EKC model; by using the FMOLS technique, they concluded that renewable energy has a beneficial environmental effect. Moreover, Bekhet and Othman (2018) added renewable energy to the base of the cubic polynomial functional form of EKC and confirmed its positive role in environmental sustainability.

At the regional level, Dong et al. (2018), using data for global samples across six regions, found that the growth of renewable energy use leads to the reduction of CO_2 emissions. They additionally reported that this negative impact is greater in South and Central America and Europe and Eurasia than in other regions.

In terms of causality, Cai et al. (2018) revealed that a bidirectional causality relationship exists in Germany between these two variables, while for the Unites States, the causality relationship is unidirectional, from renewable energy use to CO_2 emissions.

To explore the contribution of renewable energy to environmental quality, our hypothesis is developed as follows:

Hypothesis 3: The higher the renewable energy use, the lower the CO_2 emissions in G20 economies.

2.4. Services Trade and CO_2 Emissions

The trade openness-environment link has been widely examined, based on the EKC model; some studies have reported that trade openness positively affects CO_2 emissions (Lau et al., 2014; Li et al., 2017; Hasanov et al., 2018).

Li et al. (2017) used an input-output model and found that the increase in scale of China's steel export raises CO_2 emissions. Hasanov et al. (2018) used data from nine oil-exporting countries, and their long-run estimation results show that a 1% rise in imports leads to a 0.3–0.4% increase in CO_2 emissions, while a 1% rise in exports reduces CO_2 emissions by 0.6–0.8%.

However, other studies argue that trade openness improves environment quality (Shahbaz et al., 2017a; Frutos-Bencze et al., 2017). Specifically, Ling et al. (2015) decompose the trade effect into scale effect, technology effect, composition effect, and comparative advantage effect to explore the impact of trade on environment. They found that the scale effect has a positive effect on CO_2 emissions, while the technique effect on CO_2 emissions is negative after a threshold income level.

While a number of studies have examined the impact of trade on the environment, the linkage between services trade and the environment is relatively unexplored. Only a few researchers have begun to use the services trade as an explanatory variable to examine the trade-environment nexus. For example, Zhang and Zhang (2018), in their studies on China, examined the effect of services trade based on the EKC model. The empirical results show that the services trade mitigates CO_2 emissions. Thus, to check whether the services trade improves environmental quality in G20 economies, our hypothesis is presented as follows:

Hypothesis 4: The larger the volume of services trade, the lower the CO_2 emissions in G20 economies.

3. Empirical Analysis

3.1. Empirical Model

To test our hypotheses, we establish the following two empirical models.

First, to investigate the validity of the inverted U-shaped EKC hypothesis, model 1 was set up as CO_2 emissions (CO_2) is the dependent variable, while the independent variables are GDP per capita (*GDP*), internet use (*INTER*), renewable energy (*RE*), and services trade (*ST*). Moreover, based on the existing EKC model, a quadratic estimation term of *GDP* (GDP^2) is added as an independent variable.

Model 1:

$$CO_{2it} = \alpha_0 + \alpha_1 GDP_{it} + \alpha_2 GDP_{it}^2 + \alpha_3 INTER_{it} + \alpha_4 RE_{it} + \alpha_5 ST_{it} + \varepsilon_{it}$$

Under the EKC hypothesis, the parameters of α_1 and α_2 are expected to be $\alpha_1 > 0$ and $\alpha_2 < 0$, which indicate that with an increase in GDP per capita, CO_2 emissions first increase, and after reaching a threshold (turning point), CO_2 emissions decrease, showing an inverted U-shape relation between GDP per capita and CO_2 emissions. The subscript i refers to countries, and t represents the year.

By taking the derivative of model 1, the turning point of GDP per capita can be determined as follows:

$$\frac{\partial \mathrm{E}(CO_{2it})}{\partial GDP} = \alpha_1 + 2\alpha_2 GDP_{it} = 0$$

To examine whether an inverted U-shape relation exists between internet use and CO_2 emissions based on the EKC framework, model 2 takes the dependent variable of CO_2 emissions (CO_2) and independent variables of internet use (*INTER*), GDP per capita (*GDP*), renewable energy (*RE*), and services trade (*ST*). Additionally, the square term of *INTER* ($INTER^2$) is added to our model 2:

Model 2:

$$CO_{2it} = \beta_0 + \beta_1 INTER_{it} + \beta_2 INTER_{it}^2 + \beta_3 GDP_{it} + \beta_4 RE_{it} + \beta_5 ST_{it} + \varepsilon_{it}$$

According to the EKC concept, CO_2 emissions increase as internet use rate improves; however, as internet use rate reaches a higher level, CO_2 emissions may reduce. For hypothesis 2 to be valid, the parameters of β_1 and β_2 are expected to be $\beta_1 > 0$ and $\beta_2 < 0$.

Similarly, by taking the derivative of model 2, the turning point of internet use can be determined as follows:

$$\frac{\partial \mathrm{E}(CO_{2it})}{\partial INTER} = \beta_1 + 2\beta_2 INTER_{it} = 0$$

Moreover, hypothesis 3 and 4 can be tested with the above two models. For hypothesis 3 and 4 to be valid, the parameters of α_4, α_5, β_4, and β_5 are expected to be a negative value.

3.2. Data Sources

In this study, our full sample dataset includes the period of years from 1995 to 2016 in 19 individual economies of the G20. To fully address the concern that the impacts of GDP per capita, internet use, renewable energy, and services trade on CO_2 emissions may differ across various economic levels, these 19 economies in the G20 were classified into two groups based on the International Monetary Fund's (IMF) country classification: advanced economies and developing economies.

