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RESEARCH ARTICLE

Estimating the energy consumption function: evidence from across the globe

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Abstract

The motivation for the current study stem from the United Nations Sustainable Development Goals (UN-SDGs) such as access to clean (SDG-7) and responsible energy consumption (SDG-12) and climate change mitigation (SDG-12). This chase for these goals is pertinent for sustainable economic growth and environmental sustainability. This becomes necessary given the global demand for energy which comes has it environmental consequences given anthropogenic effect. To this end, the present study seeks to identify the factors determining the energy consumption function for 79 economies across the globe. For empirical investigation, 44 years data of five regions, namely Asia and Pacific, Europe, Africa, Latin America, and the Middle East and Arab States, is analyzed. A multivariate regression model and the method of least squares are employed to achieve set of objectives. The least squares result of the regions and single country of the regions are not significantly different from each other. Every region exhibits a common narrative that economic growth, carbon emissions, and urbanization are the key factors determining the consumption function in most of the sample economies. The empirical findings revealed that energy consumption function is determined by economic growth, urbanization, and carbon emissions. In the light of these findings, it is recommended that energy policy needs to be designed considering the significance of economic growth and environmental quality, and consequently it leads toward the achievement of the sustainable development goals.

Keywords SDGs · Sustainability · Responsible energy consumption · Economic growth · CO_2 emissions · Carbon reduction

JEL Classification Q4 · O4 · Q5

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Introduction

Increase in energy consumption is the sign of economic growth for a country as it is considered as the driving force behind industrial activity (EIA 2018). Energy consumptions facilitate the industrial activity and other primary factors of economic growth. Azam (2020) credited Comprehensive National Energy Strategy (1998) that claims "Energy is the lifeblood of modern economies. It powers our factories, heated our homes, and facilitates more people and goods all with the flick of a switch or the turn of an ignition key." In a closed economy, energy consumption mainly depends on economic growth. In the case of an open economy, international factors like trade openness and net foreign direct investment (FDI) and domestic factors like clean energy production and urbanization affect economic growth which in turn affect energy consumption (Dalei 2016). It has been believed that energy consumption is primarily determined by gross domestic product (GDP), while over the time, empirical studies unveiled various potential factors that determine the energy usage. Energy

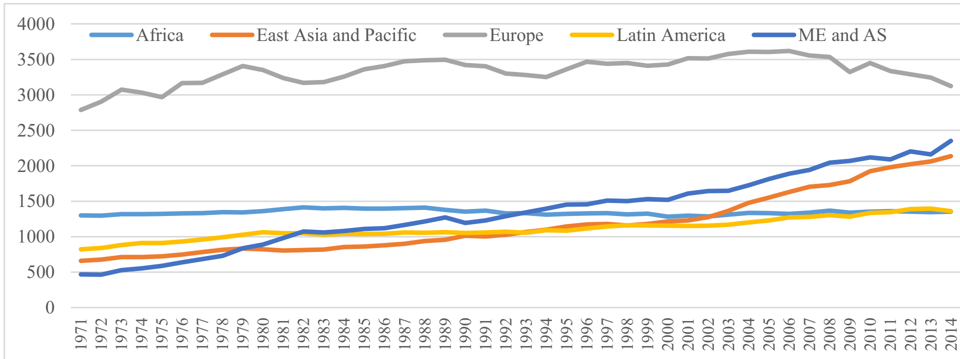

Fig. 1 Trends of energy consumption in various regions. Source: World Development Indicators (2021)

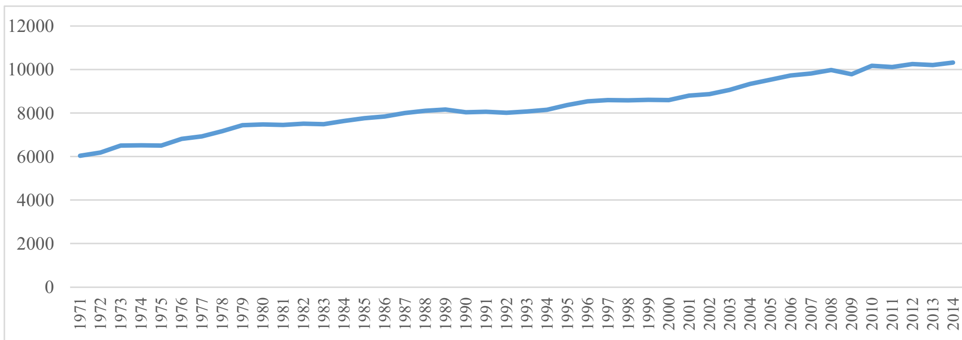

Fig. 2 Trend of global energy consumption. Source: World Development Indicators (2021)

consumption function is the most debated topic among researcher that argues ambiguous results. The seminal work of Balabanoff (1994) on examining the energy consumption function for Latin American economies concluded that the economic growth and energy prices are the key determinants. With the passage of time, researchers have been using trade openness, inward foreign direct investment (FDI), urbanization, population growth, financial development, globalization, industrialization, natural resources, foreign remittances, human capital index, economic complexity, carbon emission, relative energy prices and energy intensity, etc. as the factors determining energy consumption function (Shahbaz and Lean 2012; Wang 2014; Azam et al. 2015a, b; Doytch and Narayan 2016; Nawaz et al 2020). However, the findings of these studies contain conflicting empirical results. For reliable and efficient empirical results, further endeavors are required to explore common possible drivers of the energy consumption across the globe.

There is a broad narrative that the importance of energy as a commodity in the country's economic development and expansion cannot be overstated. Energy production and consumption, like other economic growth variables, is a critical predictor of economic development (Chontanawat et al. 2006). Clearly, the availability of cost-effective, accessible, and higher-quality energy inputs has had a significant role in promoting economic growth in both developing and developed countries (Stern 2019). Sources of energy have always and everywhere played a prominent role for economic progress and social well-being (Koutroumanidis et al. 2009). As a result, the importance of biomass, particularly fuelwood, as a significant renewable energy source capable of contributing significantly, has grown since the 1973 oil shocks. In contrast, some past research has revealed the negative impacts of excessive energy consumption, such that Neumayer (2003) found that the manufacturing sector is typically considered to be more polluting than the services sector. Peng and Bao (2006) highlighted that excessive use of environmental assets caused an increase in industrial pollution emissions. As a result, increased industrial expansion leads to deterioration of environmental quality. Supposedly, perception growth, in combination with rapid urbanization, the increased demand of goods and services by an affluent middle class, and changing mode of production, has a severe negative impact on the nations' economic growth prospects (UNESCAP 2008). The forgoing discussion revealed the importance of energy usage and the need to identify the true determinants of energy consumption across the globe.

The data on energy consumption in different region and the world from 1971 to 2014[1] is used to plot the trend overtime, in Figs. 1 and 2. The energy consumption in different regions across the world has different increasing trends. However, some plots have negative trends in some

[1] We intend to use longer period and updated data, but consistent updates were only available on certain variables up to 2015 in the World Development Indicators (2021).

particular periods, but the overall series shows that energy consumption is increased in the sample time span. Particularly, East Asia and Pacific, Latin America, the Middle East and Arab States, and the World as a whole have significant positive trends in the energy consumption over time. On the other hand, energy consumption in European countries has increasing trend from 1971 to 2006, but later it is decreased over time. Lastly, the most fluctuated energy consumption magnitude exists in African countries, but overall, it also gains a bit of increase. Overall, the trend of energy consumption in the world can be seen in Fig. 2. Hence, the energy consumption throughout the world is increasing over time.

Consistent with the theoretical backdrop, the contribution of this study to the literature of energy economics is multifold. *Firstly*, a larger sample size is considered for the analysis of this study. The study used data of 79 economies across the globe based on the availability of data. *Secondly*, the study used the most common and straightforward econometric technique which departs from all econometric problems by incorporating the growth rate of each variable in the equation. *Thirdly*, the determinants in the energy consumption function are similar in each country's case, and the data is retrieved from a single reliable and most authentic source. *Finally*, though there are several factors that influence energy consumption, this research focuses solely on the impacts of income as defined by GDP growth, urbanization growth, FDI inflow growth, trade openness growth, and carbon emission growth.

