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The impact of CO₂ emissions and economic growth on energy consumption in 58 countries



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ABSTRACT

This paper attempts to investigate the impact of economic growth and CO₂ emissions on energy consumption for a global panel of 58 countries using dynamic panel data model estimated by means of the Generalized Method of Moments (GMM) for the period 1990–2012. We also estimate this relationship for three regional panels; namely, from Europe and North Asia, Latin America and Caribbean, and Sub-Saharan, North African and Middle Eastern. The empirical evidence indicates significant positive impact of CO₂ emissions on energy consumption for four global panels. Economic growth has a positive impact on energy consumption and statistically significant only for the four panel.

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1. Introduction

Over the past two decades, the topic of causal relationship between energy consumption and macroeconomics variables has been analyzed by many researchers. Numerous studies have examined the causal relationship between energy consumption and several independent variables such as economic growth, financial development, employment and population. Energy is considered to be the life line of an economy, the most vital instrument of socio economic development and recognized as one of the most important strategic commodities (Sahir and Qureshi, 2007). Energy is not only essential for the economy but its supply is uncertain (Zaleski, 2001). It is a strategic source that influences the outcomes of wars, fuels and strangles economic development and pollutes as well as cleans up the environment. In the era of globalization, a rapidly increasing demand for energy and dependency of countries on energy indicates that energy will be one of the biggest problems in the world in the next century. This requires alternative and renewable sources of energy. Traditional growth theories focus much on labor and capital as major factors of production and ignore the importance of energy in the growth process (Stern and Cleveland, 2004).

The question of causal relationship between energy consumption, environment and economic growth has been well-studied in the economics literature. Different studies have focused on different countries, time periods, proxy variables and the different

econometric methodologies used for energy consumption, environment and growth relationship. The empirical outcomes of these studies have been varied and sometimes conflicting. The results seem to be different on the direction of causality and long-term versus short-term impact on energy policy.

The relationship between economic growth, energy, and CO₂ emissions, has been an active research area (see, e.g. Jumbe, 2004; Al-Iriani, 2006; Ang, 2007; Halicioglu, 2007; Halicioglu, 2009; Soytas et al., 2007; Sheinbaum-Pardo et al., 2012; Lean and Smith, 2009; Chang et al., 2009; Apergis and Payne, 2009, 2010; Bartleet and Gounder, 2010; Menyah and Rufael, 2010; Ozturk and Acaravci, 2010; Niu et al., 2011; Arouri et al., 2012). Our objective, in this study, is to investigate the impact of economic growth and CO₂ emissions on energy consumption for a panel of 58 countries during 1990–2012. For this reason, we used, as an investigate technique, a dynamic panel data model, which follows the spirit of the conventional 'growth model' framework.

The following study is different from the existing literature on the impact of economic growth and environment on energy consumption. We do not use the panel unit root and the panel cointegration approaches, as it is in the literature today. We rather use a dynamic panel data model, which follows the spirit of the conventional 'growth model' framework. This approach shows that there is a strong theoretical foundation for the empirical analysis. Since they only depict short-run impacts, growth models cannot be modeled within a co-integrating framework. The reason is simple. All variables in a energy form model are stationary, while co-integration (long-run impacts) demands that all variables, as a pre-requisite, need to be non-stationary. Our approach in this study is to estimate the short-run elasticities and not to estimate the long-run elasticity given our growth form modeling approach. There

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is a strong motivation for us to apply a growth form approach to analyze the impact of economic growth and CO₂ emissions on energy.

The rest of the study is organized as follow: Section 2 gives a brief literature review. Section 3 talks about the data and methodology used in the study. Section 4 discusses the results in detail while Section 5 concludes the study with some policy implications.

2. Brief review of literatures

The subject of the effect of economic growth and CO₂ emissions has been well-documented in the econometric energy literature. Different contributions have focused on different countries, time periods, and have used different proxy variables for energy usage. In the next paragraphs we will review some of previous studies related to the effect of economic growth, CO₂ emissions, capital, financial development, and population on energy consumption.

This literature can be divided into sub title to explain how each variable affects energy consumption. Thus this paper reviews the literature under four subsections, e.g. (1) How GDP affects energy?; (2) How CO₂ emission affects energy consumption?; (3) How does financial development affect energy consumption?; (4) How does population affect energy consumption? (5) How does capital and labor affect energy consumption? We discuss them in turn below.