Accordingly, the advanced economies subpanel includes nine countries (i.e., Australia, Canada, France, Germany, Italy, Japan, Korea, United Kingdom, United States), while the developing economies consist of data for 10 countries (i.e., Argentina, Saudi Arabia, Indonesia, India, Brazil, China, Mexico, Russian Federation, Turkey, South Africa).

Appendix (1) presents the variables and data descriptions. The dependent variable of CO_2 emissions, measured in tonnes per capita, are taken from the Global Carbon Project (GCP). The independent variables consist of GDP per capita, services trade, internet use, and renewable energy. Data of GDP per capital, services trade, and internet use are derived from the World Development Indicators database, while data of renewable energy is collected from the Organization for Economic Co-operation and Development database.

We use real GDP per capita (constant 2010 US$) as a measure of economic growth. Services trade is measured as the ratio of the sum of service exports and imports to GDP. Following Zaghdoudi (2017) and Ozcan and Apergis (2018), the internet use variable is measured using individuals who had used the internet in the last three months (% of population). Renewable energy is measured in renewable energy use per capita GDP, and is calculated by renewable energy use (tonne of oil equivalent)/ GDP (constant 2010 US$) following the study of Dong et al. (2018). Table 2 reports the summary of statistics descriptive.

Table 2. Summary of Statistics Descriptive

Panel	Statistics	*CO_2*	*GDP*	*INTER*	*RE*	*ST*
Full sample	Mean	8.561840	22978.48	36.48024	0.028726	9.529164
	Maximum	21.28300	55777.35	94.62000	0.225040	21.01766
	Minimum	0.808000	677.0355	0.004955	1.01E-05	2.055087
	STd. Dev	5.776352	17388.71	30.41560	0.040444	4.014747
	Observations	418	418	418	418	418
Advanced economies	Mean	11.97944	39607.39	54.58307	0.008191	10.88191
	Maximum	21.28300	55777.35	94.62000	0.038096	21.01766
	Minimum	5.134000	12055.23	0.524413	0.000791	3.840829
	STd. Dev	4.749329	9141.977	28.86885	0.008502	4.095912
	Observations	198	198	198	198	198
Developing economies	Mean	5.486000	8012.463	20.18768	0.047208	8.311689
	Maximum	19.76800	21507.96	74.88000	0.225040	19.74858
	Minimum	0.808000	677.0355	0.004955	1.01E-05	2.055087
	STd. Dev	4.814436	5054.837	21.18661	0.048220	3.529328
	Observations	220	220	220	220	220

Note: STd. Dev. indicates standard deviation.

4. Results

4.1. Results of Panel Unit Root Tests

To check the stability and examine the integration level of selected variables, the panel unit root tests are conducted. All tests have the null hypothesis with a unit root (non-stationary); the results are presented in Table 3. Clearly, most variables are non-stationary at level. However, when the first difference is taken, all selected variables become stationary at 1% significant level, indicating that all variables are integrated on the order of one I (1). Accordingly, this result enables us to test whether a cointegration relation exists among the selected variables in the long run by developing the Johansen Fisher panel cointegration test.

Table 3. Unit Root Test

Categories	Full sample		Advanced economies		Developing economies	
	Level	1st Difference	Level	1st Difference	Level	1st Difference
CO_2						
ADF - Fisher Chi-square	51.2060	212.294***	26.3124	121.153***	24.8936	91.1407***
PP - Fisher Chi-square	49.7406	292.389***	29.2123**	171.384***	20.5283	121.005***
GDP						
ADF - Fisher Chi-square	48.5551	119.843***	21.3776	68.4933***	27.1775	51.3494***
PP - Fisher Chi-square	22.7715	148.034***	13.9300	91.0978***	8.84146	56.9361***
GDP^2						
ADF - Fisher Chi-square	27.8163	119.644***	20.2140	70.1411***	7.60222	49.5028***
PP - Fisher Chi-square	21.3094	162.281***	14.1845	98.7421***	7.12486	63.5389***
INTER						
ADF - Fisher Chi-square	21.9586	97.3773***	3.36285	57.6836***	18.5958	39.6937***
PP - Fisher Chi-square	13.6258	127.284***	1.94152	66.3416***	11.6842	60.9420***
$INTER^2$						
ADF - Fisher Chi-square	9.72896	113.884**	6.79254	66.8122***	2.93643	47.0719***
PP - Fisher Chi-square	8.03182	125.264***	7.57660	67.3440***	0.45522	57.9196***
RE						
ADF - Fisher Chi-square	49.1763	172.206***	11.8229	104.216***	37.3534**	67.9892***
PP - Fisher Chi-square	91.6952***	497.265***	6.65044	162.665***	85.0448***	334.600***
ST						
ADF - Fisher Chi-square	46.2570	167.007***	27.8308	65.3442***	18.4262	101.662***
PP - Fisher Chi-square	35.1460	194.455***	11.6223	71.0051***	23.5238	123.450***

Note: ***, **, * denote statistical significance at 1%, 5%, and 10% level, respectively.

4.2. Results of Cointegration Test

The Johansen Fisher panel cointegration test is applied to examine the long run cointegration relations among the variables. The results from both trace tests and max-eigen value tests show the existence of long-run equilibrium relationships at 1% significant level for each of the models, as well as for all three panels (Table 4).