The rest of the manuscript is structured as follows: The review of relevant literature is reported in the "Review of literature" section, the data and empirical methodology are described in the "Data and empirical methodology" section. The "Results and discussions" section presents empirical findings, followed by analysis and discussion. Finally, the "Conclusion and policy implications" section includes the concluding remarks.

Review of literature

During the late 1970s, the connection between energy use and economic growth gained attraction. Kraft and Kraft (1978) discovered evidence to support the link between income and energy consumption in the USA. Akarca and Long (1979) suggested a unidirectional link between energy usage and employment levels. Furthermore, Bekhet and Othman (2011) found a significant correlation between energy consumption and income. In another study by Bekhet and Othman (2014), they observed a long-term connection between energy consumption and economic activity in Malaysia from 1971 to 2011. They argued that yearly series for corporate value added, foreign direct investment, and export should be used to represent creative economic activities because of their potential to absorb technological advances from other economies through knowledge, labor mobility, and scale impact. A wide range of studies estimated energy consumption function based on different time span, regions, econometric techniques, and determinants. Specifically, the income level is considered the most important determinant of energy consumption in the vast literature (Richmond and Kaufmann 2006). Moreover, there is common narrative in the developing countries that grow first and clean later, so the economic expansion may cause the huge carbon emissions which is directly associated with energy consumption. Additionally, urbanization (Zhang and Zhang 2018), inward FDI, and trade openness (Phuc et al. 2020) are also found as strong factors of energy consumption function. In this regard, some of the theoretical and empirical literature is listed in the succeeding subsections.

Theoretical evidence

First and foremost, the relationship of economic growth and energy consumption contain some general views (Nayan et al., 2013). The simple view states that economic growth determines energy consumption, while the other one considers the energy consumption as a determinant of economic growth. In contrast, the next view suggests that there is bidirectional causality between energy consumption and economic growth. The first view is the focus of this study; therefore, it is supported with empirical evidence in the succeeding subsection. Further, the nexus between FDI and trade openness with energy consumption are also supported by various literatures theoretically. Trade openness means the deregulation of capital and reduction in the barriers of trade that may fluctuate economic activities. However, if the nature of these economic activities is same, then it creates pollution (Grossman and Krueger 1991). Hence, the FDI inflow directly causes the economic growth which in turn affects the environment and energy consumption. The link between the FDI and trade openness with energy consumption is also supported by empirical studies discussed in the next subsection.

Likewise, urbanization and CO_2 emissions also determine the energy consumption; hence their link can be justified with some relevant theories like the theory of urban environmental transition, the theory of ecological modernization, and the theory of compact cities (Madlener and Sunak, 2011; Sharif et al. 2020; Sarkodie et al. 2020;Alola et al. 2021; Onifade et al. 2021a; Onifade et al. 2021b; Gyamfi et al. 2022a, b; Bekun 2022). The environmental transition theory explains environmental issues regarding the urban evolution (McGranahan and Satterthwaite, 2002). The aim of the modern society to pursue the developed status is to concentrate on energy-intensive manufacturing which directly increases the energy consumption. Here, the concept of modernization is linked with urbanization, which is also explained by the theory of ecological transition. This theory explains the urbanization role in social transformation and its importance as indicator of modernity. Further, the theory of ecological transition states that industrialized countries ignore the pollution in the early stages to achieve faster growth. The reallocation of rural region into urban encourages the dwellers to engage themselves in high energy-intensive economic activities contrary to agriculture. Urbanization also brings modernization in the agriculture with mechanization which heavily increases the energy consumption (Jones 1991). On the other hand, the theory of compact cities explains the associated benefits from urbanization, as it creates economies of scale which in turn eliminate the pressure on the infrastructure in urban areas and bring efficiency, which further reduce the energy use (Capello and Camagni 2000).

Empirical evidence

The nexus between the income and energy consumption is confirmed by the various empirical literature. In this regard, Yu and Choi (1985) found causal relationship between GNP and energy consumption in the Philippines and South Korea. This causal relationship is also confirmed by Masih and Masih (1996) using the sample of six Asian countries. On the other hand, the study found no causality between income and energy consumption in Singapore, Malaysia, and the Philippines. Contrary to the later argument, Asafu-Adjaye (2000) confirmed bidirectional causality between income and energy consumption in the Philippines and Taiwan. Joyeux and Ripple (2011) conducted the study of 56 developed and less developed economies and confirmed unidirectional causality from income to energy consumption. However, Ahmed et al. (2015) showed bidirectional causality between income and energy consumption in the case of Pakistan. A robust connection between energy consumption and economic growth was confirmed by Bilgen (2014). Their finding also showed a significant relationship between emission of greenhouse gases and energy consumption.

A few erstwhile studies used trade openness as in input of energy consumption; for example, the empirical finding of Cole (2006) revealed that trade liberalization increases the economic growth which further increased the energy demand for a panel of 32 countries over 1975–1999. Furthermore, trade liberalization boosts capitalization, which has a significant impact on energy consumption. They argued that trade openness might not affect energy consumption directly, but it affects energy consumption through other indicators. Jena and Grote (2008) explained that trade openness and energy consumption has close link. Sadorsky (2012) found long run relationship between trade openness and energy consumption in South American economies from 1980 to 2007. A significant link in the environmental quality and energy consumption also existed which is backed by wide empirical studies. In this regard, long run relationship between energy consumption, carbon emission, and economic growth was confirmed by Azlina and Mustapha (2012). The results further unveiled a unidirectional causality from income and carbon emission to energy consumption in the period from 1975 to 2010. Although economic growth needs more FDI inflow, this increases carbon emission that further degraded the environment quality (Omri et al. 2014). The causality flowing from CO_2 to energy consumption was also confirmed by Soytas and Sari (2009). As strong determinants of energy consumption, trade openness and carbon emission variables are taken as regressors in this study to avoid the omitted variable bias which might mislead the results for least squares estimator (Jargowsky, 2005).

The extant literature indicated that urbanization is also a vital determinant of energy consumption. These structural transformations of economy, migration toward urban areas, increase the energy consumption which is confirmed by various empirical studies (Mishra et al. 2009; Poumanyvong and Kaneko 2010; Madlener and Sunak 2011), which further affect environmental quality due to huge carbon emission (Eslami et al. 2021). The shift of labor force from rural areas to urban areas significantly increased the energy consumption because energy is a normal good and urban population in contrary uses more energy (Sadorsky 2013). Furthermore, urbanization leads to increase in the demand of manufactured goods compared to that of agricultural good for which the energy requirement is more (Imai 1997). The growth rate in the urban population might also encourage economies of scale in the production process along with high energy consumption (Jones 1991).

The relationship of FDI and energy consumption is empirically analyzed by some prior studies; for example, Mielnik and Goldemberg (2002) observed that increase in FDI causes to lower the energy consumption for 20 less developed countries from 1987 to 1996. Likewise, Dube (2009) found a long run relationship between core variables when FDI is used as a moderating variable for South Africa. In their study, Muddakr et al. (2013) found that GDP, financial development, and FDI inflows significantly fluctuate energy consumption in the case of India over 1975–2011, while results found are mix for the rest of SAARC countries. Sbia et al. (2014) observed that carbon emissions, FDI, and trade openness reduced the energy demand, while clean energy and GDP increase the energy use in the UAE over 1975Q1–2011Q4.