2.1. How GDP affects energy?

The energy-growth nexus is of great interest for economists as well as for policymakers because of its significant policy implication. Some researchers argue that economic growth and key macro-variables are the determinants of energy consumption and hence apply these variables to project energy consumption (Li, 2003; Crompton and Wu, 2005; Skeer and Wang, 2007). For example, Cheng (1999) applied the Granger causality method on the India data for the time period 1952–1995. The result showed that the direction of causality runs from economic growth to energy consumption both in the short-run and in the long-run. No causal relation is found between energy consumption to economic growth. Similarly, Chan and Lee (1996) used a vector error correction model (VECM) techniques and co-integration to analyze China's energy consumption behavior, suggesting that energy price, income and the share of heavy industry output in national income are significant factors affecting energy consumption. Aqeel and Butt (2001) investigated the causal relationship between energy consumption, economic growth and employment in Pakistan and realized that economic growth causes total energy consumption. Wei (2002) examined the long-run relationship between total energy consumption and some main economic factors such as energy price, income and the share of heavy industry in the GDP and found that energy consumption and main variables are co-integrated. On the other hand, if there is a reverse chain of causality from income to energy, then this denotes a less energy-dependent economy such that energy conservation policies may be implemented with little adverse or no effects on income (Jumbe, 2004). On a panel of six countries of the Gulf Cooperation Council, Al-Iriani (2006) found that energy consumption and GDP are co-integrated but unlike Lee's (2005) results, he found that causation ran from real GDP to energy consumption. Similarly, Joyeux and Ripple (2007) found that energy consumption and real GDP in a panel of East Indian Ocean countries were not cointegrated.

In another study, Squalli (2007) suggests the possibility that an increase in energy consumption may have a negative impact on the real GDP. Such a possibility could result from excessive energy consumption. Like in many other studies, Twerefou, Akoena

et al. (2007) using the vector autoregressive method revealed that economic growth Granger cause energy consumption proxied by electricity and petroleum products consumed for Ghana. Similar results were found in Turkey by Halicioglu (2007) who also found that income has a more significant impact in on energy consumption in Turkey. Nguyen-Van (2008) has tried to find out the relationship between energy consumption and economic growth Oxubusing a semi-parametric panel data analysis. His findings suggest that energy consumption in the developing countries would rise more rapidly than expected. Huang et al. (2008) not find causality the between energy use and economic growth in low-income groups, but found that economic growth in middle- and high-income countries leads to a higher energy consumption.

Indeed, Chang et al. (2009) by using the panel threshold regression (PTR) model for the OECD countries over the period 1997–2006, asserted that the level of economic growth of a country influences the use energy as a way to respond to oil price shocks. For Karanfil (2009), the causality between economic growth and energy consumption is not justified just by a bivariate model. He suggested adding to the model one of the financial variables such as domestic credit to private sector, stock market capitalization or liquid liabilities. He also argued that interest rates and exchange rates can affect energy consumption through energy prices. Using panel data from 158 countries for the period 1980–2004 and employing semi-parametric partially linear panel model, Von (2009) reports that energy consumption leads to an increase in economic growth but the effect of time trend is not significant.

Furthermore, Bartleet and Gounder (2010) studied the causal relationship between energy consumption and multivariate models. They found that economic growth, employment and energy consumption have co-integration relationship. The causality results show that economic growth causes energy consumption and economic activity determines the increase of the energy demand. Li et al. (2011) considered a sample of 30 provinces in China and tested the long-run co-integration relationship between the real GDP per capita and energy consumption. They found a positive long-run co-integrated relationship between the variables. Shabbir et al. (2014) examined the relationship between Renewable and Nonrenewable Energy Consumption, Real GDP and CO₂ Emissions, using the Structural VAR Approach method in Pakistan. Their results show that in the short-term, rising energy is fulfilled with the help of nonrenewable and renewable energy consumption. However, the rise in nonrenewable energy consumption lifts real GDP up in short-run. Moreover, the CO₂ emissions worsen economic activity, real GDP falls but renewable energy consumption largely grows. The rise in renewable energy consumption boosts economic activity, and real GDP breeds. Most of times, an increase in renewable energy consumption is an effort to substitute it for non-renewable energy consumption, resulting in lower level of CO₂ emissions.

2.2. How CO₂ emission affects energy?

Shyamal and Rabindra (2004) using a decomposition method, examined the factors that influenced the changes in the level of energy-related CO₂ emissions. They found that emissions of CO₂ in the industrial sector showed a decreasing trend due to improved energy efficiency and fuel switching. However, the effect of the pollution coefficient and energy intensity on CO₂ emissions in the agricultural sector was almost negligible. On the other hand, energy intensity varied a wider range and had a greater impact on energy-induced CO₂ emissions than the pollution coefficient. Sheinbaum-Pardo et al. (2012) decomposed energy consumption and CO₂ emissions for the Mexican manufacturing industrial in the

1990–2008 periods, using the LMDI method. They found important changes in the structure effect that pushed down emissions for 10 manufacturing industries' subsectors. The energy intensity and the carbon index effect were negative in all the subsectors, with the exception of cement and some other subsectors.

