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An econometric study of the impact of economic growth and energy use on carbon emissions: Panel data evidence from fifty eight countries

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ABSTRACT

The aim of this paper is to provide new empirical evidence on the impact of economic growth and energy use on carbon emissions (CO_2 emissions) for fifty eight countries over the period 1990–2012 by using a panel data model. We also apply this model in order to implement three regional sub-groups; European and North Asian region, Latin American and Caribbean region, and the Middle Eastern, North African and sub-Saharan region. The results revealed that the energy use has a positive impact on the carbon dioxide emissions for all the panels. The impact of economic growth on the environment has received increased attention as global warming and other environmental problems become more serious. Indeed, the per capita GDP has a positive and statistically significant impact on carbon for the global panel, for the Europe and North Asia, and for the Middle Eastern, North Africa, and sub-Saharan Africa. Furthermore, our empirical results indicate the presence of an inverted U-shaped curve between carbon dioxide emissions and GDP per capita.

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1. Introduction

The relationship between economic growth and carbon dioxide emissions is considered as one of the most important empirical relationships tested in the economic literature, (see e.g., Copeland and Taylor [23], Payne [62], Halkos and Tzeremes [34], among others). The environmental Kuznets curve (EKC) was firstly defined by Simon Kuznets [43]. The EKC hypothesis assumes that the environmental quality first deteriorates until a certain level of income is reached and then improves as economic development proceeds. In addition, some studies confirmed that the EKC hypothesis posits an inverted U-shaped relationship between economic growth and environmental degradation [15,21,32,44,73]. This hypothesis indicates that an additional increase of economic growth can improve the environmental quality or CO_2 emissions. The works of [82,22,25,49] provided an extensive study on the economic growth-environmental pollution nexus with EKC

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hypothesis. Since there is a large and growing world-wide consumption of fossil fuels, the amount of CO_2 emissions in our environment has been increasing.

The linkage between economic growth, energy use, and carbon dioxide emissions has been an active research area, For instance, Mehrara [53] investigated the relationship between per capita energy use, and economic growth in a panel of 11 selected oil exporting countries during the 1971–2002 periods. Their empirical results showed a unidirectional causality from per capita GDP to per capita energy use. The findings imply also that the energy conservation through reforming energy price policies has no damaging repercussions on per capita GDP for this group of countries. Akbostanci and Turut-Asik [2]; analyzed the link between pollution emissions and income in Turkey by using time series for 1968–2003 and 1992–2001 periods. Their results supported the existence of the EKC hypothesis that could not be reached.

Apergis and Payne [9] used the sign vector error correction model for six Central American countries to analyze the causal link between CO_2 emissions, energy consumption and economic growth. Energy consumption has a positive and statistically significant impact on CO_2 emissions while real output exhibits the inverted U-shape pattern associated with the EKC hypothesis. In addition, the results indicated a unidirectional causality from energy consumption and, respectively, to emissions along with a bidirectional causality between energy consumption and economic growth. More recently, Zhang and Cheng [87] has investigated the existence and the direction of causality relationship between economic growth, energy consumption, and CO_2 emissions in China. Empirical results showed a unidirectional Granger causality running from per capita GDP to energy consumption, and a unidirectional Granger causality running from energy consumption to CO_2 emissions in the long run. For 43 developing countries, Menyah and Wolde-Rufael [54] analyzed the causation between CO_2 emissions and economic growth. Their empirical analysis showed that the income elasticity in the long run is smaller than the short run, implying that CO_2 emission has fallen with a rise of the income.

Finally, Saidi and Hammami [69] studied the linkages between energy consumption and economic growth using data from Tunisia. Their empirical findings showed that there exists a bidirectional causal relationship between energy consumption and economic growth in the long-run. In the same way, Mounir et al. [55] affirmed that there is a unidirectional relationship from GDP to CO_2 emissions in the short term for Tunisia. Alshehry and Belloumi [4] examined the relationships between energy consumption, carbon emissions (CO_2 emissions) and economic growth in Saudi Arabia during the 1971–2010 periods. Their results showed that there exists a long-run unidirectional causality stand from energy consumption to per capita GDP and carbon emissions, bidirectional causality between carbon emissions and economic growth. In the short-run, there is unidirectional causality running from carbon emissions to energy consumption and economic growth. In the same way, Saidi and Hammami [70] examined the causal link between per capita energy consumption, per capita CO_2 emissions and per capita GDP in fifty eight countries. Their results indicate that there is a bidirectional causality relationship between per capita energy consumption and per capita GDP and a bidirectional causality relationship between energy consumption and CO_2 emissions.

The purpose of this paper is to investigate the impact of economic growth and energy use on carbon emissions (CO_2 emissions) for a panel of fifty eight countries. The present study is different from the previous ones in the following ways. First, Empirical models are estimated using panel generalized method of moments (GMM system) regression techniques. Second, we used, as an investigating technique, a dynamic panel data model, which follows the spirit of the conventional 'growth model' framework. Since they depict only short-run impacts, growth model cannot be modeled within a co-integrating framework. The reason is that all the variables in a growth form model are stationary, while co-integration (long-run impacts) demands that all the variables, as a pre-requisite, need to be non-stationary. Our approach is to estimate the short-run elasticities but not the long-run one given our growth form modeling approach. There is a strong motivation for us to apply a growth form approach to examine the impact of economic growth and energy use on carbon emissions (CO_2 emissions). Third, our literature survey typically suggests that few studies have examined the impact of growth and energy on the environment. They mainly consider Europe and North Asia, Latin America and the Caribbean, and the Middle East, North Africa and sub-Saharan Africa.