Table 4. Johansen Fisher Panel Cointegration Test

Hypothesized No. of CE(s)	Full sample		Advanced economies		Developing economies	
	Trace test	Max-eigen test	Trace test	Max-eigen test	Trace test	Max-eigen test
Model 1: $CO_2 = f(GDP, GDP^2, INTER, RE, ST)$						
None	2611***	4196***	1217***	1875. ***	1394. ***	2321***
At most 1	825.8***	469.4***	370.3***	185.5***	455.5***	283.9***
At most 2	444.7***	316.5***	215.9***	129.4***	228.7***	187.1***
At most 3	206.3***	134.3***	110.3***	72.64***	95.96***	61.63***
At most 4	103.9***	67.86***	53.91***	34.34**	50.02***	33.52**
At most 5	70.39***	70.39***	36.09***	36.09***	34.30**	34.30**
Model 2: $CO_2 = f(INTER, INTER^2, GDP, RE, ST)$						
None	2235***	3735***	1133***	1845***	1102. ***	1889***
At most 1	714.6***	404.3***	352.8***	190.4***	361.8***	213.9***
At most 2	371.0***	211.0***	190.3***	112.5***	180.8***	98.48***
At most 3	193.5***	114.4***	94.63***	53.50***	98.90***	60.88***
At most 4	110.4***	73.09***	57.13***	35.15***	53.27***	37.94***
At most 5	73.11***	73.11***	40.07***	40.07***	33.04**	33.04**

Note: ***, **, * denote statistical significance at 1%, 5%, and 10% level, respectively.

4.3. Estimation Results for All G20 Economies

After employing the cointegration test, the long-run equilibrium relation among all variables is confirmed; it allows us to explore the long-term elasticity of our models. We adopt FMOLS technique, which is widely used in a EKC model for long run estimations (Farhani et al., 2014; Paramati et al., 2017; Omri et al., 2019; Qiao et al., 2019). Table 5 reports the long-run elasticities for all G20 economies as a whole.

The results of model 1 show that coefficients of *GDP* and GDP^2 on CO_2 are positive and negative respectively and are statistically significant at 1% level. This suggests the existence of an inverted U-shape relation between GDP per capita and CO_2 emissions in G20 economies, which supports our hypothesis 1. The turning point of GDP per capita can be calculated as follows by using the coefficients from Table 5:

$$GDP_{it}(\text{turing point}) = \frac{-\alpha_1}{2\alpha_2} = \frac{-0.000559}{2*(-7.29\text{e}-09)} = 38{,}340\text{US\$}$$

The result suggests that CO_2 emissions first show an upward trend, however, when reaching the per capita GDP level of US$ 38,340, CO_2 emissions begin to decline. Moreover, it is worth mentioning that the turning point estimated above are still above the mean value of per capita GDP for the full sample (US$ 22,978.48), which indicates that many G20 economies have not yet reached the level of per capita GDP at which CO_2 emissions will be reduced as per capita GDP increases.

In Model 2, CO_2 is affected positively by *INTER* and negatively by $INTER^2$, which supports an inverted U-shape relation between internet use and CO_2 emissions; these results support hypothesis 2. The turning point of internet use rate can be calculated as follows:

$$INTER_{it}(\text{turing point}) = \frac{-\beta_1}{2\beta_2} = \frac{-0.060565}{2*(-0.000687)} = 44\%$$

The result indicates that CO_2 emissions are likely to increase first as the internet use rate improves, however, when reaching an internet use rate of 44%, CO_2 emissions tend to decrease. The calculated turning point of internet use rate for the full sample is still above the mean value (36.48 %), meaning that many G20 countries have not yet reached the level of internet use rate at which CO_2 emissions decrease as internet use rate increases.

In both Model 1 and 2, renewable energy negatively affects CO_2 emissions at 5% significant level, which supports our hypotheses 3. An increase in one unit of renewable energy leads to a reduction in CO_2 emissions by 10–12 units in the long run. Services trade also show a negative impact on CO_2 emissions and is significant at 1% level. An increase in one unit of services trade volume causes CO_2 to decline by around 0.12–0.16 units in the long run. This support our hypotheses 4.

Table 5. Long-run Elasticities for all G20 Countries

Variables	Model 1	Model 2
GDP	0.00056***	0.00003
GDP^2	-7.29e-09***	
INTER	-0.00014	0.06057***
$INTER^2$		-0.00069***
REI	-10.79600**	-12.60804**
ST	-0.15806***	-0.12952***
Turning point	Turning point of GDP per capita	Turning point of internet use rate
	38,340US$	44%

Note: ***, **, * denote statistical significance at 1%, 5%, and 10% level, respectively.

4.4. Comparison Analysis for Advance and Developing Economies of G20

To investigate whether the impact varies with different economic levels, we divide G20 economies into two groups: advance and developing economies. Table 7 displays the long run estimates by economic levels.

For advance economies, *GDP* has a positive coefficient value on CO_2, while GDP^2 has a negative coefficient value, suggesting an inverted U-shape relationship between GDP per capita and CO_2 emissions. The turning point of GDP per capita is calculated as US$ 42,356. It means that CO_2 emissions increases first as the GDP per capita rises, however, after reaching the per capita GDP level of US$ 42,356, CO_2 emissions will decline. The coefficient value of *INTER* and $INTER^2$ are positive and negative, respectively, suggesting an inverted U-shape relation between internet use and CO_2 emissions. The turning point of internet use rate is estimated as 27%. It means that CO_2 emissions is likely to increase first with rising rates of internet use, however, when reaching an internet use rate of 27%, CO_2 emissions are likely to decline. Renewable energy has a negative impact on CO_2 emissions: an increase in one unit of renewable energy causes CO_2 emissions to decline by around 88–107 units in the long run. Service trade is negatively related to CO_2 emissions: an increase in one unit of services trade volume cause to a reduction in CO_2 emissions by around 0.26 unit.