In a nutshell, economic growth, FDI, urbanization, trade openness, and carbon emission are considered as strong determinants of energy consumption in different time series and panel studies. However, each study incorporated a little bit of change in the determinants. For instance, Nasreen and Anwar (2014) focused on trade openness, energy consumption, and economic growth and found cointegration and bidirectional causality between variables. Moreover, Mudakkar et al. (2013) targeted the economic growth and FDI as the determinants of energy consumption and also incorporated financial development and relative energy prices as explanatory variables. Further, a time series study conducted by Zaman et al. (2012) determined consumption function for economic growth, urbanization, and FDI inflows. The study of Azam et al. (2015b) incorporated the human development index in the energy function for three Asian economies and found significant results. Dalei (2016) took all these determinants discussed earlier except urbanization and add relative energy prices as an explanatory variable and found significant results. In the recent literature, some of the studies incorporated new factors and methods in the function of energy consumption which also play a significant role. Nathaniel and Bekun (2020) found that urbanization and energy usage are the major drivers of CO_2, while trade performed the opposing for Nigeria over 1980Q1–2016Q4. Li et al. (2020) confirmed the significant effect of energy prices, energy productivity, eco-innovation, human capital, and income on energy consumption for OECD countries over 1990–2017. Nawaz et al. (2020) observed that economic complexity has a negative effect on energy consumption for Pakistan from 1972Q1 to 2018Q4. Recently, in their study, Shafiullah et al. (2021) added research and development spending, economic policy uncertainty, and oil price as additional factors in renewable energy consumption function in the USA from 1986 to 2019. The study estimated the nonparametric test and unveiled that there is nonlinear cointegration among selected variables. Other than the outlined variables, several other studies have explored the nexus between energy consumption, economic growth, and their interplay with CO_2 emissions. For instance, Onifade et al. (2021b) examined the nexus between energy consumption and economic growth while controlling for urbanization and renewable energy consumption in an STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology) framework. The study highlighted the detrimental impact of energy consumption on economic growth for the Organization of the Petroleum Exporting Countries (OPEC). The study also outlines that renewable energy improves environmental quality over the study period. Similarly, Gyamfi et al. (2022a, b) also resonated the detrimental role of urban population on the environment. The study also alluded to the existence EKC for E7 economies over investigated period.

A summary of previous studies on the factors determining energy consumption are also reported in Table 1.

Data and empirical methodology

In order to explore significant factors of the energy consumption, we use the annual frequency data for sample countries under the time span of 1972 to 2015. Although each country has their own time series model, we categorize the estimated results based on different regions which are elaborated in the coming discussion. Data for all countries and each time series is obtained from the World Development Indicators (2021) and the World Bank Database. List of countries are given in the Appendix as Table 8 along with its categories with respect to their specific regions. Table 2 presents the definition of variables, their proxy for the empirical estimation, and sources of data. The growth rate of each variable is calculated as percentage change over time.

Theoretical foundation of the model

Broadly, the literature mainly agreed on the consensus that energy function is directly related to the economic expansion that is income of the country, i.e., the study leverages on energy-induced growth hypothesis where energy is considered key driver for economic expansion (see Ozturk 2010; Mudakkar et al. 2013; Adom 2015; Paramati et al. 2018). In line with erstwhile studies, the foremost determinant in the energy consumption is income which is backed by economic growth in the following model.

$$E_t = \alpha + \beta_1 EG_t + \varepsilon_t \tag{1}$$

In Eq. (1), E represents the energy consumption, EG is the economic growth of the country, and ε is the error term. In addition to the economic growth, particular studies in the economic growth also indicated that several other factors affect the energy consumption together with carbon emission, urbanization (Jones 1991), trade openness, and FDI (Paramati et al. 2018; Rafindadi et al. 2018). These factors have consequently been included in the estimation process of this study. Thus, a multiple variate regression model which has also been used by many prior studies (including Cole 2006; Azam et al 2015b; Dalei 2016; Canh et al. 2021) is used in this study and can be expressed symbolically as follows:

$$E_t = \alpha + \beta_1 EG_t + \beta_2 TO_t + \beta_3 UP_t + \beta_4 FDI_t + \beta_5 CCO_{2t} + \varepsilon_t \tag{2}$$

where E is the energy consumption, EG is the economic growth, TO is the trade openness, UP is the urbanization, FDI is the net foreign direct investment inflows, and $CO2$ is the carbon emissions. ε is the error term and subscript t represents the time series.

The initial step in the time series analysis is to check the order of integration of variables by several informal and formal unit root tests. Hence, the analysis of this study is extended to various economies in time series framework; therefore, we have to eliminate this complication from the data. In order to assume all variables as stationary at level, we transform these variables in growth rate by calculating its percentage change over time. In this manner, the variable E is the growth rate of the energy consumption, EG is the growth rate of GDP per capita, TO is the growth rate of trade openness, UP is the growth rate of urban population, FDI is the growth rate of net inflows of foreign direct investment,

Table 1 Selected previous studies on energy consumptionQuery

Author(s)	Data, country(s), estimator(s)	Regressand	Regressors	Findings
Shafiullah et al. (2021)	1986–2019, USA, nonparametric test of cointegration; nonparametric test of the Granger causality	Renewable energy use	Economic policy uncertainty, population, R&D spending, real crude oil price, economic growth	Nonlinear cointegration exists. Robust nonlinear causation exists in both directions, i.e., bidirectional causality between renewable energy and economic policy uncertainty. Negative long run association between renewable energy use and policy uncertainty
Canh et al. (2021)	1991–2014, 115 economies; system GMM	Energy use	Income, urbanization, industrialization, trade openness, FDI	Income significantly influences the energy consumption in the global sample This influence is stronger in the low- and middle-income countries Urbanization and FDI have negative effect while industrialization has positive effect on energy use
Li et al. (2020)	1990–2017; OECD countries; Durbin-Hausman group mean cointegration test, cross-sectional ARDL, augmented mean group	Renewable energy use	Income, human capital, energy productivity, energy prices, and eco-innovation	Study confirms significant long run relation between renewable energy consumption and its determinants
Nawaz et al. (2020)	1972Q1–2018Q4; Pakistan; quantile ARDL model; quantile causality test of Troster (2018)	Energy use	Natural resources, economic growth, energy prices, export, economic complexity	Natural resources, economic growth, and oil prices have positive contemporaneous effect on energy consumption. Economic complexity has negative effect, while export has insignificant effect on energy consumption. Causality flowing from natural resources, growth, and oil prices to energy use
Nathaniel and Bekun (2020)	1980Q1–2016Q4; Nigeria; ARDL bound test, Bayer and Hanck cointegration test, causality test	Environment (CO_2 emission)	Energy use, urbanization, economic growth, trade openness	Long run link exists among variables. Energy consumption and urbanization are the major drivers of CO_2. Trade openness performs a negative role in CO_2. Unidirectional causality flowing from urbanization to CO_2
Dalei (2016)	1982–2013; China, Japan, and India; pooled OLS	Energy use	Economic growth, FDI inflows, trade openness, CO_2, electricity production	Economic growth, trade openness, and carbon emission play an important role in energy use Economic growth and carbon emission have negative significant effect on energy consumption while trade openness has positive sign

Table 1 (continued)

Author(s)	Data, country(s), estimator(s)	Regressand	Regressors	Findings
Azam et al. (2015b)	1980–2012; Indonesia, Malaysia, and Thailand; least square method	Energy use	Economic growth, population, FDI, trade openness, HDI, and urbanization	FDI inflows, economic growth, human development index, and trade openness have positive and significant impact on energy consumption. Urbanization has positive significant impact on energy use in the case of Thailand and Malaysia, while population has positive significant impact only in Malaysia
Nasreen and Anwar (2014)	1980–2011; 15 Asian countries; panel cointegration; panel causality	Energy use	Economic growth, trade openness, and energy prices	Cointegration exists among variables Economic growth and trade openness have positive impact on energy use. A bidirectional causality exists in economic growth and energy consumption, trade openness, and energy use
Mudakkar et al. (2013)	1975–2011; SAARC countries; Granger causality using MWALD test, Toda-Yamamoto–Dolado-Lutkepohl method	Energy use	Economic growth, relative price of energy to non-energy goods, FDI, and financial development	Energy consumption Granger cause growth factors either “accepted neutrality hypothesis,” “growth hypothesis,” and “conservation hypothesis”; “feedback hypothesis” in different SAARC countries
Zaman et al. (2012)	1975–2010; Pakistan bound testing procedure; dynamic short run causality using the Wald *F* test	Electricity use	Economic growth, population, and FDI inflows	Income, FDI, and population growth have positive effect on energy consumption. Cointegration exists between energy consumption and its determinants Unidirectional causality exists which flows from population growth to energy consumption