The rest of the article is divided into six main sections. Section 2 gives a brief review of literature; the data source and descriptive statistic are outlined in Section 3. The empirical model and econometric methodology are discussed in Section 4. The empirical findings are reported in Section 5, and finally in Section 6, there are the conclusions and policy implications that were drawn.

2. A brief review of literature

2.1. Literature review on economic growth and carbon dioxide emissions

Numerous existing studies suggested that economic development and technology advancement significantly influence carbon dioxide emissions. For instance, Perman and Stern [63] analyzed the relationship between sulfur emissions and per capita GDP for 74 countries, using a co-integration analysis to test the EKC hypothesis. These authors showed that the EKC is a problematic concept, at least in the case of sulfur emissions. Markandya et al. [51] investigated the linkage between sulfur emissions and economic growth for 12 Western European countries. The results showed that there is an inverted U-shaped relationship between per capita GDP and carbon emissions. In addition, environmental regulations are found to reduce the EKC and they can also shift the turning point of the curve. According to the EKC hypothesis, Managi [50] showed that economic growth and the reduction of environmental degradation are compatible goals. Besides, the author affirmed that there is an inverted U-shaped relationship between economic performance and environmental pollution. However, this study tested the hypothesis that there are increasing returns to abating pollution. The findings showed the importance of including an environmental productivity variable in the EKC framework.

A recent study by Soytas et al. [80] has investigated the effect of energy consumption and output on carbon dioxide emissions in the United States, using the Granger causality relationship between income, energy consumption, and carbon emissions. The findings showed that income does not Granger cause the carbon emissions in the US in the long run. Hence, income growth by itself may not become a solution to the environmental problems. Furthermore, Soytas and Sari [81], using the same approaches and variables as that of Soytas et al. [80], investigated the causality relationship between economic growth, carbon dioxide emissions and energy consumption in Turkey. The most interesting result is that the carbon emissions seem to Granger cause energy consumption. The lack of a long run causal relationship between economic growth and CO_2 emissions may imply to reduce carbon emissions; Turkey does not have to forgo economic growth. To the best of our knowledge, Narayan and Narayan [56] tested the EKC hypothesis for 43 developing countries long-run and short-run between carbon emissions and economic growth. Their results showed that it is evident that a country reduces carbon dioxide emissions as its income increases. In addition, the authors examined the EKC hypothesis for panels of countries constructed on the basis of regional location using the panel co-integration and the panel long-run estimation techniques. These authors found that only for the Middle East and South Asia panels that income elasticity in the long run is smaller than that of the short run, implying that CO_2 emission falls with increased revenues.

Finally, in a study of 93 developing countries, Narayan and Popp [57] tested the hypothesis of CKE on the basis of the short- and long-run income elasticities vis-a-vis CO_2 emissions. In other words, if the long-run income elasticity is smaller than the short-run elasticity, then it will be evident for them that a country reduces CO_2 emissions as its income increases. The writers found that the income elasticity in the long-run is smaller than that of the short-run, which implies that carbon dioxide emission fall with the rise of the income for the Middle Eastern panel.

2.2. Literature review on energy use and carbon dioxide emissions

In recent years, many researchers have been significantly interested in the factors that affect the emission of carbon dioxide associated with energy use and many interesting results were obtained. For instance, Sari and Soytas [71] found a positive impact of energy on the environment and a unidirectional relationship running from energy consumption to pollution emissions. For Malaysia, Ang [5] analyzed the dynamic linkages between economic growth, carbon emissions, and energy consumption using a multivariate vector error correction model. Their results showed that energy consumption has a direct impact on the level of environmental pollution. Lean and Smyth [45] analyzed the causation between energy consumption, carbon dioxide emissions and income for the ASEAN countries using a panel vector error correction model. Their findings showed that there is a positive and significant long-run relation between electricity consumption and CO_2 emissions. In another study, Apergis and Payne [9] dealt with the causal relationship between carbon emissions, energy consumption, and output for six Central American countries. Their results indicated that energy consumption has a positive and statistically significant impact on CO_2 emissions but the real output exhibits the EKC hypothesis in the long-run. On the other hand, Halicioglu [33] examined the relationship between CO_2 emissions, energy consumption, per capita GDP, and foreign trade in Turkey over the 1960–2005 periods. The results indicated that there is a long-run relationship between the variables. The CO_2 emissions are determined by energy consumption, GDP and foreign trade.

For the panel studies, Apergis and James [11] investigated the relationship between carbon dioxide emissions, energy consumption, and real output using a panel vector error correction model for 11 countries of the Commonwealth Independent States over the 1992–2004 periods. In the long-run, energy consumption has a positive and statistically significant impact on carbon dioxide emissions whereas the real output follows an inverted U-shape pattern associated with the EKC hypothesis. Bhattacharyya and Ghoshal [17], in another study, investigated the relationship between CO_2 emissions, energy consumption and per capita real GDP in 25 countries. They found a positive impact of energy consumption on carbon dioxide emissions and causality running from energy consumption to CO_2 emissions for most countries. According to Kim and Baek [42], energy consumption has a damaging long run effect on CO_2 emissions for both developed and developing countries, that is, an increase in per capita energy consumption leads to environmental degradation.