For developing economies, *GDP* has a negative coefficient value on CO_2, while GDP^2 has a positive coefficient value. It indicates that a U-shape relationship exists between GDP per capita and CO_2 emissions. The turning point of GDP per capita is calculated as US$ 7,809. This suggests that CO_2 emissions initially decline until reaching a per capita GDP point of

US$ 7,809, where an increase in CO_2 emissions can be identified. *INTER* and *$INTER^2$* have no significant impacts on *CO_2*, indicating that there is no inverted U-shape relation between internet use and CO_2 emissions. In addition, renewable energy negatively affects CO_2 emissions: an increase in one unit of renewable energy reduces CO_2 emissions by around 11–28 units in the long run. Services trade also has a negative impact on CO_2 emissions: an increase in one unit of services trade volume leads to a reduction in CO_2 emissions by around 0.09–0.13 units in the long run.

The following observations emerge from a comparison of advanced and developing economies. First, there is an inverted U-shape relationship between GDP per capita and CO_2 emissions in advanced economies, but there is a U-shape relationship in developing economies. For advanced economies, the rising level of GDP per capita first increases CO_2 emissions, however, after reaching the GDP per capita level of US$ 42,356, the CO_2 emissions tends to decline as the GDP per capita rises. On the contrary, for developing economies, the increase of GDP per capita initially decrease CO_2 emissions, however, after reaching a GDP per capita level of US$ 7,809, CO_2 emissions is likely to increase as the GDP per capita rises.

Second, the existence of an inverted U-shape relationship is found between internet use and CO_2 emissions in advanced economies, while there is no impact of internet use on CO_2 emissions in developing economies. It suggests that, in advanced economies, an increase in internet use rate initially increases CO_2 emissions, but after attaining the internet use rate of 27%, the CO_2 emissions tend to decline as the internet use rate increases.

Third, renewable energy has a more negative impact on CO_2 emissions in advanced economies than in developing economies. It means that the rising level of renewable energy leads to a greater reduction in CO_2 emissions in advanced economies.

Finally, services trade has a greater negative impact on CO_2 emissions in advanced economies than in developing economies. The growth in services trade volume causes a higher decline in CO_2 emissions in advanced economies.

Table 7. Long-run Elasticities for Advance and Developing Economies

Variables	Model 1		Model 2	
	Advanced economies	**Developing economies**	**Advanced economies**	**Developing economies**
GDP	0.00088***	-0.00058***	0.00005	0.00007
GDP^2	-1.04e-08***	3.72e-08***		
INTER	-0.00514	0.01510*	0.02959*	0.03107
$INTER^2$			-0.00055***	-0.00007
REI	-88.61761*	-28.04699***	-106.7350*	-11.47752*
ST	-0.26241***	-0.13581***	0.04907	-0.09976*
Turning point	Turning point of GDP per capita		Turning point of internet use rate	
	42,356US$	7,809US$	27%	Na

Note: ***, **, * denote statistical significance at 1%, 5%, and 10% level, respectively.

5. Conclusions and Limitations

This paper analyzed the economic and non-economic factors affecting CO_2 emissions based on panel data of G20 economies during 1995–2016. We conducted a comparative analysis of advanced and developing economies of the G20. To examine the impact, the EKC model was employed with additional explanatory variables such as internet use, renewable energy, and services trade.

The empirical findings for all G20 economies show the existence of an inverted U-shape relationship between GDP per capita and CO_2 emissions. The turning point of per capita GDP is US$38,340. In addition, the existence of an inverted U-shape relation was found between internet use and CO_2 emissions with turning points at 44% for the internet use rate in G20 economies. Renewable energy and services trade have negative impacts on CO_2 emissions. As renewable energy use and service trade volumes increase, CO_2 emissions is more likely to decrease.

The comparative results for advance and developing economies show that there is an inverted U-shape relationship between GDP per capita and CO_2 emissions with turning point at US$ 42,356 for GDP per capita in advanced economies. However, for developing countries, the inverted U-shape EKC phenomenon did not exist, because despite their eagerness to pursue economic growth instead of preserving the environment, they had not reached a certain level of income. Moreover, there is an inverted U-shape relation between internet use and CO_2 emissions with turning points at 27% for internet use rate in advanced economies. However, for developing economies, the inverted U-shape relation did not exist, because they had not installed sufficient network infrastructure to facilitate it. Renewable energy and service trade has a more negative impact on CO_2 emissions in advanced economies than in developing economies. The rising level of renewable energy and service trade volume lead to a greater reduction of CO_2 emissions in advanced economies.

Three policy implications are identified as follows. First, the results advocate for the development of adequate ICT infrastructure and improved internet use rate to enhance environmental sustainability, not only in advanced nations, but also in developing countries.

Second, the findings show that renewable energy plays a significant role in decreasing CO_2 emissions in G20 economies, especially in advanced economies. We suggest that G20 policy-makers optimize the mix of energy consumption and increase the share of renewable energy within the total number of energy components.

Finally, the results confirmed the potential role of the services trade in environmental sustainability. The international services trade can enhance environmental quality by encouraging the import of modern technologies for the services sector, thereby decreasing CO_2 emissions levels. Thus, we suggest that to reduce the CO_2 emissions of G20 economies, it is necessary to adjust the trade structure and improve the services trade volume.