Lean and Smith (2009) examined the causal relationship between carbon dioxide emissions and energy consumption through a panel vector error correction model for five ASEAN countries over the period 1980–2006. The long-run estimates indicate that there is a statistically significant positive association between energy consumption and emissions. In Iran, a one-way causal relationship from energy consumption (petroleum products and natural gas consumption) to CO₂ emission was found. However, there was no causal relationship running from fossil fuels consumption to CO₂ emission. Moreover, there was no evidence that CO₂ emission, petroleum products, fossil fuel consumption led to economic growth (Lotfalipour et al., 2010). In South Africa, Menyah and Rufael (2010) found a positive effect of CO₂ emissions on energy consumption.

Similarly, Niu et al. (2011) show a positive relationship between energy consumption and CO₂ emissions in eight Asian economies. Despite although the use of the CO₂ emission per capita and energy efficiency of energy in the developing countries is much lower than it is in the developed ones, it is per unit of energy is much higher than it is in the developed countries. Arouri et al. (2012) used the bootstrap panel unit root tests and co-integration techniques to investigate the relationship between carbon dioxide emissions, energy consumption, and real GDP for 12 Middle East and North African Countries (MENA) over the period 1981–2005. Their results show that in the long-run, there is a positive significant impact of energy consumption on CO₂ emissions. Shahbaz et al. (2014) investigated the non-linear relationship between foreign direct investment and environmental degradation using panel data of 110 developed and developing economies. The results indicated that environmental Kuznets curve exists and foreign direct investment increases environmental degradation.

2.3. How does financial development affect energy consumption?

The relationship between energy consumption and financial development has drawn much interest in recent years. For example, Dan and Lijun (2009) examined the impact of financial development on energy consumption in China. Their study showed a Granger-causality running from energy consumption to financial development, while the reverse relationship is insignificant. Shahbaz et al. (2010) found a significant and positive effect of financial development on energy consumption in Pakistan. This analysis indicated a bidirectional relationship between financial development and energy consumption. Moreover, Sadorsky (2010) examined 22 emerging economies (1990–2006) using different indicators of financial development. This includes bank deposits as share of the GDP, the stock market turnover ratio, the stock market capitalization, and total stock market value traded over the GDP. His results showed that energy consumption is positively linked to economic growth but the impact is small.

Indeed, Sadorsky (2011) examined the impact of financial development on energy consumption using data of 9 Central and Eastern European frontier economies. He stated that financial development increases energy demand once the deposit money bank assets to the GDP, the liquid liabilities to the GDP, the stock market capitalization, the financial system deposits to the GDP, are used as measures of financial development. In Malaysia, Islam et al. (2011)

indicated that financial development and economic growth have a positive impact on energy consumption.

Similarly, in the case of Malaysia, Tang and Tan (2012) examined the effect of financial development on energy both in the short and long run. Shahbaz and Lean (2012) examined energy demand in Tunisia and the reported results showed that financial development increases energy demand resulting from economic growth. However, a long run bi-directional causality is also found between energy consumption and financial development. Then, Chtioui (2012) found a causal relationship from energy consumption to financial development both in the short and in the long run in Tunisia. Al-Mulali and Sab (2012) studied the impact of energy consumption on economic growth and financial development. Their results showed that energy consumption is an important variable in improving economic growth and financial development. With a panel data, using GMM-system, Xu (2012) examined the nexus between financial development and energy consumption over the period 1999–2009 set on a of 29 provinces in China. The results showed a positive significant relationship between energy consumption and financial development. Moreover, Islam et al. (2013) reported that financial development; economic growth and population are driving forces to increase energy demand in Malaysia. A feedback effect is also reported between financial development and energy consumption in long run but financial development has a Granger cause energy demand in the short run.

2.4. How does population affect energy consumption?

Several studies showed that population and economic growths are major driving forces behind increased energy use, and a cause of CO₂ emissions. Newman and Kenworthy (1989), in a pioneering study, pointed out to a negative correlation between population density and gasoline consumption using cross-sectional data from 32 large cities around the world in 1980. Batliwala and Reddy (1993) noted that energy demand depends on per capita energy use. Energy needs in several African urban centers are being met with bio-fuel. Besides, York et al., 2003 pointed out that the energy use with respect to the population is close to the unity. As the living standard rises and population continues to grow, energy use and CO₂ emissions in city areas do the same (Fong et al., 2007). Liddle (2004) found that urbanization and population density have a negative impact on the per capita road transportation energy use. This implies that populous, highly urban cities have less demand for personal transport.