On the other hand, Saboori and Soleymani [66] carried out a study on Iran over the 1971–2007 periods in order to investigate the relationship between carbon dioxide, economic growth and energy consumption using the EKC hypothesis. The results obtained suggest the existence of three forms of long-run relationship between the variables when CO_2 emissions, economic growth and energy consumption are the dependent variables. Their results do not support the EKC hypothesis which assumes an inverted U-shaped relationship between income and environmental degradation. They employed the Autoregressive Distributed Lag (ARDL) model as the estimation method and found that energy consumption has a positive and significant impact on CO_2 emissions in the long run.

In another paper, Arouri et al. [14] examined the effect of energy consumption and per capita GDP on carbon dioxide emissions for 12 MENA countries over the 1981–2005 periods. Their results showed that, in the long-run, energy consumption has a positive significant impact on CO_2 emissions. More interestingly, they showed that per capita GDP has a quadratic relationship with CO_2 emissions for the region as a whole. In addition, Boopen and Harris [19] investigated the relationship between energy, emissions and economic growth in Mauritius in the presence of trade activities, with capital and labor as other control variables. Using annual data from 1960 to 2011, they found that the variables are non-stationary and co-integrated. The results showed that energy consumption has a significant impact on CO_2 emissions. In country case studies, Yang et al. [86] studied the dynamic relationship between carbon emissions, energy consumption, and economic growth in Shanghai, by adopting the co-integration and vector error correction methods. The empirical results showed that, in the long-run, there is a positive relationship of equilibrium between carbon emission and energy consumption.

2.3. Literature review on urbanization, trade openness and carbon dioxide emissions

Trade openness is a vital factor that could influence the environmental quality. The impact of trade liberalization can be decomposed into scale, technique, and a composition effect was conducted by Antweiler et al. [8]. Nevertheless, contradictory results are found in the empirical literature on the role of trade openness. Several researchers, like [28,31], concluded that trade is beneficial for the environment; however, others consider it harmful [1,20]. Nasir and Rehman [59] used the ADF unit root test and Johansen and Juselius [39] co-integration test which supported EKC in Pakistan and reported a positive impact of trade openness on CO_2 emissions whereas Shahbaz et al. [75] found that trade openness reduces CO_2 emissions.

In the case of developing countries, Fan et al. [26] examined the link between carbon emissions and urbanization, and found a negative relationship between urbanization and carbon dioxide emissions. Regarding the urbanization-CO_2 emission relationship, Dhakal [24] found that 40% of the contribution in CO_2 emissions was made by 18% increase of the population in the large cities of China. In a similar study, Jalil and Mahmud [38] found that the carbon emissions are mainly determined by income and energy consumption in the long-run. Trade has a positive but statistically insignificant impact on CO_2 emissions. Using panel data of 17 developed countries, Liddle and Lung [47] proved a positive but insignificant impact of urbanization on carbon dioxide emissions when aggregate carbon dioxide emissions are used as dependent variables. Urbanization has a positive and statistically

Table 1
Summary of previous studies about the impact of energy use and economic growth on carbon dioxide emissions.