6. Limitations and Future Research

This study mainly analyzed the non-economic determinants of environmental sustainability but not analyzed the recent developments of carbon neutrality. As of 2021, countries representing more than 60% of harmful greenhouse gasses and more than 70% of the world economy would have committed to achieve carbon neutrality by the end of 2050. Carbon neutrality is referred to achieving net-zero carbon dioxide emissions. This can be done by balancing producing carbon dioxide with its removal or by reducing emissions from country. Not only every country but also city, financial institution and company should setup plans for net zero, and prepare the right way to that goal, which means cutting global emissions by 45 per cent by 2030 compared with 2010 levels. Republic of Korea, USA, European Union, United Kingdom and more than 110 countries have committed to do so.

China has pledged to achieve the goal before 2060. European Union is going to establish a carbon border adjustment mechanism(CBAM). The CBAM would place a carbon tax on imports of certain goods from outside the EU, in an effort to reduce the risk of carbon emission in the process of manufacturing. Future research, therefore, could analyze the impact of CBAM through in-depth research with more specific and recent data on each country. In addition, it will be better to analyze the effect of CBAM on the carbon emission in a various perspective.

Appendix / Appendices

Appendix 1. Summary of Data Description and Source

Signs	Variables	Variable definitions	Sources
CO_2	CO_2 emissions	CO_2 emissions per capita (tonnes per capita)	Global Carbon Project (GCP)
GDP	GDP per capita	GDP per capita (constant 2010 US$)	World Bank (WDI)
INTER	Internet use	Individuals using the internet (% of population)	World Bank (WDI)
RE	Renewable energy	Renewable energy use per capita GDP (tonne of oil equivalent per constant 2010US$)	OECD data
ST	Services trade	Sum of service exports and imports (% of GDP)	World Bank (WDI)

Appendix 2. Summary of Studies

Authors	Data sample	Variables	Methodology	Shape of EKC	Main findings
Studies of EKC					
Farhani et al. (2014)	• 10 MENA countries • 1990–2010	CO_2, GDP, EC, TO, MAN	FMOLS, DOLS	∩	FMOLS estimates: • 1% ↗ EC, 1.828% ↗ CO_2 • 1% ↗ TO, 0.216% ↗ CO_2
Dong et al. (2018)	• China • 1993–2016	CO_2, GDP, FF, NU, RE	ARDL, VECM	∩	• 1% ↗ FF, 1.0747% ↗ CO_2 • 1% ↗ NU, 0.0021% ↘ CO_2 • 1% ↗ RE, 0.0192% ↘ CO_2
Fujii et al. (2018)	• 276 cities in 26 countries • 2000, 2005 and 2008	CO_2, GDP, POP	Partial linear regression	∩	• The EKC hypothesis is valid for transport and residential & industry sectors.
Mikayilov et al. (2018)	• Azerbaijan • 1992–2013	CO_2, GDP	DOLS, FMOLS, CCR		• GDP (+) CO_2
Omri et al. (2019)	• Saudi Arabia • 1990–2014	CO_2, GDP, FDI, TO, FD	FMOLS, DOLS	∩	• FDI, TO, and FD have inverted U-shape relationships with CO_2.

Appendix 2. (Continued)

Authors	Data sample	Variables	Methodology	Shape of EKC	Main findings
Studies of the nexus of internet use and CO_2 emissions					
Lee and Brahmasrene (2014)	• Nine ASEAN countries • 1991–2009	ICT, CO_2, GDP, HCD	DOLS, FMOLS, CCR		• 1% ↗ ICT, 0.660% ↗ CO_2
Zhang and Liu (2015)	• 29 provinces of China • 2000–2012	ICT, CO_2, INDU, UR, EI, GDP	FE		• Eastern regions: 1% ↗ ICT, 0.0286% ↘ CO_2 • Central regions: 1% ↗ ICT, 0.129% ↘ CO_2
Salahuddin et al. (2016a)	• OECD countries • 1991–2012	INTER,FD, TO, GDP, CO_2	PMG, FOLS,DOLS		• INTER (+) CO_2 (LR)
Salahuddin et al. (2016b)	• Australia • 1985–2012	INTER, FD, GDP, CO_2	ARDL		• No significant association between INTER and CO_2 emissions (LR)
Higón et al. (2017)	• 142 countries • 1995–2010	ICT, GDP, CO_2, INDU	POLS, FE	∩	• An inverted U-shaped relation exists between ICT and CO_2 emissions.
Ozcan and Apergis (2018)	• 20 emerging countries • 1990–2015	INTER, CO_2, GDP, FD, TO, EC	MG, AMG, GM-FMOLS		• 1% ↗ INTER, 0.02~0.04% ↘ CO_2 • INTER→ CO_2
Asongu et al. (2018)	• 44 countries of sub Saharan Africa • 2000–2012	ICT, CO_2, CO_2 from liquid fuel consumption	GMM		• ICT has a positive net impact on CO_2 • Mobile phone penetration alone has a net negative effect on CO_2 emissions from liquid fuel consumption
Yan et al. (2018)	• 50 countries • 1995–2013	ICT, FDI, INDU, TO, EP	OLS, FE		• ICT (+) EP
Zhou et al. (2018)	• China	ICT, EI	SDA		• 1% ↗ ICT, 4.54% ↗ energy intensity
Zhang and Meng (2019)	• 115 countries • 1996–2014	INTER, CO_2, GDP, UR, INDU	FE	∩	• INTER (-) CO_2 • Internet penetration has an increasing negative impact on the reduction of CO_2.
Shabani and Shahnazi (2019)	• Iran • 2002–2013	ICT, EC, GDP, CO_2	DOLS, panel causality test	∩	• Industrial sector: ICT (+) CO_2; transportation and services sectors: ICT (-) CO_2 • Industrial and transportation sectors: ICT ↔ CO_2(SR); services sector: ICT→CO_2 (SR), ICT, GDP, EC → CO_2 (LR)