Ewing and Rong (2008) extended the analysis on the impact of the urban form on the residential energy consumption by using household level data from the US Residential Energy Use Survey for 2001 and a country-level measure of sprawl. They found that residents in sprawling counties, who live in single-family detached big houses, consumed more energy than residents in compact counties. However, using cross-sections of US household data, Su (2011) estimated the elasticity of gasoline consumption to population density –0.064, after controlling household characteristics, freeway road density, and congestion. These studies confirm the empirical relationship between the population density and energy use (Heres-Del-Valle and Niemeier, 2011; Liu and Shen, 2011; Vance and Hedel, 2008).

Garau et al. (2013) studied the impact of population on energy use. Their results are obtained from a calibrated overlapping generation general equilibrium model for Italy. While, have found that a pronounced aging population leads to a reduction in energy use, although in principle, the increase in the share of old people produces a shift in consumption towards a more energy intensive mix of goods and services. Shaari et al. (2013) have examined the re-

relationship among population, energy consumption and economic growth from 1991 to 2011 in Malaysia. The results showed that population has a positive effect on energy consumption.

2.5. How does capital stock and labor force affect energy consumption?

In most previous studies of the interaction between energy consumption and economic growth, there was a failure to find other channels of causality and contradicting outcomes that may result. The causality test of energy and income, excluding other important inputs (capital, labor), might fail to detect a causal relationship in if the substitution effects that could exist between energy consumption and other inputs is ignored (Ghali and El-Sakka, 2004).

Motivated by the substitution between energy, capital, and labor, Stern (2000) investigated Granger causality between energy and income in a multivariate model including capital and labor for the US. Additionally, energy is known to influence the productivity of capital and labor, but there is a lack of consensus on the relationship between energy and employment. Researches such as Cheng (1995), Erol and Yu (1987) and Yu and Jin (1992) found contradictory results as to the relationship between energy consumption and employment. Lee and Chang (2008) found a positive and significant relationship between energy consumption and economic growth by including capital stock in the model for some Asian countries. Further, for a group of 22 OECD countries, Lee et al. (2008) reported a bidirectional relationship between energy consumption and capital stock. Using the neo-classical production function, Bartleet and Gounder (2010) found that capital stock plays an important role in determining the direction of causal relationship between energy consumption and economic growth, besides; employment significantly affects the energy consumption.

3. Econometric modeling and data

3.1. Econometric modeling

Some researchers on energy, such as Squalli (2007), Huang et al. (2008), Lee and Chang (2008), Chang et al. (2009), Zhang and Cheng (2009), Shahbaz et al. (2010), Sadorsky (2011), Su (2011), Li et al. (2011), Shabbir et al. (2014) and Shahbaz et al. (2014) among others, included economic growth, CO₂ emissions, financial development, capital stock, labor force, and total population variables in their empirical models to study the impact of these variables on energy consumption. They generally found that these variables are important and have a statistically significant influence on economic growth. Thus, our proposed model, which seems to be consistent with the broader literature on the determinants of energy consumption cited above, takes the following form:

$$\text{ENRC} = f(\text{GDP}, \text{CO}_2, \text{FD}, \text{POP}, \text{K}, \text{L}). \quad (1)$$

This essentially states that total energy consumption per capita (ENRC) is a function of economic growth per capita (GDP), CO₂ emissions (metric tons per capita) (CO₂), capital stock (K), total population (POP), labor force (L), and financial development (FD). Since our study is a panel data study, Eq. (1) can be written in the following form:

$$\begin{aligned} \text{gENRC}_t = & \beta_0 + \beta_1 \text{gGDP}_t + \beta_2 \text{gCO}_{2t} + \beta_3 \text{FD}_t + \beta_4 \text{gK}_t \\ & + \beta_5 \text{gPOP}_t + \beta_6 \text{gL}_t + \mu_t. \end{aligned} \quad (2)$$

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

$$\begin{aligned} \text{gENRC}_{i,t} = & \beta_0 + \beta_1 \text{gGDP}_{i,t} + \beta_2 \text{gCO}_{2i,t} + \beta_3 \text{FD}_{i,t} \\ & + \beta_4 \text{gK}_{i,t} + \beta_5 \text{gPOP}_{i,t} + \beta_6 \text{gL}_{i,t} + \varepsilon_{i,t}. \end{aligned} \quad (3)$$