Source: Author’s compilation

Table 2 Variable's description and data sources

Label	Definition	Variables	Sources
E	Energy consumption growth	Energy use (kg of oil equivalent per capita)	WDI (2021)
EG	Economic growth	GDP growth	WDI (2021)
TO	Trade openness growth	Trade ratio to GDP	WDI (2021)
UP	Urbanization growth	Urban population growth	WDI (2021)
FDI	FDI growth	FDI inflows	WDI (2021)
CO2	Carbon emission growth	CO2 emission (metric ton per capita)	WDI (2021)

Source: Author's construction

and *CO2* is the growth rate of carbon emission. Table 2 provides the complete description of variables and its measurement.

Furthermore, economic growth is directly linked with energy consumption. This association is supported by prominent literature in the energy economics (Kraft and Kraft 1978; Yu and Choi

Table 3 Least squares estimate (Europe)

Country Time span	Estimated equations	
Albania 1981–2014	$E = .0187 + .0051EG - .0002TO - .014UP - .008FDI + .297CO2$ $(0.28)(1.94^{*})(-.31)(-.79)(-.33)(2.96^{***})$	$F = 7.96^{***}$ $R^2 = 0.58$
Austria 1972–2015	$E = .003 + .003\text{EG} - .00004\text{TO} - .006\text{UP} + .0003\text{FDI} + .479\text{CO2}$ $(0.14)(1.77^{*})(-0.16)(-1.72)(0.68)(6.81^{***})$	$F = 12.81^{***}$ $R^2 = 0.62$
Belgium 1972–2015	$E = .032 + .001\text{EG} - .0001\text{TO} - .014\text{UP} + .0007\text{FDI} + .611\text{CO2}$ $(0.28)(1.94^{*})(-.31)(-1.79)(-.33)(2.96^{***})$	$F = 20.15^{***}$ $R^2 = 0.72$
Bulgaria 1981–2014	$E = .026 + .002\text{EG} - .0002\text{TO} - .008\text{UP} - .008\text{FDI} + .495\text{CO2}$ $(1.06)(2.14^{*})(-.10)(-1.09)\left(-3.50^{***}\right)(6.04^{***})$	$F = 23.96^{***}$ $R^2 = 0.82$
Cyprus 1976–2014	$E = .092 + .001\text{EG} - .0007\text{TO} - .001\text{UP} - .004\text{FDI} + .760\text{CO2}$ $(1.47)\ (0.85)\ (-1.48)\ (-1.30)\ (-0.66)(5.75^{***})$	$F = 14.78^{***} R^2 = 0.69$
Denmark 1972–2015	$E = -0.22 + .004\text{EG} + .0001\text{TO} + .005\text{UP} - .002\text{FDI} + .531\text{CO2}$ $(-1.35)\ (3.24^{***})\ (0.77)\ (0.47)\ (-2.11^{**})(14.6^{***})$	$F = 64.10^{***} R^2 = 0.89$
Finland 1972–2015	$E = .004 + .003\text{EG} - 00006\text{TO} + .001\text{UP} + .0004\text{FDI} + .422\text{CO2}$ $(0.11)\ (2.50^{**})\ (-0.13)\ (0.14)\ (0.16)(9.88^{***})$	$F = 26.36^{***} R^2 = 0.77$
France 1972–2015	$E = .064 - .00005\text{EG} - .0009\text{TO} - .009\text{UP} + .001\text{FDI} + .499\text{CO2}$ $(2.49^{**})\ (-0.02)\ (-1.98)\ (-0.64)\ (0.50)(6.48^{***})$	$F = 12.78^{***} R^2 = 0.62$
Greece 1972–2014	$E = .018 + .001\text{EG} - .0001\text{TO} - .012\text{UP} - .0003\text{FDI} + .844\text{CO2}$ $(0.67)\ (1.69)\ (-0.21)\ (-1.57)\ (-1.83)(9.46^{***})$	$F = 44.54^{***} R^2 = 0.85$
Ireland 1972–2014	$E = .005 - .0001\text{EG} - .00001\text{TO} - .0005\text{UP} + .003\text{FDI} + .811\text{CO2}$ $(0.41)\ (-0.27)\ (-0.02)\ (-0.13)\ (1.83)(10.95^{***})$	$F = 30.45^{***} R^2 = 0.80$
Italy 1972–2015	$E = .019 + .0003\text{EG} - .0002\text{TO} - .006\text{UP} + .00005\text{FDI} + .819\text{CO2}$ $(1.49)\ (0.25)\ (-0.94)\ (-2.20)\ (2.44^{**})(10.96^{***})$	$F = 71.85^{***} R^2 = 0.90$
Netherlands 1972–2014	$E = .032 + .002\text{EG} \pm .0004\text{TO} + .010\text{UP} \pm .001\text{FDI} + .617\text{CO2}$ $(0.98)\ (0.94)\ (-1.90)\ (1.90)\ (-0.52)(8.41^{***})$	$F = 20.27^{***} R^2 = 0.72$
Norway 1972–2015	$E = -.117 + .003\text{EG} + .001\text{TO} + .002\text{UP} - .0003\text{FDI} + .105\text{CO2}$ $(-0.67)\ (0.65)\ (0.65)\ (0.12)\ (-0.07)(2.08)$	$F = 0.62 R^2 = 0.07$
Portugal 1972–2015	$E = -.028 + .001\text{EG} + .0003\text{TO} + .010\text{UP} + .0004\text{FDI} + .644\text{CO2}$ $(-0.52)\ (0.88)\ (0.46)\ (2.25)\ (2.26)(7.79^{***})$	$F = 20.07^{***} R^2 = 0.72$
Spain 1972–2015	$E = .037 + .005\text{EG} - .0007\text{TO} - .008\text{UP} + .006\text{FDI} + .413\text{CO2}$ $(2.18^{**})\ (3.10^{***})\ (-2.28^{**})\ (-1.61)\ (2.02)(5.12^{***})$	$F = 23.00^{***} R^2 = 0.75$
Switzerland 1972–2105	$E = .005 + .0003\text{EG} + .0001\text{TO} - .024\text{UP} + .001\text{FDI} + .622\text{CO2}$ $(0.19)\ (0.12)\ (0.38)\ (-1.38)\ (1.96)(5.94^{***})$	$F = 8.83^{***} R^2 = 0.62$
Turkey 1972–2015	$E = .011 + .003\text{EG} - .0002\text{TO} - .002\text{UP} - .005\text{FDI} + .524\text{CO2}$ $(0.67)\ (4.40^{***})\ (-1.84)\ (-1.74)\ (-1.85)(7.10^{***})$	$F = 31.28^{***} R^2 = 0.80$
UK 1972–2015	$E = .023 + .001\text{EG} - .0003\text{TO} - .006\text{UP} - .0003\text{FDI} + .686\text{CO2}$ $(0.81)\ (0.89)\ (-2.65)\ (-1.96)\ (-2.38)(9.69^{***})$	$F = 32.93^{***} R^2 = 0.81$

Source: *t*-statistics are given in parenthesis. Asterisks *, **, and *** represent 1%, 5%, and 10% significant level

Table 4 Least squares estimates (Asia and Pacific region)