Appendix 2. (Continued)

Authors	Data sample	Variables	Methodology	Shape of EKC	Main findings
Studies of the nexus of renewable energy and CO_2 emissions					
Shafiei and Salim (2014)	• OECD countries • 1980–2011	NRE, RE, INDU, POP, UR, GDP, CO_2	AMG		• 1 % ↗ RE, 0.004 % ↘ CO_2 • 1 % ↗ NRE, 1.038 % ↗ CO_2
Paramati et al. (2017)	• G20 countries • 1991–2012	FDI, EE, SMC, POP, RE, NRE, GDP, CO_2	FMOLS		• Full sample: 1% ↗ RE, 0.038% ↘ CO_2 • Advanced economies: 1 % ↗ RE, 0.024% ↘ CO_2 • Developing economies: 1 % ↗ RE, 0.062% ↘ CO_2
Ito (2017)	• 42 developing countries • 2002–2011	RE, NRE, GDP, CO_2	GMM, PMG		• 1 % ↗ RE, 0.11~0.25 % ↘ CO_2 • 1% ↗ NRE, 0.56~0.93 % ↗ CO_2
Bekhet and Othman (2018)	• Malaysia • 1971–2015	RE, GDP, CO_2	VECM Granger causality analysis, DOLS, FMOLS	N	• RE (-) CO_2 • GDP ↔ CO_2, CO_2 → RE (SR); CO_2, GDP → RE (LR)
Balsalobre-Lorente et al. (2018)	• Five European Union countries • 1985–2016	REC, TO, NAR, EIN, GDP, CO_2	PLS	N	• RE (-) CO2
Cai et al. (2018)	• G7 countries • 1965–2015	CEC, GDP, CO_2	ARDL cointegration test, Granger causality test		• Germany: CEC and CO_2 co-integrated with CO_2; Japan: CEC and GDP co-integrated with CO2. • CEC ↔ CO_2 in Germany; CEC → CO_2 in United States.
Dong et al. (2018)	• 128 countries • 1990–2014	RE, POP, GDP, CO_2	FMOLS, CCEMG		• North America: 1% ↗ RE, 0.1603% ↘ CO_2; South and Central America: 1% ↗ RE, 0.3242% ↘ CO_2; Europe and Eurasia: 1% ↗ RE, 0.1917% ↘ CO_2; Middle East: 1% ↗ RE, 0.1107% ↘ CO_2; Africa: 1% ↗ RE, 0.1884% ↘ CO_2; Asia Pacific: 1% ↗ RE, 0.1018% ↘ CO_2; Global panel: 1% ↗ RE, 0.1184 % ↘ CO_2.
Qiao et al. (2019)	• 19 G20 countries • 1990–2014	RE, AGI, GDP, CO_2	FMOLS	∩	• Full sample: 1% ↗ RE, 0.130% ↘ CO_2 • Advanced economies: 1 % ↗ RE, 0.156% ↘ CO_2 • Developing economies: 1 % ↗ RE, 0.036% ↘ CO_2

Appendix 2. (Continued)

Authors	Data sample	Variables	Methodology	Shape of EKC	Main findings
Studies of the nexus of trade and CO_2 emissions					
Lau et al. (2014)	• Malaysia • 1970–2008	TO, FDI, GDP, CO_2	Bounds test, VECM Granger causality analysis	∩	• TO (+) CO_2 • FDI (+) CO_2
Ren et al. (2014)	• Industrial sector of China • 2000–2010	TO, FDI, GDP, CO_2	GMM	∩	• TO (+) CO_2
Omri et al. (2015)	• 12 MENA countries	FD, TO, GDP, CO_2	GMM	∩	• TO $\rightarrow$ CO_2
Shahbaz et al. (2017a)	• Unites States • 1960–2016	RE, TO, OP, GDP, CO_2	Bounds test, VECM Granger causality analysis	N	• TO (-) CO_2
Shahbaz et al. (2017b)	• 105 countries	TO, GDP, CO_2	FMOLS, VECM Granger causality analysis		• TO (+) CO_2 • TO $\leftrightarrow$ CO_2 for global level and middle-income countries • TO $\rightarrow$ CO_2 for high- and low-income countries
Frutos-Bencze et al. (2017)	• CAFTA-DR member countries	TO, FDI, CO_2	GMM	∩	• TO (-) CO_2
Hasanov et al. (2018)	• Nine oil-exporting countries • 1995–2013	Import, export, GDP, CO_2	FMOLS, DOLS, PMG		• 1% $\nearrow$ import, 0.3-0.4% $\nearrow$ CO_2 • 1% $\nearrow$ export, 0.6-0.8% $\nearrow$ CO2
Mutascu (2018)	• France	TO, CO_2,	Time frequency approach		• No co-movement between TO and CO_2 at high frequency • CO_2 (+) TO at medium frequency; TO (+) CO_2 at low frequency
Zhang and Zhang (2018)	• China • 1982–2016	ST, ER, FDI, GDP, CO_2	ARDL bound test, VAR Granger causality test	∩	• ST (-) CO_2 • ST $\leftrightarrow$ CO_2