We can also divide both provided by population and get each series in per capita terms:

$$\begin{aligned} \text{gENRC}_{i,t} = & \beta_0 + \beta_1 \text{gGDP}_{i,t} + \beta_2 \text{gCO}_{2i,t} + \beta_3 \text{FD}_{i,t} \\ & + \beta_4 \text{gK}_{i,t} + \beta_5 \text{gPOP}_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (4)$$

where i represents country (in our study, we have 58 countries); t represents time (our time frame is 1990–2012); gENRC represents the energy consumption rate of per capita, FD is domestic credit to the private sector as a share of the GDP, gGDP represents the growth rate of per capita GDP, gCO₂ the growth rate of per capita CO₂ emissions, gK represents the growth rate of capital stock, and gPOP represents the growth rate of population.

3.2. Data source and descriptive statistic

The data used in this the study are taken from the World Development Indicator (WDI, 2013-CD-ROM), and cover 1990–2012. The variables used are the energy consumption (measured in kilogram (kg) of oil equivalent per capita), CO₂ emissions (measured in metric tons per capita), economic growth (proxied in GDP per capita (constant 2005 US\$)), capital stock (measured by gross fixed capital formation (constant 2005 US\$)), financial development (total credit to private sector as a ratio of GDP), Labor, and POP refers to the total population. The specific countries selected for the study and the timeframe was dictated by data availability. They include: (i) the European and North Asian countries, 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; (ii) the Latin American and Caribbean region, consisting of 15 countries, namely: Argentina, Bolivia, Brazil, Nicaragua, Chile, Costa Rica, Ecuador, Guatemala, Honduras, Mexico, Panama, Paraguay, Peru, Uruguay, and Venezuela; and (iii) 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, Jordan, Kenya, Morocco, Mozambique, South Africa, Senegal, Sudan, Syrian Arab Republic, Togo, Tunisia, and Zambia.

The descriptive statistics mean, standard deviation (Std. Dev.) and the coefficient of variation (CV) of these variables are recorded below in Table 1. CO₂ emission is measured in metric tons per capita. The mean growth rate of CO₂ emissions per capita is the highest in the global countries, Middle Eastern, North African, and sub-Saharan, European and North Asian, and Latin American and the Caribbean, respectively. It is also noted that the European and North Asian countries are more volatile to CO₂ emissions; its coefficient of variation is 18.087, which is the highest compared to other panel countries coefficient of variation.

Moreover, the average growth rate for GDP per capita are recorded highest for global panel, followed by Sub-Saharan/North Africa and Middle East, Europe and North Asian region, and Latin America and Caribbean. It is also noted that the Sub-Saharan/North Africa and Middle East are more volatile in GDP per capita; its coefficient of variation is 15.172, which is the highest when compared to other panel countries coefficient of variation.

Finally, energy consumption is measured at the equivalent of kg of oil per capita. The average growth rate for energy use is the highest for global countries, followed by the Sub-Saharan/North Africa and Middle East, Europe and the North Asian region, and Latin America and Caribbean, respectively. Hence, the coefficient of variation for consumption of 16.354 is reported for the Sub-Saharan/North Africa and Middle East.

Table 1
Descriptive statistics by panels of countries.

Variables	Mean	Std. dev	CV
<i>All sample countries</i>			
Energy consumption per capita	5.665	69.922	12.342
GDP per capita	27.475	399.581	14.543
CO ₂ emissions per capita	25.506	395.077	15.489
Financial development	71.589	62.459	0.872
Capital stock	21.738	277.659	12.772
Population	19.037	296.391	15.569
<i>European and North Asian region</i>			
Energy consumption per capita	2.055	31.304	15.233
GDP per capita	3.994	46.511	11.645
CO ₂ emissions per capita	2.274	41.132	18.087
Financial development	122.473	62.388	0.509
Capital stock	6.275	84.807	13.515
Population	13.444	147.878	10.999
<i>Latin American and Caribbean region</i>			
Energy consumption per capita	1.109	12.385	11.167
GDP per capita	1.679	17.075	10.169
CO ₂ emissions per capita	2.173	20.110	9.254
Financial development	41.313	24.080	0.582
Capital stock	4.129	31.423	7.610
Population	14.941	183.164	12.259
<i>Middle Eastern, North African and Sub-Saharan region</i>			
Energy consumption per capita	2.730	44.648	16.354
GDP per capita	8.432	127.934	15.172
CO ₂ emissions per capita	25.340	325.035	12.826
Financial development	37.004	39.930	1.079
Capital stock	9.160	101.657	11.097
Population	5.150	48.239	9.366

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

Table 2 shows the correlation matrix. The correlation between economic growth and energy consumption is positive. Capital is positively related to the GDP. The relation between population and economic growth is positive. The relation between capital stock and population is negative. The correlation indicates a positive correlation between the CO₂ emissions and all the other variables. Financial development is positively correlated with the population, economic growth, CO₂ emissions, and capital. A negative correlation exists between population and energy consumption.