Country Time span	Estimated equations	
Australia 1972–2015	$E = .014 + .005EG - .000TO + .001UP - .002FDI + .340CO2$ $(0.58)(.58^{**})(-1.40)(0.17)(-1.23)(2.99^{***})$	$F = 5.70^{***}$ $R^2 = 0.428$
Bahrain 1981–2014	$E = -.035 - .002EG + .0003TO - .001UP - .007FDI + .470CO2$ $(-0.69)(-1.51)(1.59)(-1.34)(-2.82^{***})(4.85^{***})$	$F = 10.19^{***}$ $R^2 = 0.64$
Bangladesh 1972–2014	$E = .010 - .003EG + .0009TO - .0005UP + .0009FDI + .949CO2$ $(0.51)(-2.18^{**})(2.12^{**})(-0.32)(1.20)(2.80^{***})$	$F = 3.21^{**}$ $R^2 = 0.30$
China 1980–2014	$E = -.073 - .0007EG + .001TO + .010UP - .00004FDI + .314CO$ $(-1.06)(-0.36)\left(2.73^{**}\right)(1.88)(-0.12)(2.38^{**})$	$F = 9.6^{***}$ $R^2 = 0.62$
India 1972–2014	$E = .012 - .00006EG + .0003TO - .003UP + .0008FDI + .316CO2$ $(0.56)\ (-0.09)\ (1.67)\ (-1.89)\ (0.53)(4.38^{***})$	$F = 9.30^{***} R^2 = 0.55$
Indonesia 1972–2014	$E = -.046 + .003EG + .0004TO + .004UP + .001FDI + .108CO2$ $(-0.79)\ (1.75^{*})\ (0.61)\ (1.89)\ (0.40)(1.22)$	$F = 1.51R^2 = 0.16$
Iran 1972–2014	$E = -.068 - .002EG + .001TO + .009UP + .002FDI + .561CO2$ $(-1.44)(-1.57)\ (1.97)\ (1.27)\ (1.02)(3.11^{***})$	$F = 3.05^{**} R^2 = 0.29$
Japan 1972–2015	$E = .022 + .004EG - .001TO + .001UP + .00006FDI + .501CO2$ $(1.32)\ (3.14^{***})\ (-2.08^{**})\ (0.26)\ (0.03)(4.45^{***})$	$F = 14.74^{***} R^2 = 0.65$
Korea 1972–2014	$E = .033 + .004EG - .0004TO + .0005UP - .001FDI + .395CO2$ $(1.01)\ (2.45^{**})\ (-1.19)\ (0.15)\ (-0.93)(3.40^{***})$	$F = 17.84^{***} R^2 = 0.70$
Malaysia 1972–2014	$E = .022 + .003EG - .00008TO - .001UP - .0006FDI + .486CO2$ $(0.32)\ (1.09)\ (-0.36)\ (-2.10)\ (-1.04)(3.26^{***})$	$F = 3.51^{***} R^2 = 0.32$
Nepal 1972–2014	$E = .019 - .0002EG + .0002TO - .004UP - .00004FDI + .026CO2$ $(1.09)(-0.21)\ (1.00)\ (-2.16^{**})\ (-0.14)\ (1.41)$	$F = 1.82R^2 = 0.19$
New Zealand 1978–2015	$E = .053 - .0004EG - .0006TO - .005UP - .0008FDI + .257CO2$ $(0.82)\ (-0.17)\ (-0.57)\ (-1.04)\ (-1.48)(3.17^{***})$	$F = 22.70^{**} R^2 = 0.29$
Pakistan 1972–2014	$E = -.015 + .001EG - .00005TO + .004UP + .002FDI + .228CO2$ $(-0.57)\ (1.25)\ (-0.08)\ (1.97)\ (1.96)(3.61^{***})$	$F = 7.68^{***} R^2 = 0.509$
Philippine 1972–2014	$E = -.018 + .002EG - .00006TO + .004UP - .0005FDI + .27CO2$ $(-0.48)(1.40)(-0.17)(0.92)(-0.40)(3.08^{***})$	$F = 5.38^{***}$ $R^2 = 0.42$
Singapore 1972–2014	$E = .216 + .011EG - .0006TO - .013UP + .007FDI - .071CO2$ $(1.38)(2.09^{**})(-1.48)(-0.83)(0.24)-0.36^{***}$	$F = 1.96$ $R^2 = 0.20$
Sri Lanka 1972–2014	$E = -.009 + .004EG - .00002TO - .003UP + .00002FDI + 185CO$ $(-0.26)(1.89^{*})\ (-0.06)\ (-2.30)\ (1.00)(4.33^{***})$	$F = 5.73^{***} R^2 = 0.43$
Thailand 1972–2014	$E = -.024 + .007EG + .0003TO - .004UP - .005FDI + .190CO2$ $(-0.96)\ (3.05^{***})\ (2.19^{**})\ (-0.97)\ (-0.91)(1.35)$	$F = 8.75^{***} R^2 = 0.54$

Source: *t*-statistics are given in parenthesis. Asterisks *, **, and *** represent 1%, 5%, and 10% significant level

1985; Azam et al. 2015a; Ahmed and Azam, 2016; Nawaz et al. 2020; Nathaniel 2020). All of these studies are in favor of a positive effect of economic growth on energy consumption. However, some of the researchers found conflicting results regarding the direction of causality (Apergis & Payne 2010; Noor and Siddiqi 2010). Going with the argument of some empirical evidence that economic growth is the engine of industrialization and industrialization mainly involved a mass energy consumption (Dalei, 2016), we hypothesize that energy consumption is primarily based on economic growth (Canh et al. 2021).

Net FDI inflow is a channel to transfer of technology, which contribute to a country's energy consumption. In a single direction, FDI is a strong determinant of economic growth which in turn affect economic growth. Based on the studies of Bento, (2011), Shahbaz et al. (2011), and Canh et al. (2021), we hypothesis the FDI as a strong factor in the energy consumption function.

Urbanization also affects energy consumption and previous empirical evidence reveals that urbanization brings the structural transformation in the economy (Mishra et al. 2009; Poumanyvong and Kaneko 2010). These transformations effect the energy consumption because the urban people are more energy consumption intensive (Sadorsky 2013). Based on these facts, urbanization has a significant role in the energy consumption.

The existing literature also confirms that trade openness affects energy consumption (Cole 2006; Canh et al. 2021) because eliminating trade barriers often brings changes in economic performance and further affects energy consumption. Like FDI, trade openness also fluctuates the energy consumption.

There is a significant link in the environmental and energy consumption (Azlina & Mustapha, 2012). Similar to our hypothesis, Soytas and Sari (2009) unveiled unidirectional causality flowing from CO_2 emission to energy consumption.