Authors	Sample and period	Methodology	Results
Perman and Stern [63]	74 countries (1960–1990)	Co-integration test	GDP and square GDP have a positive and significant impact on CO_2 emissions.
Markandya et al. [51]	12 Western European countries (1850–2001)	Unit root test, co-integration test	Inverted U-shaped relationship between income and pollution.
Richmond and Kauffman [65]	20 developed countries (1973–1997)	Co-integration test	Energy consumption and per capita GDP have a positive impact on CO_2 emissions
Managi [50]	48 states (1970–1997)	EKC hypothesis	Inverted U-shaped relationship between GDP per capita and environmental pollution.
Fan et al. [26]	Developing countries (1975–2003)	STIRPAT model	Urbanization has a positive impact on CO_2 emissions.
Soytas et al. [80]	USA (1960–2004)	Granger causality; Variance decomposition	EC and GDP have a positive impact on CO_2 emissions.
Ang [5]	Malaysia (1971–1999)	Panel co-integration test and Vector error correction; Granger causality	A positive impact of energy consumption on CO_2 emissions.
Halicioglu [33]	Turkey (1960–2005)	Panel co-integration test; Granger causality	• Economic growth has a more significant impact on the CO_2 emissions • CO_2 emissions are determined by energy consumption, GDP per capita.
Lean and Smyth [45]	ASEAN countries (1980–1960) (1980–2006)	Vector error correction; Granger causality	A positive and significant relation between EC and CO_2 emissions.
Apergis and Payne [9]	Six central American countries (1971–2004)	EKC hypothesis	Energy consumption has a positive and statistically significant impact on CO_2 emissions.
Jalil and Mahmud [38]	China (1975–2005)	Panel co-integration test; Granger causality; ARDL	Trade openness has a positive but statistically insignificant impact on CO_2 emissions.
Narayan and Narayan [56]	43 developing countries (1980–2004)	Panel co-integration test; EKC hypothesis	A CO_2 emission has fallen with a rise in economic growth.
Apergis and James [11]	11 countries of the commonwealth independent states (1992–2004)	Vector error correction model; Panel co-integration test	• Energy consumption has a positive and statistically significant impact on CO_2 emissions • U-shape patten associated with the EKC hypothesis
Bhattacharyya and Ghoshal [17]	25 countries (1950–2000)	Co-integration test	Energy consumption has a positive impact on CO_2 emissions.
Liddle and Lung [47]	17 developed countries (1960–2005)	STIRPAT model	• A positive but insignificant impact of urbanization on CO_2 emissions • Urbanization has a positive and statistically significant impact on CO_2 emissions when carbon dioxide from transport is used as a dependent variable
Poumanyvong and Kaneko [64]	99 countries (1975–2005)	STIRPAT model	The impact the urbanization on CO_2 emissions is positive
Martinez-Zarzoso and Maruotti (2011)	Developing countries (1975–2003)	EKC hypothesis;	• Inverted U-shaped relationship between urbanization and CO_2 emissions • The increases in the urbanization rate do not contribute to higher emissions
Hossain [36]	Newly industrialize countries (NIC) (1971–2007)	Unit root tests; Co-integration tests; Granger causality	Energy consumption and per capita GDP have a positive effect on CO_2 emissions Urbanization has a negative effect on CO_2 emissions
Kim and Baek [42]	Developed and developing countries (1971–2005)	Co-integration, ARDL approach	Energy consumption causes environmental degradation.
Sharma [77]	69 countries (1985–2005)	Dynamic panel data model	• Urbanization does have a negative and statistically significant impact on CO_2 emissions for the global panel. • Urbanization has a negative but insignificant impact on CO_2 emissions in the low income, middle income, and high income panels.
Saboori and Soleymani [66]	Iran (1971–2007)	Co-integration approach; ARDL	• EKC hypothesis assumes an inverted U-shaped relationship between income and environmental degradation. • Energy consumption has a positive and significant impact on CO_2 emissions
Narayan and Popp [57]	93 developing countries (1980–2006)	Granger causality	• Economic growth has a positive and significant impact on CO_2 emissions • Energy consumption has a positive and significant impact on GDP per capita
Arouri et al. [14]	12 MENA (1981–2005)	Unit root tests and Co-integration techniques	• Energy consumption has a positive significant impact on CO_2 emissions. • Economic growth has a positive impact on CO_2 emissions
Boopen and Harris [19]	Mauritius (1960–2011)	Co-integration tests; VECM	Energy consumption has a significant impact on CO_2 emissions
Yang et al. [86]	Shanghai (2011–2020)	Panel co-integration tests; vector error correction	Energy consumption has a positive impact on CO_2 emissions
Sulaiman et al. [83]	Malaysia (1980–2009)	EKC hypothesis, ARDL; VECM	Trade openness has a significant negative effect on the CO_2 emissions in the long-run
Sadorsky [68]	Emerging economies (1971–2009)	STIRPAT model	Urbanization is positive but statistically insignificant on CO_2 emissions

Notes: EC refers to energy consumption, GDP: economic growth, CO_2: Carbone dioxide emissions, URB: Urbanization, TR: Trade openness and EKC refers to environmental Kuznets curve. STIRPAT: Stochastic Impacts by Regression on Population, Affluence and Technology. ARDL: Auto regressive distributed lag. Vector error correction mode (VECM).

Table 2
Presents descriptive statistics for all variables used in this survey.

Variables	European and North Asian region			Latin American and the Caribbean region			Middle Eastern, North African, and sub-Saharan region		
	Mean	Std. dev	CV	Mean	Std. dev	CV	Mean	Std. dev	CV
E	2.055	31.304	15.233	1.109	12.385	11.197	2.730	44.648	16.345
Y	3.994	46.511	11.645	1.470	16.652	11.327	8.432	127.934	15.172
C	2.274	41.132	18.087	2.173	20.110	9.254	25.340	325.035	12.826
URB	72.781	17.579	0.241	68.314	16.487	0.241	46.727	17.373	0.371
TR	98.825	72.874	0.737	68.478	36.190	0.528	68.088	25.519	0.374

Notes: Std dev. and CV indicate standard deviation and coefficients of variation (standard deviation-to-mean ratio), respectively.

significant impact on carbon dioxide emissions when carbon dioxide from transport is used as a dependent variable.

In their pioneering effort, Poumanyvong and Kaneko [64] investigated the empirical impact of urbanization on CO_2 emissions and energy use in 99 countries. Their results indicate that the impact the urbanization on CO_2 emissions is positive for all the income groups, but for more significant intermediary income group than for the other income groups. These new findings not only help improve the existing literature, but also can be of special interest to policy makers and urban planners. Similarly, Sharma [78] concluded that trade has a negative effect on the CO_2 emissions. On the other hand, Martínez-Zarzoso and Maruotti [52] analyzed the impact of urbanization on the CO_2 emissions in the developing countries from 1975 to 2003. Their results showed an inverted-U shaped relationship between urbanization and CO_2 emissions. Indeed, elasticity emission-urbanization is positive for low urbanization levels, which is in accordance with the higher environmental impact observed in the less developed regions. For two of the groups, a threshold level was identified beyond which the emission-urbanization elasticity is negative; besides, further increases in the urbanization rate do not contribute to higher emissions. The differential impact of urbanization on CO_2 emissions should therefore be taken into account in future discussions about the climate change policies.