Table 2
Correlation matrix.

	gENRC	gGDP	gCO ₂	gPOP	gCO ₂	FD
gENRC	1.0000					
gGDP	0.7781	1.0000				
gCO ₂	0.7549	0.9413	1.0000			
gPOP	-0.0070	0.0102	0.0053	1.0000		
gK	0.6842	0.9165	0.8823	-0.0039	1.0000	
FD	0.0479	0.0342	0.0257	0.0219	0.0186	1.0000

3.3. Analysis and discussion

In the present study, we used a dynamic panel specification where lagged levels of the energy consumption are taken into account by using the Arellano and Bond (1991) GMM estimator. Our proposed model is as follows:

$$\begin{aligned}
 \text{gENRC}_{i,t} = & \beta_0 \text{gENRC}_{i,t-1} + \delta \text{gGDP}_{i,t} + \gamma \text{gCO}_{2i,t} \\
 & + \sum_{j=1}^3 \theta_j Z_{i,t} + \mu_{i,t} + \varepsilon_{i,t}; \\
 & i = 1, \dots, N; t = 1, \dots, T
 \end{aligned} \quad (5)$$

where $\text{gENRC}_{i,t}$ stands for the energy consumption rate of country i at time, β_0 is the parameter to be estimated; Control is a vector of core explanatory variables used to model energy consumption (Capital stock, Population, and Financial development);

μ is country-specific effects; and ε is the error term. Finally, δ captures the effect of economic growth while γ captures that of the CO₂ emissions.

Eq. (5) is an example of a linear dynamic panel model (Arellano and Bond, 1991). This model contains the lagged dependent variables ($\text{gENRC}_{i,t-1}$) which are correlated with the error term. The use of panel ordinary least squares (OLS) estimator (with fixed and random effects) is problematic. Arellano and Bond (1991) developed a generalized method of moments (GMM) estimator which gives consistent parameter estimates for models of this type. In their approach, the unobserved firm-specific heterogeneity is eliminated by using a first differencing transformation. This removes the country-specific effects.

4. Main results and discussions

The lower panel of each table includes some post estimation tests of autocorrelation and instrument validity. AR(2) is Arellano and Bond (1991) tests of second order autocorrelation in the first differenced errors. When the regression errors are independent and identically distributed, the first differenced errors are, by construction, auto-correlated. Autocorrelation in the first differenced errors at orders is higher than the one that suggests that the GMM moment conditions may not be valid. Sargan test (Arellano and Bond, 1991) is a test of over identifying restrictions. A rejection from this test indicates that the model or instruments may be miss-specified. For each of the estimates reported in Tables 3–6, the AR(2) tests show no evidence of autocorrelation at conventional levels of significance. Sargan tests show no evidence of miss-specification at conventional significance levels. These results indicate that the dynamic panel energy consumption model is a good specification.

The results of the global panels are reported in Table 3. The value of ENRC_{t-1} (-0.0016) implies that energy consumption is corrected by (0.160) percent each year. We find that economic growth has positive and statistically significant effects at 1% level on energy consumption. The coefficient of economic growth is 0.445 implying that a 1% increase in the growth rate of the GDP per capita increases energy consumption by 0.445% for sample countries. The results here are consistent with these of a recent study on this subject by Aqeel and Butt (2001), Ghosh (2002) and Paul and Bhattacharya (2004), Morimoto and Hope (2004), Ghali and El-Sakka (2004), Oh and Lee (2004), Altinay and Karagol (2005), Ang (2008), Bowden and Payne (2009), Halicioğlu (2007), Odhiambo (2009), Belloumi (2009), Shahbaz and Lean (2012) and Omri (2013). Similarly, CO₂ emissions has a positive and statistically significant effect on energy consumption and statistically significant at 1% level. A 1% increase in CO₂ emissions is expected to raise energy consumption by 0.136%.