Table 5 Least squares estimates (Latin America)

Country Time span	Estimated equations	
Argentina 1972–2014	$E = .01 + .001\text{EG} + .000\text{TO} - .004\text{UP} - .000\text{FDI} + .325\text{CO2}$ $0.272.21^{**}0.07 - 0.30 - 0.203.51^{***}$	$F = 12.6^{***}$ $R^2 = 0.63$
Bolivia 1972–2014	$E = -.103 + .008EG + .0007TO + .019UP - .001FDI$ $+ .095CO2(-0.68)(1.27)(0.56)(1.94)(-0.30)(0.44)$	$F = 0.84$ $R^2 = 0.10$
Brazil 1972–2014	$E = -.05 + .001\text{EG} + .002\text{TO} + .004\text{UP} + .005\text{FDI} + .435\text{CO2}$ $(-2.26^{*})(1.37)(2.70^{**})(2.31)(1.705^{*})(6.41^{***})$	$F = 34.32^{***}$ $R^2 = 0.82$
Chile 1972–2015	$E = .015 + .003\text{EG} - .0002\text{TO} - .0006\text{UP} - .0005\text{FDI} + .421\text{CO2}$ $(0.21)(2.71^{**})(-0.31)(-0.03)(-0.53)(6.28^{***})$	$F = 23.28^{***}$ $R^2 = 0.75$
Colombia 1972–2014	$E = -.057 + .003\text{EG} + .001\text{TO} + .004\text{UP} - .003\text{FDI} + .146\text{CO2}$ $(-0.55)\ (1.11)\ (0.50)\ (2.33)\ (-0.44)(1.0)$	$F = 1.08R^2 = 0.12$
Costa Rica 1972–2014	$E = -.520 = .005\text{EG} + .0006\text{TO} - .0005\text{UP} - .025\text{FDI} + .331\text{CO2}$ $(-0.69)\ (2.03^{**})\ (0.82)\ (-0.04)\ (-0.97)(3.23^{***})$	$F = 6.21^{***}R^2 = 0.44$
Dominican Republic 1972–2014	$E = -.013 + .002\text{EG} + .00006\text{TO} - .00007\text{U} + .0006\text{FD} + .25\text{CO}$ $(-0.19)\ (0.93)\ (0.08)\ (-0.01)\ (0.38)(2.41^{**})$	$F = 14.78^{***}R^2 = 0.69$
Ecuador 1972–2014	$E = -.226 + .002\text{EG} + .002\text{TO} + .033\text{UP} - .003\text{FDI} - .056\text{CO2}$ $(-1.24)\ (0.58)\ (1.20)\ (1.35)\ (-1.07)(0.51)$	$F = 0.48R^2 = 0.11$
El Salvador 1972–2014	$E = -.058 + .002\text{EG} + .0004\text{TO} + .011\text{UP} + .001\text{FDI} + .177\text{CO2}$ $(-0.96)\ (1.10)\ (0.59)\ (1.12)\ (0.79)(1.82^{*})$	$F = 2.40^{*}R^2 = 0.24$
Guatemala 1972–2014	$E = .290 + .001\text{EG} - .001\text{TO} - .073\text{UP} - .0003\text{FDI} - .211\text{CO2}$ $(2.61^{**})\ (0.60)\ (-1.48)\ (-2.91^{***})(-0.17)(2.63^{**})$	$F = 4.71^{***}R^2 = 0.38$
Honduras 1972–2014	$E = -.006 + .004\text{EG} + .0002\text{TO} - .007\text{UP} - .007\text{FDI} + .141\text{CO2}$ $(-0.07)\ (2.07^{**})\ (0.65)\ (-2.43)\ (-1.56)(1.59)$	$F = 2.31^{*}R^2 = 0.23$
Jamaica 1972–2014	$E = -.098 + .010\text{EG} + .0007\text{TO} + .010\text{UP} + .004\text{FDI} + .396\text{CO2}$ $(-1.31)\ (4.65^{***})\ (1.08)\ (0.78)\ (1.43)\ (5.19^{***})$	$F = 13.14^{***}R^2 = 0.63$
Mexico 1972–2015	$E = -.018 + .005\text{EG} - .0002\text{TO} + .009\text{UP} - .006\text{FDI} + .077\text{CO2}$ $(-0.33)\ (4.33^{***})\ (-0.37)\ (0.71)\ (-0.76)(1.12)$	$F = 10.55^{***}R^2 = 0.58$
Nicaragua 1972–2014	$E = -.032 + .005\text{EG} + .0001\text{TO} + .006\text{UP} + .00005\text{FDI} - .01\text{CO2}$ $(-1.12)\ (5.53^{**})\ (0.68)\ (1.98)\ (0.60)(-0.23)$	$F = 9.58^{***}R^2 = 0.56$
Panama 1978–2014	$E = -.063 - .001\text{EG} + .0003\text{TO} + .006\text{UP} - .001\text{FDI} + .495\text{CO2}$ $(-0.91)\ (-0.63)\ (0.79)\ (0.40)\ (-0.48)(6.28^{***})$	$F = 10.76^{***}R^2 = 0.63$
Paraguay 1972–2014	$E = -.0511 + .003\text{EG} + .0002\text{TO} + .006\text{UP} + .0007\text{FDI} + .25\text{CO2}$ $(-1.80^{*})\ (2.76)\ (1.48)\ (0.74)\ (0.72)(4.71^{***})$	$F = 10.70^{***}R^2 = 0.59$
Peru 1972–2014	$E = -.009 + .0001\text{EG} + .0009\text{TO} - .010\text{UP} - .002\text{FDI} + 0.49\text{CO2}$ $(-0.22)\ (0.08)\ (1.25)\ (-2.41)\ (-1.98^{*})(4.20^{***})$	$F = 11.08^{***}R^2 = 0.59$
Uruguay 1972–2014	$E = -.066 + .003\text{EG} + .001\text{TO} - .001\text{UP} - .00002\text{FDI} + .403\text{CO2}$ $(-1.78)\ (2.38^{**})\ (2.34^{**})\ (-0.06)\ (-0.18)\ (8.80^{***})$	$F = 27.15^{***}R^2 = 0.78$
Venezuela 1972–2013	$E = -.101 + .00007\text{EG} + .002\text{TO} + .003\text{UP} - .002\text{FDI} + .276\text{CO2}$ $(-1.30)\ (0.01)\ (1.36)\ (2.27)\ (-1.30)(1.76^{*})$	$F = 1.63R^2 = 0.18$

Source: *t*-statistics are given in parenthesis. Asterisks *, **, and *** represent 1%, 5%, and 10% significant level

Many research works provided evidence that CO_2 is initially caused by trade openness (Nathaniel and Bekun 2020). The increase in carbon emission mainly involves industrialization and economic activities that increase economic growth, which in turn affects the energy consumption positively. Hence, like other factors, CO_2 is also considered a vital factor in the energy consumption function.

Estimation strategy

The initial step of time series estimation is to check the stationarity of the data through relevant unit root tests. This study considers the nature of all series and applies the augmented Dickey-Fuller test of unit root developed by Dickey and Fuller (1979). Hence, some of the time series are not stationary at level while stationary at 1st difference. For the said purpose, we calculate the growth rate of each variable using percentage change to avoid the problem of stationarity and to explore a valid estimate. The foremost assumption of the econometric method used in this study is all of the predictor and response variable must be stationary at level.

Equation (2) is multiple variate linear regression model, which is the base equations of estimates for all

Table 6 Least squares estimates (Africa)