Another study carried out by Hossain [36] on a panel of nine newly-industrialized countries, examined the relationship between CO_2 emissions, energy consumption, output, trade openness and urbanization. Their study indicated that the income and energy consumption have a long-run significant impact on CO_2 emissions for the Philippines and Thailand but not for Malaysia. In the long-run, a 1% increase in the energy use implies an increase of the CO_2 emissions by 1.2% and urbanization lowers CO_2 emissions by 0.6%. In contrast, Sharma [77] studied a large panel of 69 countries and found that urbanization does have a negative and statistically significant impact on carbon emissions for the global panel. For this panel, a 1% increase in urbanization causes a decrease of the CO_2 emissions by 0.7%. Urbanization has a negative but insignificant impact on carbon emissions in the low income, middle income and high income panels. Most of the studies, like that of Sulaiman et al. [83], studied the impact of electricity consumption and trade openness on the environment in Malaysia. Using the Autoregressive Distributed Lag (ARDL) approach the results showed that Trade openness has a significant negative effect on the CO_2 emissions in the long-run. Recently, Sadorsky [68] has developed a panel regression technique that allow for heterogeneous slope coefficients and cross-section dependence to model the impact of urbanization on the CO_2 emissions for a panel of emerging economies over the years 1971–2009. Their results indicated that in most specifications, the estimated coefficient on the urbanization variable is positive but statistically insignificant. Table 1 shows a summary of the empirical studies about the impact of energy use and economic growth on carbon dioxide emissions.

3. Data specifications and descriptive statistic

The main data sources used in this study collects annual data on carbon dioxide emissions, energy use, economic growth, urbanization and trade openness for the period between 1990 and 2012 from the World Development Indicators (WDI 2013-CD-ROM). The study covers 58 selected countries. They include:

(1) *The European and North Asian region*, consisting of 22 countries, namely: Albania, Belgium, Bulgaria, Denmark, France, Germany, Greece, Hong Kong, Korea, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom;
(2) *The Latin American and the Caribbean region*, consisting of 15 countries, namely: Argentina, Bolivia, Brazil, Nicaragua, Chile, Costa Rica, Ecuador, Guatemala, Honduras, Mexico, Panama, Paraguay, Peru, Uruguay, and Venezuela;
(3) *The Middle Eastern, North African, and sub-Saharan region*, consisting of 21 countries, namely: Algeria, Botswana, Cameroon, Congo, Cote D'Ivoire, Ethiopia, Gabon, Ghana, Egypt, Iran, Jordon, Kenya, Morocco, Mozambique, South Africa, Senegal, Sudan, Syrian Arab Republic, Togo, Tunisia, and Zambia.

Therefore, total data are used rather than per capita data. A carbon dioxide emission is measured in metric tons per capita. Energy use is measured in kg of oil equivalent per capita. Gross domestic product is measured in US dollars. Urbanization is the urban population as the share of total population proxy for urbanization, and trade openness ratio (TR) is the total value of real imports and exports as a percentage of the real GDP. Table 2 shows the summary statistics associated with the three variables.

The highest means of per capita carbon dioxide emissions (25.340) are in the Middle Eastern, North African, and sub-Saharan region, and energy use (2.730) is in Middle Eastern, North African, and sub-Saharan region, with the highest economic growth mean of (8.432). The lowest mean of carbon dioxide emissions (2.173), energy use (1.109) and economic growth (1.174) is in the Latin American and Caribbean region. Moreover, the Middle Eastern, North African, and sub-Saharan region, have the greatest variation (defined by the standard deviation) in the per capita carbon dioxide emissions (325.035), energy use (44.648) and economic growth (127.934), the Latin American and the Caribbean region have the least variation in each variable (carbon emissions, energy use, and economic growth).

Finally, the European and North Asian region have the greatest coefficient of variation in the per capita carbon emissions (18.087), followed by the Middle Eastern, North African and sub-Saharan region, and the Latin American and Caribbean region. The greatest coefficient of variation in the per capita economic growth (15.172) in the Middle Eastern, North African, and sub-Saharan region, followed by the European and North Asian region and the Latin American and Caribbean region. The Middle Eastern, North African,

Table 3
Correlations for the panel data set.

	gC	gY	gE	URB	TR
gC	1.0000	–	–	–	–
gY	0.9413	1.0000	–	–	–
gE	0.7549	0.7781	1.0000	–	–
URB	0.0308	0.0437	0.0666	1.0000	–
TR	−0.0104	−0.0102	−0.0160	0.2764	1.0000

*Notes: **gC:** growth rate of the per capita CO_2 emissions; **gY**: growth rate of the per capita GDP; **gE**: growth rate of the per capita energy use; **URB**: urbanization; and **TR**: trade openness.*

and sub-Saharan region present the greatest coefficient of variation in the per capita energy use (16.345) followed by the European and North Asian region and the Latin American and Caribbean region.