Table 3 shows that impact of the financial development on energy consumption is positive and significant at the 5% level. A 1% increase in domestic credit to private sector is expected to raise energy demand by 0.00027%. Financial development promotes investment, which raises energy demand due to economic growth. Easy access of credit enables consumers to purchase big ticket durable consumer items, and the usage of consumer items directly increases energy demand. Our finding is consistent with that of Karanfil (2009) and Sadorsky (2010). The coefficient of capital stock indicates that capital has a significant and positive effect on energy consumption at the 1% level. A 1% increase in capital enhances demand for energy consumption by 0.050%, ceteris paribus. This finding supports the view of Lee et al. (2008), and Bartleet and Gounder (2010). For the panel estimation, the variable of population has a significant and positive effect on energy consumption at the 10% level. This suggests that a 1% increase in population raises energy consumption directly and indirectly by 0.013%.

Table 3
Results for the global panel.

Dependent variable: per capita energy consumption (ENRC)	Coefficients	Prob. value
ENRC _{t-1}	-0.0016*	0.000
Per capita CO ₂ emissions	0.136*	0.000
GDP per capita	0.445*	0.000
Financial development	0.00027**	0.014
Capital stock	0.0050*	0.008
Population	0.013***	0.010
Constants	-0.075**	0.019
Sargan test (<i>p</i> -value)	39.23	0.995
AR(2) test (<i>p</i> -value)	-0.55	0.585

Notes: Values in parenthesis are the estimated *p*-values. Sargan-test refers to the over-identification test for the restrictions in GMM estimation. The AR(2) test is the Arellano–Bond test for the existence of the second-order autocorrelation in first differences.

* Indicate significance at the 1% level.

** Indicate significance at the 5% levels.

*** Indicate significance at the 10% level.

Table 4
Results for the Europe and North Asian countries.

Dependent variable: per capita energy consumption (ENRC)	Coefficients	Prob. value
ENRC _{t-1}	0.0029**	0.002
Per capita CO ₂ emissions	0.450*	0.000
GDP per capita	0.291*	0.000
Financial development	0.0059**	0.011
Capital stock	0.0035	0.715
Population	0.445***	0.061
Constants	-1.274***	0.059
Sargan test (<i>p</i> -value)	53.93	0.835
AR(2) test (<i>p</i> -value)	1.71***	0.087

Notes: Values in parenthesis are the estimated *p*-values. Sargan-test refers to the over-identification test for the restrictions in GMM estimation. The AR(2) test is the Arellano–Bond test for the existence of the second-order autocorrelation in first differences.

* Indicate significance at the 1% level.

** Indicate significance at the 5% level.

*** Indicate significance at the 10% level.

Table 5
Results for the Latin American and Caribbean region.

Dependent variable: per capita energy consumption (ENRC)	Coefficients	Prob. value
ENRC _{t-1}	-0.047	0.371
Per capita CO ₂ emissions	0.317*	0.000
GDP per capita	0.645**	0.011
Financial development	0.146***	0.069
Capital stock	0.024	0.360
Population	2.127	0.368
Constants	-12.182	0.130
Sargan test (<i>p</i> -value)	55.07	0.103
AR(2) test (<i>p</i> -value)	-0.80	0.426

Notes: Values in parenthesis are the estimated *p*-values. Sargan-test refers to the over-identification test for the restrictions in GMM estimation. The AR(2) test is the Arellano–Bond test for the existence of the second-order autocorrelation in first differences.

* Denotes statistical significance at the 1% level.

** Denotes statistical significance at the 5% level.

*** Denotes statistical significance at the 10% level.

The results about of the European and North Asian countries are reported in Table 4. The value of ENRC_{t-1} (0.0029) implies that energy consumption is corrected by (0.290) percent each year. Economic growth has a positive and significant impact on energy consumption at 1% level of significance. We find that 0.291% energy consumption is increased due to 1% increase in economic growth. Our results are in line with the findings of Qazi and Riaz (2008), Atif and Siddiqi (2010). Therefore, the coefficient of CO₂ emissions is 0.450 and highly significant at the 1% level. This suggests that a 1% increase in CO₂ emissions raises energy consumption directly and indirectly by 0.450%. The coefficient of the population is positive and significant at the 10% level. This implies that a 1% increase in the population raises energy consumption by 0.445%, which is consistent with the findings of Batliwala and Reddy (1993), Huang et al. (2008), and Islam et al. (2013). The same table also indicates

that financial development has a positive and significant impact on the energy use at the 5% level. More precisely, a 1% increase in financial development will increase the energy use by 0.0059%. The results are in line with those of Lean and Smith (2009). On the other hand, the variable of capital has an insignificant impact on energy consumption.

Table 5 presents the results for the Latin American and Caribbean region. The value of ENRC_{t-1} (-0.047) implies that energy consumption is corrected by (7.500) percent each year. The table shows that economic growth and CO₂ emissions are positively and significant related to energy consumption at the 5% and 1% level. This means that a 1% increase in economic growth and CO₂ emissions increases energy consumption by almost 0.645% and 0.317% respectively. Furthermore, the variable of financial development has a positive and significant impact on energy con-

Table 6
Results for the Middle Eastern, North African, and sub-Saharan region.