Country Time span	Estimated equations	
Benin 1972–2014	$E = .054 + .0001EG - .0009TO - .002UP + .00005FDI + .106CO2$ $(1.01)(0.09)(-1.03)(-1.79)(0.24)(4.38^{***})$	$F = 4.13^{***}$ $R^2 = 0.35$
Botswana 1982–2014	$E = -.087 + .003EG + .001TO - .004UP - .00006FDI + .051CO2$ $(-0.91)(1.36)(0.97)(-1.58)(-0.22)(1.01)$	$F = 1.29R^2 = 0.19$
Cameron 1972–2014	$E = .004 + .001EG - .0004TO + .001UP + .0005FDI + .010CO2$ $(0.18)(1.82^{*})(-0.95)(1.91)(1.35)(1.39)$	$F = 1.68$ $R^2 = 0.18$
Congo Rep 1972–2014	$E = .067 + .005EG + .0004TO - .031UP + .0002FDI - .009CO2$ $(0.60)\ (2.28^{**})\ (0.74)\ (-1.32)\ (0.27)(-0.34)$	$F = 1.33R^2 = 0.15$
Cote d'Ivoire 1972–2014	$E = -.031 + .001EG + .0009TO - .008UP + .013FDI + .092CO2$ $(-0.28)\ (0.42)\ (0.76)\ (-2.02)\ (1.04)(1.35)$	$F = 1.08R^2 = 0.12$
Gabon 1972–2014	$E = .124 - .001EG - .0006TO - .008UP + .001FDI + .296CO2$ $(0.88)\ (-0.60)\ (-0.39)\ (-0.53)\ (0.94)(2.66^{**})$	$F = 1.7$ $R^2 = 0.18$
Ghana 1972–2014	$E = .034 + .004EG - .0007TO - .002UP + .006FDI + .099CO2$ $(0.68)\ (2.38^{**})\ (-2.61^{**})\ (-0.21)\ (1.22)(1.70^{*})$	$F = 2.52^{**}R^2 = 0.25$
Kenia 1972–2014	$E = .028 + .001EG - .0003TO - .002UP - .00006FDI + .063CO2$ $(1.14)\ (1.59)\ (-0.75)\ (-2.01)\ (-0.52)(2.28^{**})$	$F = 2.54^{**}R^2 = 0.25$
Mauritius 1977–2014	$E = -.094 + .003EG + .0007TO - .0008UP - .0004FDI + .26CO2$ $(-1.93^{*})\ (2.35^{**})\ (1.80)\ (-0.10)\ (-0.11)(3.88^{***})$	$F = 8.52^{***}R^2 = 0.57$
Nigeria 1972–2014	$E = -.127 - .001EG + .001TO + .018UP + .004FDI + .056CO2$ $(-4.13^{***})\ (-2.47^{**})\ (5.19^{***})\ (3.61^{***})\ (1.91^{**})(3.31^{***})$	$F = 6.50^{***}R^2 = 0.46$
Senegal 1972–2014	$E = .041 + .001EG - .0001TO - .010UP + .0004FDI + .046CO2$ $(0.71)\ (0.72)\ (-0.15)\ (-1.90)\ (0.86)(0.94)$	$F = 0.68R^2 = 0.08$
South Africa 197–2014	$E = -.063 + .004EG + .0002TO + .015UP + .00001FDI + .27CO2$ $(-0.83)\ (1.76^{*})\ (0.32)\ (2.08)\ (0.02)\ (3.07^{***})$	$F = 3.77^{***}R^2 = 0.33$
Togo 1972–2014	$E = .053 + .002EG - .0007TO + .003UP + .0001FDI + .049CO2$ $(0.90)\ (2.39^{**})\ -2.14^{**})\ (2.23)\ (0.05)(3.93^{***})$	$F = 3.92^{***}R^2 = 0.34$
Zimbabwe 1975–2013	$E = .003 + .0007EG - .00002TO - .001UP + .001FDI + .208CO2$ $(0.10)\ (1.35)\ (-0.05)\ (-2.56)\ (-0.91)(5.21^{***})$	$F = 9.62^{***}R^2 = 0.59$

Source: *t*-statistics are given in parenthesis. Asterisks *, **, and *** represent 1%, 5%, and 10% significant level

countries. It includes all variables in growth form and assumed that all variables are stationary at level. Therefore, the need of reporting unit root test results is not necessary, and we directly moved to the estimation process. The estimation is solely based on the ordinary least square, for the results of energy consumption function. Ordinary least squares (OLS) is a type of linear least squares method for estimating the unknown parameters in a linear regression model. According to literature and academicians, OLS is the best method if there is no econometric problem in the data, and all of variables are stationary at level. This technique applied by prominent studies to find the determinants of energy consumption function (Dalei 2016; Kotsila and Polychronidou 2021).

In the post estimation tests, this study considers the Durbin-Watson statistic to check the presence/absence of autocorrelation and use *F*-statistic to check the overall significance of the model. Moreover, R^2 statistic is also employed, which states that how much predictors do explain the energy consumption.

Results and discussions

This section reports and discusses our results region wise. Although the time series models and variables are the same for each country, each estimate is based and given as per the availability of data. Moreover, two regions, Europe and Latin America, contain the same number of countries, i.e., eighteen countries, while the remaining regions, Asia & Pacific, Africa, and the Middle East and Arab States reported the results of seventeen, fourteen, and nine countries, respectively. The results of each region are given in a separate table for the purpose of comparison in the regions. All in all, the succeeding two sections incorporate brief interpretation and discussion on empirical results.

In line with the methodology of this study, the empirical results are estimated through OLS and reported separately for each country in the following tables. Consequently, Tables 3, 4, 5, 6, and 7 record the estimates of sample countries in the regions of Europe, Asia and Pacific, Latin America, Africa, and the Middle East and Arab States,

Table 7 Least squares estimates (Middle East and Arab States)

Country Time span	Estimated equations	
Algeria 1972–2014	$E = -.174 + .007EG + .001TO + .028UP - .000FDI - .055CO2$ $(-2.27^{**})(3.31^{***})(1.69)(2.62^{**})(-1.29)(-.93)$	$F = 4.40^{***}$ $R^2 = 0.37$
Egypt 1972–2014	$E = -.144 + .0008EG + .001TO + .039UP - .001FDI + .479CO2$ $(-2.82^{***})\ (0.30)\ (2.33^{**})\ (2.34^{**})\ (-1.86^{*})(4.36^{***})$	$F = 9.24^{***} R^2 = 0.55$
Iraq 1972–2014	$E = -.013 + .0003EG - .0004TO + .019UP - .00002FDI + .67CO$ $(0.36)\ (0.59)\ (-1.50)\ (1.73)\ (-0.08)(10.69^{***})$	$F = 28.26^{***} R^2 = 0.79$
Jordan 1977–2014	$E = -.059 + .001EG + .0006TO - .004UP - .0003FDI + .771CO2$ $(-1.10)\ (0.92)\ (1.45)\ (-2.26)\ (-0.32)(7.66^{***})$	$F = 18.60^{***} R^2 = 0.74$
Oman 1972–2014	$E = .022 - .0006EG - .0002TO + .017UP - .004FDI + .225CO2$ $(0.11)\ (-0.10)\ (-0.10)\ (1.25)\ (-0.90)(1.64)$	$F = 1.48^{***} R^2 = 0.16$
Saudi Arabia 1972–2014	$E = -.148 - .003EG + .002TO + .005UP + .0008FDI + .364CO2$ $(-1.39)\ (-1.45)\ (1.49)\ (0.61)\ (20.40)(1.55)$	$F = 1.76 R^2 = 0.19$
Sudan 1973–2014	$E = -.021 + .0005EG + .00009TO + .0005U - .0001FDI + .14CO$ $(-0.70)\ (0.50)\ (0.14)\ (2.18)\ (-2.04^{**})(3.77^{***})$	$F = 5.38^{***} R^2 = 0.42$
Tunisia 1972–2014	$E = -.034 + .004EG + .0002TO + .0005UP + .004FDI + .429CO2$ $(-0.62)\ (2.62^{**})\ (0.57)\ (0.09)\ (0.089)(3.61^{***})$	$F = 7.07^{***} R^2 = 0.48$
UAE 1972–2015	$E = .001 + .003EG - .0001TO - .005UP - .003FDI + .555CO2$ $(0.14)\ \left(2.83^{***}\right)(-0.40)\ (-1.98)\ (-1.24)\ (6.48^{***})$	$F = 39.45^{***} R^2 = 0.83$

Source: *t*-statistics are given in parenthesis. Asterisks *, **, and *** represent 1%, 5%, and 10% significant level

respectively. Reminding the "Review of literature" section of this study, each variable selected in the models plays a vital role in explaining energy consumption. The results unveil that most of the economies exhibit the same results in terms of statistical significance and goodness of fit of the model. Moreover, the *F*-statistics also confirm the overall significance of the underlying models. However, the similarity in estimates of every region allows the author to explain overall the results in the current section collectively.

Overall, the estimates of all regions show that economic growth has positive and statistically significant coefficients in almost all sample economies. This indicates that there is a positive and significant impact of economic growth on energy consumption in the selected sample countries. However, the estimate of few economies exhibits insignificant coefficient economic growth, but overall, it can be generalized as statistically significant and positive based on the more over less criteria. Most of the economies experience economic growth as a significant determinant of energy consumption in each region. Nonetheless, the explanation of the energy consumption by its predictors in the function is different across countries and regions but statistically significant. The coefficient sign of economic growth is also correct as expected, as this study assumes that increase in economic activity increases the energy consumption in the country or a region.