Table 3 shows the correlations between the panel data variables. The correlation analysis indicated a positive correlation between energy use and carbon emissions. Economic growth is positively correlated with carbon emissions. Energy use and economic growth are positively correlated. Trade openness and energy use are negatively correlated. A negative correlation exists between trade openness and economic growth. Trade openness and carbon emissions are negatively correlated. Urbanization is positively correlated with energy use, economic growth, carbon emissions, and trade openness.

4. The model and estimation technique

4.1. The model

Following the empirical literature in energy economics, the present paper aims to examine the impact of economic growth and energy use on environmental degradation (CO_2 emissions) by incorporating urbanization and energy use in the carbon dioxide emission function. For this reason, we will test the validity of the EKC hypothesis, which is advanced by Simon Kuznets.

In fact, [6,14], among others, included energy use and economic growth variable in their empirical models to study the impact of these two variables on the carbon emissions. They generally found that energy use and economic growth have positive effects and play an important role in explaining the carbon emissions. In other studies, [77,67,27] showed that urbanization, trade openness, have a negative and positive impact on the carbon emissions. Thus, our proposed model (in growth form with a time series specification), which seems to be consistent with the broader literature on the determinants of the carbon dioxide emissions cited above, takes the following from:

$$gC_t = \delta_0 + \delta_1 gY_t + \delta_2 gY_t^2 + \delta_3 gE_t + \delta_4 URB_t + \delta_5 TR_t + \varepsilon_t \qquad (1)$$

Since our study is a panel data study, Eq. (2) can be written in panel data form as follows:

$$gC_{i,t} = \delta_0 + \delta_1 gY_{i,t} + \delta_2 gY_{i,t}^2 + \delta_3 gE_{i,t} + \delta_4 URB_{i,t} + \delta_5 TR_{i,t} + \varepsilon_{i,t} \qquad (2)$$

where $i=1,\ldots\ldots, N$ for each country in the panel and $t=1,\ldots., T$ refers to the time period. Variables given are in growth rate. gC is the growth rate of the carbon dioxide emissions (measured in metric ton per capita); gE is the growth rate of energy use (measured in kt of oil equivalent per capita); gY is the growth rate of the per capita GDP (measured in 2005 US dollars); gY^2 is the growth rate of the square of per capita GDP; TR is measured as exports plus imports as a percentage of GDP; and URB is measured the urban population. The parameters δ_1, δ_2, δ_3, δ_4, and δ_5 represent the long-run elasticity estimates of per capita carbon dioxide emissions with respect to per capita GDP (Y), per capita squared GDP (Y^2), per capita energy use (E), urbanization (URB) and trade openness (TR) respectively. The coefficients are hypothesized as follows: (1) δ_3 to reflect an increase in energy use yields an increase in carbon dioxide emissions, (2) Under the EKC hypothesis, the signs of δ_1 and δ_2 are expected to be positive and negative, respectively, in order to reflect the inverted U-shape pattern.

4.2. Estimation technique

In this study, we have a dynamic panel data model of lagged levels of the dependent variables (per capita GDP, energy use, and carbon dioxide emissions). Our dynamic model with panel data is estimated by using the Generalized Method of Moments (GMM system) estimator. An econometric model of the following form is estimated:

$$gC_{i,t} = \delta_0 gC_{i,t-1} + \alpha gY_{i,t} + \beta gE_{i,t} + \sum_{j=1}^{3} \theta_j control_{i,t} + \mu_{i,t} + \varepsilon_{i,t} \qquad (3)$$

where $gC_{i,t}$ stands for the growth rate of per capita carbon dioxide emissions of country i at time t, δ_0 is the parameter to be estimated; *control* is a vector of core explanatory variables used to model carbon emissions (squared per capita GDP, urbanization, and trade openness); μ is the country specific effects; and ε is the error term. Finally, β captures the affect of energy use, and α captures the effect of economic growth. Since the lagged dependant variables (gC_{t-1}) are correlated with the error term, the use of the panel ordinary least squares (OLS) estimator (with fixed and random effects) is a problematic. Arellano and Bond's [12] approach can solve this problem by first differentiating the above equation. Moreover, [13,18] develop a generalized method of moments (GMM) estimator which yields consistent parameter estimates for models of this type.

5. Empirical findings

The table below includes some post estimation tests for autocorrelation and instrument validity. AR (2) is Arellano and Bond's [12] test for second order autocorrelation in the first differenced errors. When the regression errors are independent and identically distributed, the first differenced errors are, by construction, autocorrelated. Autocorrelation in the first differenced errors at orders higher than what is suggested; the GMM system conditions may not be valid. Sargan test [12] over identifies the restrictions. A rejection from this test indicates that the model or instruments may be miss-specified. The AR (2) tests show no evidence of autocorrelation at conventional levels of significance for each of the estimates reported in Tables 4 and 5. Sargan tests show no evidence of miss-specification at conventional significance levels. These results indicate that the dynamic panel CO_2 emissions model is a good specification.

The sign of the coefficient of the lagged C_{t-1} term is negative at 1% level of significance. This corroborates the established relationship between the variables. The empirical evidence indicates that the coefficient of the carbon emissions with respect to energy use is 0.843 at 1% level of significance. It implies that 1% increase in per capita energy use will lead to 0.843% increase in per capita carbon emissions. This positive impact of energy use on carbon emissions is in line with that of [35,30,48,72,7,38]. Similarly the coefficient of the per capita GDP confirms the existence of inverted-U relationship between economic growth and carbon emissions. The results indicate that 1% rise in the per capita GDP will rise of the carbon emissions by 0.927%. These findings are consistent with the empirical evidence of [79,29]. On the other hand, the per capita carbon emissions are positively related to the per capita square GDP. These results, which are different from those given in [9,10,44], are completely contrary to the EKC hypothesis.