Dependent variable: per capita energy consumption (ENRC)	Coefficients	Prob. value
ENRC _{t-1}	-0.0022	0.537
Per capita CO ₂ emissions	0.056*	0.000
GDP per capita	0.482*	0.000
Financial development	0.020	0.279
Capital stock	0.00029	0.972
Population	0.519***	0.098
Constants	-0.507	0.804
Sargan test (<i>p</i> -value)	54.28	0.826
AR(2) test (<i>p</i> -value)	-0.98	0.329

Notes: Values in parenthesis are the estimated *p*-values. Sargan-test refers to the over-identification test for the restrictions in GMM estimation. The AR(2) test is the Arellano–Bond test for the existence of the second-order autocorrelation in first differences.

* Indicate significance at the 1% level.

*** Indicate significance at the 10% level.

Table 7
Summary of the results for all four panels.

	Global panel	European and Asian	Latin American and Caribbean region	Middle Eastern, North African, and sub-Saharan region
Per capita CO ₂ emissions	✓ (+)	✓ (+)	✓ (+)	✓ (+)
GDP per capita	✓ (+)	✓ (+)	✓ (+)	✓ (+)
Financial development	✓ (+)	✓ (+)	✓ (+)	(+)
Capital stock	✓ (+)	✓ (+)	(+)	(+)
Population	✓ (+)	✓ (+)	(+)	✓ (+)

✓ denotes statistical significance (+) denotes it has positive effect on the per capita CO₂.

sumption at 10% level. This implies augmentation 1% raises energy consumption by 0.146%. Finally, the variable of capital and population has an insignificant impact on energy consumption.

Table 6 contains results for the Sub-Saharan/North African and Middle Eastern panel. The value of ENRC_{t-1} (-0.0022) implies that energy consumption is corrected by (0.220) percent each year. The results show that the CO₂ emissions are statistically significant at the 1% level. The magnitude of 0.056 implies that a 1% increase of the CO₂ emissions increases energy consumption by 0.056%. It is found that economic growth has not a significant impact on energy consumption of the Sub Saharan/North African and Middle Eastern panel. Similarly, the coefficient of financial development and capital are positively correlated (0.00020 and 0.053) but not significant. Finally, the coefficient of the population indicates that population has a significant and positive effect on energy consumption at the 10% level. A 1% increase in the population raises energy consumption by 0.519%.

Table 7 summarizes the results concerning the effects of CO₂ emissions and economic growth on energy consumption for the four panels. First, we have found that the effect of economic growth on energy consumption is positive and statistically significant in the four panels. This indicates that an increase in economic growth implies increase energy consumption. This result is generally consistent with those of Siddiqui (2004), Khan and Qayyum (2007), and Baranzini et al. (2013). Second, CO₂ emissions have a positive and statistically significant effect on energy consumption in the four panels. Third, we found that financial development has a positive and statistically significant effect on energy consumption only for the global panel, Europe and Asia, and for the Latin American and Caribbean region. Our results are in line with the findings of Dan and Ljun (2009), Karanfil (2009), Sadorsky (2010), and Tang and Tan (2012). Moreover, capital has a positive and statistically significant effect on energy consumption only for the global panel. Finally, population has a positive and statistically significant effect on energy consumption only for the Middle Eastern, North Africa, and sub-Sahara, the Europe and North Asia, and for the global panel.

5. Conclusion and policy implications

Although the literature on energy consumption, CO₂ emissions, and economic growth for has improved over last few years, there is no study that examined the effect of economic growth and CO₂ emissions on energy consumption using a growth framework and simultaneous equation models. The results are based on time data panel from 1990 to 2012. We have examined this effect not only on a global panel consisting of 58 countries but also on a number of sub-panel regions.

Our results show that the effect of economic growth on energy use is positive and statistically significant in the global panel. CO₂ emissions have a positive and statistically significant effect on energy consumption in the four panels. This implies that economic growth, CO₂ emissions and energy consumption are complementary.

The empirical results show that the impact of the financial development on energy consumption is positive and statistically significant only for the global panel, for the Europe and North Asia, and for the Latin American and Caribbean region. When financial development stems from banking sector or stock market, greater financial development leads to an increase in energy consumption. This finding is consistent with the bulk of the financial development–energy literature (see, for example, Islam et al., 2013; Kakar et al., 2011; Ozturk and Acaravci, 2012; Sadorsky, 2010, 2011; Xu, 2012).

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