The second most influential variable in the energy consumption function is carbon emission. Likewise, the estimates of each region have also consensus on the positive effect of carbon emissions on energy consumption. Particularly, the empirical evidence in Tables 3, 4, 5, 6, and 7 suggests that carbon emissions contain positive and statistically significant coefficients in the energy consumption function. This indicates that increase in the magnitude of carbon emissions positively fluctuate the energy consumption in the sample countries and regions. Like economic growth, the effect of carbon emission on energy consumption varies across countries in terms of magnitude; however, it is positive and statistically significant. Generally, in almost all sample countries, carbon emission is recorded as a strong determinant of energy consumption. The direction of the carbon emissions are also correct as expected because the carbon emissions are strongly connected with industrial activity in the country which in turn causes the energy consumption.

Furthermore, the rest of all variables have insignificant impact on energy consumption in almost all of the sample economies. The results unveil that FDI, trade openness, and urbanization have statistical insignificant coefficients in terms of energy consumption. This shows that these are not a strong and significant factor in energy consumption function. In contrast, the case of Nigeria and Egypt is quite different. The energy consumption function of these two economies exhibit that all of the included factors strongly and significantly determine energy consumption in respective countries. However, the case of these two might not be generalized for all sample countries, because the rest of all empirical evidence in Tables 3, 4, 5, 6, and 7 shows that the effect of FDI, trade openness, and urbanization are not significantly different from zero.

The nexus between economic growth and energy consumption is explored by various researchers in the literature of energy economics. Empirical evidence in the literature explained that economic growth contains industrial activity which in turn directly impacts energy consumption positively (Dalei, 2016). The explanation of energy consumption by regressors is different across countries but it is statistically significant and according to expectations of this study. These findings are according to theory and in line with most of the studies conducted in this area (Masih and Masih 1997; Samia and Anwar 2014; Azam et al 2015a, b). On the other hand, it strictly contradicts the results of Dalei (2016) and Nathaniel et al (2020), as they showed economic growth as a negative predictor of energy consumption.

The second most key variable in the model is carbon emissions. As directed by literature, carbon emissions have a strong impact on the energy consumption through other macroeconomic variables like economic growth. Likewise, the results of this study argue that carbon emissions have a positive and high significant impact on the energy consumption in overall sample economies. The sign and significance of the carbon emissions coefficient is in line with previous empirical evidence which consider carbon emissions as a core determinant of energy consumption (Soytas and Sari, 2009). On the other hand, it contradicts vast empirical evidence which is in favor of the inverse relationship of carbon emissions and economic growth and further energy consumption (Alkhathlan and Javid, 2013; Zou and Zang 2020).

Although the rest of all variables are shown as strong determinants of energy consumption in the previous literature, the results reported for this study contradict this narrative. Findings of the previous empirical evidence showed that FDI, trade openness, and urbanization are core factors which play a vital role in the energy consumption. However, in the case of this study, all of the sample countries' estimates are evident that these variables are not significant statistically. This means that these variables have no relationship with energy consumption and no impact on the energy consumption regardless of their coefficient sign. Simply, in the case of FDI, trade openness, and urbanization, this study opposes the view of previous literature. However, in case of economic growth and carbon emissions, it is in line with prior literature on energy consumption function.

Conclusion and policy implications

Conclusion

The aim of this study is to model the energy consumption function and find significant determinants of energy consumption among all the factors illustrated by the relevant literature. For this purpose of a common narrative, the study is conducted on the global data. Therefore, for this purpose, data of 79 economies comprising five different regions are collected annually over the period 1972 to 2015. All variables, considered factors in energy consumption function including response variable, are transformed to growth rates to avoid estimation issues in the analysis. To fulfill the requirement of this study, the least squares technique is implemented to get the empirical evidence on the said scenario. The conclusion drawn from the empirical evidence is reported below.

Almost all of the empirical estimates in consumption functions of each region encompass the test of autocorrelation and overall significance. Serial correlation test suggests that there are no autocorrelations in the estimated models, and *F*-tests recommend high significance of these estimated models. Particularly, the findings of the study unveil that there are positive and significant impacts of economic growth, carbon emissions, and urbanization on energy consumption in most of the sample economies. On the contrary, the estimates find no impact in the case of net FDI and trade openness on energy consumption. However, the case of Nigeria and Egypt is exceptional, which provides strong evidence that economic growth, FDI, trade openness, urbanization, and carbon emissions have strong and statistically significant impact on energy consumption. All in all, findings of this study suggest that there are two significant determinants of energy consumption in selected factors and sample countries that are economic growth and carbon emissions.

The contribution of this study is as follows. First, we use a mass sample of economies across the globe having reliable data. Then, the study transforms each variable in growth rate to avoid the econometric complexity and use a straightforward econometric technique for estimation. Further, the consumption functions of each country are estimated and reported separately, to achieve valid and reliable estimates. Moreover, the factors which are commonly used in a wide literature are selected in consumption function and are same in the estimated models for all sample economies.

Policy recommendations

Based on the empirical evidence, this research recommends that the policymakers should support the export-oriented industry by distribution of products that supports the interest of the investors helping the country in the long term. The findings of this study strongly recommend that energy policy needs to be designed considering the importance of economic growth and environmental quality. Furthermore, from a policy perspective, given the perpetual energy demand globally especially energy from fossil fuel sources has drawn attention of all stakeholders, namely energy economist, environment economist, and government administrators. This concerns call for alternative energy sources given that the sampled economies thrive on its energy sector. However, consistent dependent on conventional energy sources comes with its environmental implications. Our study lends credence to the energy-induced growth hypothesis. This suggests that government administrators in the investigated economies need to promote more of its energy sector otherwise economic growth will be compromised. Additionally, caution should be taken on the trajectory for energy-driven economy. This is pertinent given the environmental cost of energy consumption especially non-renewable energy. Thus, a balance for green economy without compromise for environmental sustainability over the investigated economies.

Appendix

Table 8 List of region-wise countries

Europe	Latin America	Asia and Pacific	Africa	Middle East and Arab States
Albania	Argentina	Australia	Benin	Egypt
Austria	Bolivia	Bahrain	Botswana	Iraq
Belgium	Brazil	Bangladesh	Cameron	Jordon
Bulgaria	Chile	China	Congo Rep	Oman
Cyprus	Colombia	India	Cote d'Iv	Saudi Arabia
Denmark	Costa Rica	Indonesia	Gabon	UAE
Finland	Dominican R	Iran	Ghana	Sudan
France	Ecuador	Japan	Kenia	Algeria
Greece	El Salvador	Korea Rep	Mauritius	Tunisia
Ireland	Guatemala	Malaysia	Nigeria	
Italy	Jamaica	Nepal	Senegal	
Malta	Mexico	New Zeeland	S. Africa	
Netherland	Nicaragua	Pakistan	Togo	
Norway	Panama	Philippines	Zimbabwe	
Portugal	Paraguay	Singapore		
Spain	Peru	Sri Lanka		
Switzerland	Uruguay	Thailand		
Turkey	Venezuela			

Source: Author's compilation

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Author contribution The first author Prof Dr. Muhammad Azam was responsible for the conceptual construction of the study's idea. The second author Dr. Ali Gohar managed the literature section, while the third author managed the data gathering and preliminary analysis, and Dr. Festus Victor Bekun was responsible for proofreading and manuscript editing.

Availability of data and materials The data for this present study are sourced from WDI as outlined in the data section.

Code availability All codes for the analysis are available in STATA and E-views statistical software.

Declarations

Ethics approval The authors mentioned in the manuscript have agreed for authorship read and approved the manuscript and given consent for submission and subsequent publication of the manuscript.

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