The impact of urbanization is negative and it is statistically significant at 10% level of significance. This implies that a 0.024% decline in per capita carbon emissions is linked with a 1% increase in urbanization. These results are consistent with that of Hossain [36]. Likewise, the trade openness coefficient has a positive but statistically insignificant impact on the per capita carbon emissions. However, this finding is contrary to what of Khalil and Inam [41], who probed that international trade is harmful to the environmental quality in Pakistan, and of Halicioglu [33], who stated that foreign trade increases carbon emissions in Turkey.

Table 5 presents the estimated results of different regions. Beginning with the panel of European and North Asian region, findings indicate that the impact of the lagged dependent variable C_{t-1} is positive and so significant on the current carbon emissions. The impact of energy use on carbon emissions is positive at 1% level of significance. The results suggest that a 1% increase of energy use leads to an expected increase on the carbon emissions by 0.993%. The findings are in line with those of Arouri et al. [14]. The sign of the Y is positive at 5% level of significance. The coefficient shows that a 1% increase of economic growth is expected to increase the carbon emissions by 2.138%. Our empirical exercise indicates that economic growth is a major contributor to CO_2 emissions in Europe and North Asia. The negative sign of the per capita square GDP confirms delinking of the carbon emissions and a higher level of per capita GDP. The results confirm the existence of EKC hypothesis which states that the carbon emissions increase with economic growth at initial stages. The emissions start to decline after the stabilization point as economy achieves a sustainable level of economic growth. These results are supported by the findings of Nasir and Rehma [58]. Furthermore, the trade openness coefficient is negative at 10% level of significance. This means that a 1% decrease of trade openness leads to 0.0011% decrease of carbon emissions. Finally, there is no impact of urbanization on carbon emissions. This result is in line with Liddle and Lung [47].

Regarding Latin American and Caribbean region, the coefficient of the Y and the Y^2 has a negative and positive impact on carbon emissions at 10% level of significance, respectively. This result indicates the existence of a U-shape relationship between per capita carbon emissions and per capita real GDP and confirms that carbon emissions will be declined at initial level of economic growth, then reaches a turning point and increases with the higher level of economic growth. However, the coefficient of the C_{t-1} is (-0.041), indicates that any deviation from the long-run equilibrium between the variables is corrected about 4.10% for each period. Moreover, the per capita energy use has a significant and positive impact on the carbon emissions, which indicates that the carbon emissions increase by 0.744% when there is a 1% increase of the energy use. This implies that an increase in energy consumption increases the environmental degradation. This finding is in line with that of [80,87]. Furthermore, the coefficient of trade openness is negative but statistically insignificant impact on carbon emissions. Similarly, the urbanization variable (0.819) is negative but statistically insignificant impact on the carbon emissions.

Finally, for the Middle Eastern, North African and sub-Saharan region, the sign of the coefficient of the lagged C_{t-1} term is negative at 1% level of significance. This finding establishes a long run relation between the running variables. The value of the lagged carbon emissions term (-0.088) suggests that the changes of the carbon emissions from short to long run is corrected by 8.80% each year. Our findings suggest that economic growth has a positive effect on CO_2 emissions. The coefficient of economic growth is (23.132), which indicates that the per capita carbon emissions increase by 23.132% when there is a 1% increase in the per capita GDP. This result is consistent with the findings of Kais and Ben Mbarek [40] and generally supported by the findings of [74,73,75,84,46,32] who reported an inverted U-shaped

Table 4
Result for the global panel.

Dependent variable: per capita carbon emissions	Coefficient	*P*-value
C_{t-1}	-0.0049	(0.000)*
Y	1.912	(0.000)*
Y^2	0.927	(0.000)*
E	0.843	(0.000)*
URB	-0.024	(0.093)***
TR	-0.046	0.143
Constants	2.361	0.010
AR(2)	-0.56	0.578
Sargan	37.58	0.997

Notes: Values in parenthesis are the estimated p-values.
Sargan test refers to the over-identification test for the restrictions in GMM estimation.
AR (2) is Arellano and Bond [12] *tests for autocorrelation in differences.*
* *Indicate significance at the 1% level.*
*** *Indicate significance at the 10% level.*

Table 5
Estimation results for the three sub-panels.