Note: ***1) Variables:*** EC=energy consumption, TO= trade openness, MAN= manufacture value added, FF= fossil fuels consumption, NU= nuclear energy consumption, RE= renewable energy consumption, POP = population, FD= financial development, HCD=human capital development, INDU= industrialization, UR= urbanization, EI=energy intensity, INTER= internet use (or internet penetration), EP= energy productivity, NRE= non-renewable energy consumption, EE= energy efficiency, SMC= stock market capitalization, REC= renewable electricity consumption, NAR=natural resource, EIN=energy innovation, CEC= clean energy consumption, ARI=agricultural value added, OP=oil price, ER=exchange rate, ST=services trade; ***2) Methods:*** ARDL=autoregressive distributed lag, VECM=vector error correction model, CCR=canonical cointegration regression, FE= fixed-effect analysis, PMG=pooled mean group, POLS= pooled ordinary least squares, MG= group estimator, AMG= augmented mean group estimator, GM-FMOLS=group-mean fully modified ordinary least squares, GMM= generalized method of moments, SDA= three-tier structural decomposition analysis, PLS=partial least squares, CCEMG=common correlated effects mean group, VAR=vector autoregression ***3)*** MENA countries denote Middle East and North African countries, CAFTA-DR denote Central American Free Trade Agreement-Dominican Republic ***4) Symbols:*** $\leftrightarrow$ denotes bidirectional causality, $\rightarrow$ denotes unidirectional causality, $\nearrow$ denotes increase of variables, $\searrow$ denotes decline of variables, (+) denotes positive impact, (-) denotes negative impact, SR denotes short-run term, LR denotes long-run term.

References

Asongu, S. A., S. L. Roux and N. Biekpe (2018), "Enhancing ICT for environmental sustainability in sub-Saharan Africa", *Technological Forecasting & Social Change*, 127, 209–216.

Asongu, S. A. (2018), "ICT, openness and CO_2 emissions in Africa", *Environmental Science and Pollution Research*, 25, 9351–9359.

Berkhout, F. and J. Hertin (2001), "Impacts of information and communication technologies on environmental sustainability: speculations and evidence. Organisation for Economic Co-operation and Development Report", United Kingdom. Available at: http://www.oecd.org/science/inno/1897156.pdf.

Bekhet, H. A. and N. S. Othman (2018), "The role of renewable energy to validate dynamic interaction between CO_2 emissions and GDP toward sustainable development in Malaysia", *Energy Economics*, 72, 47–61.

Balsalobre-Lorente, D., M. Shahbaz, D. Roubaud and S. Farhani (2018), "How economic growth, renewable electricity and natural resources contribute to CO_2 emissions?", *Energy Policy*, 113, 356–367.

Cai, Y. F., C. Y. Sam and T. Chang (2018), "Nexus between clean energy consumption, economic growth and CO_2 emissions", *Journal of Cleaner Production*, 182, 1001–1011.

Dong, K.Y., G. Hochman, Y. Q. Zhang, R. J. Sun, H. Li and H. Liao (2018), "CO_2 emissions, economic and population growth, and renewable energy: empirical evidence across regions", *Energy Economics*, 75, 180–192.

Farhani, S., S. Mrizak, A. Chaibi and C. Rault (2014), "The environmental Kuznets curve and sustainability: a panel data analysis", *Energy Policy*, 71, 189–198.

Frutos-Bencze, D., K. Bukkavesa and N. Kulvanich (2017), "Impact of FDI and trade on environmental quality in the CAFTA-DR region", *Applied Economics Letters*, 24(19), 1393–1398.

Fujii, H., K. Iwata, A. Chapman, S. Kagawa and S. Managi (2018), "An analysis of urban environmental Kuznets curve of CO_2 emissions: empirical analysis of 276 global metropolitan areas", *Applied Energy*, 228, 1561–1568.

Grossman, G. M. and A. B. Krueger (1991) "Environmental impacts of a North American free trade agreement", National Bureau of Economic Research Working Paper No.3914. NBER, Cambridge, MA.

GeSI (2015) *Global e-Sustainability Initiative. SMARTer 2030. ICT Solutions for 21st Century Challenges*. Available at: http://smarter2030.gesi.org/downloads/Full_report.pdf.

Han, B., D. Wang, W. Ding and L. Han (2016), "Effect of information and communication technology on energy consumption in China", *Nat Hazards*, 84, S297–S315.

Higón, D. A., R. Gholami and F. Shirazi (2017), "ICT and environmental sustainability: a global perspective", *Telematics and Informatics*, 34, 85–95.

Hasanov, F. J., B. Liddle and J. I. Mikayilov (2018), "The impact of international trade on CO_2 emissions in oil exporting countries: territory vs consumption emissions accounting", *Energy Economics*, 74, 343–350.

Ito., K. (2017), "CO_2 emissions, renewable and non-renewable energy consumption, and economic growth: evidence from panel data for developing countries", *International Economics*, 151, 1–6.

IEA (2018), *International Energy Agency*. Global Energy and CO_2 Status Report. Available at: https://www.iea.org/geco/.

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

Lau, L. S., C. K. Choong and Y. K. Eng (2014), "Investigation of the environmental Kuznets curve for carbon emissions in Malaysia: do foreign direct investment and trade matter?", *Energy*

Policy, 68, 490–497.

Ling, C. H., K. Ahmed, R. B. Muhamad and M. Shahbaz (2015), "Decomposing the trade-environment nexus for Malaysia: what do the technique, scale, composition, and comparative advantage effect indicate?", *Environmental Science and Pollution Research*, 22, 20131–20142.