Dependent variable: per capita carbon emissions						
Variables	European and North Asian region		Latin American and Caribbean region		Middle Eastern, North African, and sub-Saharan region	
	Coefficient	*P*-value	Coefficient	*P*-value	Coefficient	*P*-value
C_{t-1}	0.0029	(0.000)*	-0.041	(0.136)	-0.088	(0.000)*
Y	2.138	(0.005)**	-59.329	(0.085)***	23.132	(0.053)***
Y^2	-0.995	(0.008)**	28.823	(0.084)***	-11.586	(0.054)***
E	0.993	(0.000)*	0.744*	(0.000)*	0.788	(0.000)*
URB	-0.0079	(0.622)	0.819	(0.142)	0.0017	(0.960)
TR	-0.0011	(0.079)***	-0.096	(0.420)	-0.051	(0.056)***
Constants	0.085	(0.945)	-44.319	(0.162)	6.072	(0.056)***
AR(2)	1.81	(0.071)***	-0.93	(0.354)	0.30	(0.761)
Sargan	72.12	(0.254)	69.01	(0.343)	59.24	(0.051)***

Notes: Values in parenthesis are the estimated p-values.
Sargan test refers to the over-identification test for the restrictions in GMM estimation.
AR (2) is Arellano and Bond [12] *tests for autocorrelation in differences.*
* *Indicate significance at the 1% levels.*
** *Indicate significance at the 5% levels.*
*** *Indicate significance at the 10% levels.*

Table 6
Summary of the results for all four panels.

Variables	Global panel		European and North Asian region		Latin American and Caribbean region		Middle Eastern, North African, and sub-Saharan region	
	Sign	Statistical significance	Sign	Statistical significance	Sign	Statistical significance	Sign	Statistical significance
Y	+	✓	+	✓	−	✓	+	✓
Y^2	+	✓	−	✓	+	✓	−	✓
E	+	✓	+	✓	+	✓	+	✓
URB	−	✓	−		+		+	
TR	−		−	✓	−		−	✓

✓Denotes the statistical significance and (−)/(+) denotes it has negative or positive effect on the carbon dioxide emission.

relationship between carbon dioxide emissions and the per capita real GDP. Similarly, the negative coefficient of the square GDP indicates a U-shaped relationship between the per capita CO_2 emissions and the per capita square GDP. The sign of energy use is positive at the 1% level of significance, which implies that a 1% increase of the energy use leads to an increase of the carbon emissions by 0.788%. Moreover, the coefficient of urbanization is positive but insignificant impact on carbon emissions. Trade openness has a negative and significant impact on carbon emissions at 10% level. Trade openness sector lowers carbon emissions by 0.051%. These findings are consonance with [16,3].

In summary, the impact of energy use and economic growth on the carbon emissions for the four panels are presented in Table 6.

First, we found that the impact of economic growth on the carbon emissions is positive only for the global panel, Europe and North Asia, and the Middle East, North Africa, and sub-Saharan Africa, and statistically significant in the all panels. Similarly, it is found that the per capita square GDP has a positive impact on the carbon emissions and statistically significant impact only for the global panel and for the Latin America and the Caribbean. Furthermore, the per capita square GDP has a negative impact and statistically significant only for the European and North Asian, and the Middle Eastern, North African, and sub-Saharan region. Second, energy use has a positive impact and statistically significant on the carbon emissions for all the panels. This result indicates that an increase in energy use tends to increase carbon emissions. Our results are in line with the findings of [60,70]. Third, we found that trade openness has a negative impact and statistically significant on the carbon emissions for the global panel, and for the Middle Eastern, North African, and sub-Saharan region. Our results are different from the findings of Iwata et al. [37]. Similarly, urbanization has a negative and statistically significant impact on the carbon emissions for global panel, but the coefficient is positive and not significant for the Middle Eastern, North African, and sub-Saharan region, and for the Latin American and Caribbean region.

6. Conclusion and policy implications

The main finding of this paper is that the link between the growth rate of the overall consumption and emissions is relatively high for some countries. The increase in trend of carbon emissions has prompted a number of policy responses. Several studies suggested ways of reducing carbon emissions. This document has attempted to empirically analyze the impact of energy use, economic growth on the carbon emissions using dynamic panel data models for a global panel of 58 countries over the 1990–2012 periods. The results show that: (1) per capita energy use has a positive impact on carbon emissions in the four panels. This positive impact of per capita energy use on carbon emissions is in line with that of [38,5]. Since energy use increases the carbon emissions, we suggest that the policy makers take corrective measures to replace the fossil fuel with renewable energy for consumption and production purposes. (2) Both linear and non-linear terms (Y and Y^2) provide evidence in supporting a U-inverted relationship between economic growth and the per capita carbon emissions. An increase in the per capita GDP tends to increase per capita carbon emissions; while a negative sign of per capita squared GDP term seems to corroborate the delinking of the carbon emissions and per capita GDP at the higher level of income. This evidence supports the EKC hypothesis, by revealing that the carbon emissions increase in the initial stage of the per capita GDP. This result is consistent with those of Ozturk and Acaravci [61]. (3) Trade openness has a negative effect on the carbon emissions for Europe and North Asia; but urbanization negatively affects the carbon emissions for the global panel.

We can conclude that carbon emissions tend to increase as energy use increases. On the other hand, 58 countries should make efforts to reduce carbon emissions and strengthen the management of energy and carbon in order to fight energy waste, attenuate carbon emissions and ensure safe and sustainable development without harming the economic development. Guidance for future researches would be to analyze the impact of economic growth, energy use on carbon emissions and other variables, such as automobile use, health expenditure and financial development. [76,85], incorporated financial development as a variable when examining the relationship between energy use, economic growth, and carbon emissions. Likewise, there is a large literature which examined the relationship between health expenditure and economic growth, while Narayan and Narayan [56] examined the influence of pollution emissions and per capita GDP on health expenditure. This research could be extended to cover the relationship between economic growth, health expenditure and alternative forms of carbon emissions.

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