Li, L., Y. L. Lei, C. Y. He, S. M. Wu and J. B. Chen (2017), "Study on the CO_2 emissions embodied in the trade of China's steel industry: based on the input–output model", *Nat Hazards*, 86, 989–1005.

Maddala, G. S. and S. Wu (1999), "A comparative study of unit root tests with panel data and a new simple test", *Oxford Bulletin of Economics and Statistics*, 61, 631–652.

Mutascu, M. (2018), "A time-frequency analysis of trade openness and CO_2 emissions in France", *Energy Policy*, 115, 443–455.

Mohlin, K., J. R. Camuzeauxa, A. Mullerb, M. Schneiderc and G. Wagner (2018), "Factoring in the forgotten role of renewables in CO_2 emission trends using decomposition analysis", *Energy Policy*, 116, 290–296.

Mikayilov, J. I., M. Galeotti and F. J. Hasanov (2018), "The impact of economic growth on CO_2 emissions in Azerbaijan", *Journal of Cleaner Production*, 197, 1558–1572.

McKinsey (2019), *McKinsey Global Institute*. Globalization in Transition: The Future of Trade and Value Chains.

Omri, A., S. Daly, C. Rault and A. Chaibi (2015), "Financial development, environmental quality, trade and economic growth: what causes what in MENA countries", *Energy Economics*, 48, 242–252.

Ozcan, B. and N. Apergis (2018), "The impact of internet use on air pollution: evidence from emerging countries", *Environmental Science and Pollution Research*, 25, 4174–4189.

Omri, A., J. Euchi, A. H. Hasaballah and A. Altit (2019) "Determinants of environmental sustainability: evidence from Saudi Arabia", *Science of the Total Environment*, 657, 1592–1601.

Pao, H.T. and C. M. Tsai (2010), "CO_2 emissions, energy consumption and economic growth in BRIC countries", *Energy Policy*, 38, 7850–7860.

Paramati, S. R., D. Mo and R. Gupta (2017), "The effects of stock market growth and renewable energy use on CO_2 emissions: evidence from G20 countries", *Energy Economics*, 66, 360–371.

Qiao, H., F. T. Zheng, H. D. Jiang and K. Y. Dong (2019), "The greenhouse effect of the agriculture-economic growth-renewable energy nexus: evidence from G20 countries", *Science of the Total Evironment*, 671, 722–731.

Røpke, I. and T. C. Christensen (2012), "Energy impacts of ICT - insights from an everyday life perspective", *Telematics and Informatics*, 29, 348–361.

Ren, S., B. Yuan, X. Ma and X. H. Chen (2014), "International trade, FDI and embodied CO_2 emissions: a case study of Chinas industrial sectors", *China Economic Review*, 28, 123–134.

Riti, J. S., D. Y. Song, Y. Shu and M. Kamah (2017), "Decoupling CO_2 emission and economic growth in China: is there consistency in estimation results in analyzing environmental Kuznets curve? ", *Journal of Cleaner Production*, 166, 1448–1461.

Shafik, N. (1994), "Economic development and environmental quality: an econometric analysis", *Oxford Economic Papers*, 46, 757–773.

Shafiei, S. and R. A. Salim (2014), "Non-renewable and renewable energy consumption and CO_2 emissions in OECD countries: a comparative analysis", *Energy Policy*, 66, 547–556.

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

Salahuddin, M., K. Alam and I. Ozturk (2016b), "Is rapid growth in internet usage environmentally sustainable for Australia? An empirical investigation", *Environmental Science and Pollution Research*, 23, 4700–4713.

Shahbaz, M., S. A. Solarin, S. Hammoudeh and S. J. H. Shahzad (2017a), "Bounds testing approach to analyzing the environment Kuznet curve hypothesis with structural beaks: the role of biomass energy consumption in the unites states", *Energy Economics*, 68, 548–565.

Shahbaz, M., S. Nasreen, K. Ahmed and S. Hammoudeh (2017b), "Trade openness-carbon emissions nexus: the importance of turning points of trade openness for country panels", *Energy Economics*, 61, 221–232.

Shabani, Z. D. and R. Shahnazi (2019), "Energy consumption, carbo dioxide emissions, information and communications technology, and gross domestic product in Iranian economic sectors: a panel causality analysis", *Energy*, 169, 1064–1078.

Williams, E. (2011), "Environmental effects of information and communications technologies", *Nature*, 479, 354–358.

World Bank, (2019), *World development indicators*. Available at: https://databank.worldbank.org/source/world-development-indicators.

Yan, Z. M., R. Shi and Z. M. Yang (2018), "ICT development and sustainable energy consumption: a perspective of energy productivity", *Sustainability*, 10, 2568.

Zhang, C. G. and C. Liu (2015), "The impact of ICT industry on CO_2 emissions: a regional analysis in china", *Renewable and Sustainable Energy Reviews*, 44, 12–19.

Zaghdoudi, T. (2017), "Internet usage, renewable energy, electricity consumption and economic growth: evidence from advanced economies", *Economics Bulletin*, 37(3), 1612–1619.

Zhang, Y. and Zhang, S. F. (2018) "The impacts of GDP, trade structure, exchange rate and FDI inflows on China's carbon emissions", *Energy Policy*, 120, 347–353.

Zhou, X. Y., D. Q. Zhou and Q. W. Wang (2018), "How does information and communication technology affect China's energy intensity? A three-tier structural decomposition analysis", *Energy*, 151, 748–759.

Zhang, Z. B. and X. H. Meng (2019), "Internet penetration and the environmental Kuznets curve: a cross-national analysis", *Sustainability*, 11, 1358.