Nuclear energy, CO_2 emissions and economic growth

The case of developing and developed countries

Abdullah Alam
International Islamic University, Islamabad, Pakistan

Abstract

Purpose – The paper aims to study the relationship between economic growth, nuclear energy consumption and carbon dioxide (CO_2) emissions for a panel of 25 countries over a period of 1993-2010. Through this study, the author has provided an insight into one of the available sources of energy, i.e. nuclear energy and its impact on economic growth and CO_2 emissions.

Design/methodology/approach – Separate panels are created for developing and developed economies. Short- and long-run causalities between the variables are established using error correction mechanism.

Findings – For the developed countries, short-run causality running from CO_2 emissions to economic growth was estimated, whereas strong form of causality indicated the dependence of CO_2 emissions on economic growth and nuclear energy consumption was seen to impact CO_2 emissions. For the developing countries, both the short-run and strong-form causality estimates indicate that economic growth causes CO_2 emissions.

Practical implications – On policy front, developing countries can safely adopt CO_2 cut-back policies as they are not found to impact economic growth. For the developed countries, such policies may impede growth in the short run, but in the long run these policies do not affect the economic growth.

Originality/value – Keeping in mind the significance of nuclear energy consumption in economic growth and less/no GHG emissions generated by nuclear energy, this study validates its significance. This study, to the best of the author's knowledge, considers the largest panel (i.e. 25 countries) to date and the only study that focuses on studying three different panels (complete dataset, developed countries, developing countries) in one study and applies the vector error correction mechanism to study the causal relationship between nuclear energy consumption, CO_2 emissions and economic growth.

Keywords Economic growth, CO_2 emissions, Nuclear energy consumption

Paper type Research paper

1. Introduction

In the present era, electricity consumption has increased by leaps and bounds as compared to previous periods. Electricity generation sources such as fossil fuels are believed to contribute significantly towards the carbon dioxide (CO_2) (green-house gas (GHG)) emissions. CO_2 emissions have increased appreciably in the past few years and are projected to appreciate in the subsequent years[1].

There is a prolonged and continued debate on the reduction of global warming and diminution of the CO_2 emissions. Considering the fact that world energy consumption is bound to increase with the passage of time[2], considering its relationship with growth, resources must be identified and developed to sustain the growing need of

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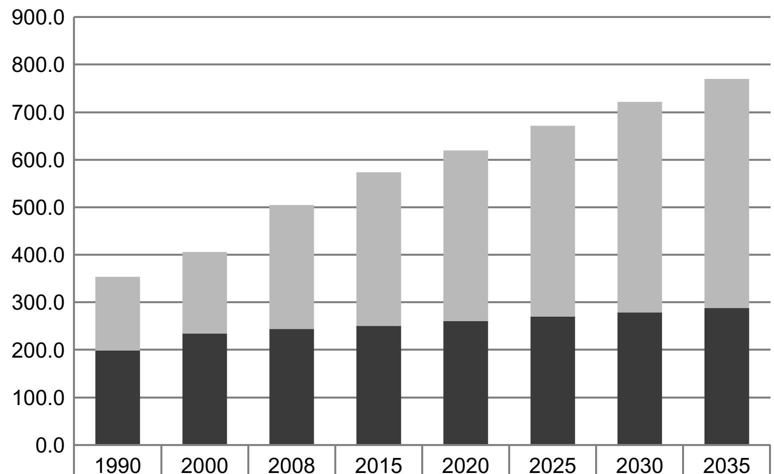
energy through efficient and secure options. Alternate energy resources such as wind, solar, geothermal and nuclear energy are considered less/no green-house contributors (Figure 1).

Nuclear energy is one of the available alternates, considering that it is a carbon-free source of energy generation. However, researchers and policy makers have concerns regarding the large-scale implementation of this source of energy. These apprehensions include safety issues at nuclear energy processing plants, proliferation issues, disposal of radioactive wastes and the costs associated with it. Although these concerns are realistic, research and developments are initiated in this regard to reflect on the issues mentioned above. The relevance of nuclear energy as a source of future energy production roadmap can be estimated from the figures tabulated by US Energy Information Administration, International Energy Outlook 2011, which predict the world nuclear energy consumption increasing from 2,639 billion kilowatt hours in 2005 to 3,731 billion kilowatt hours in 2020 and 4,916 kilowatt hours by 2035 (Figure 2).

Many developed and developing countries are investing in nuclear energy projects as part of their energy plans because of the price precariousness associated with oil (Adamantiades and Kessides, 2009). Another issue that the countries have to deal with is to reduce the GHG emissions[3]. Also the significant relationship between economic growth and nuclear energy consumption has generated interest among policymakers to analyze and utilize nuclear energy as a consistent and growing source for their energy needs.

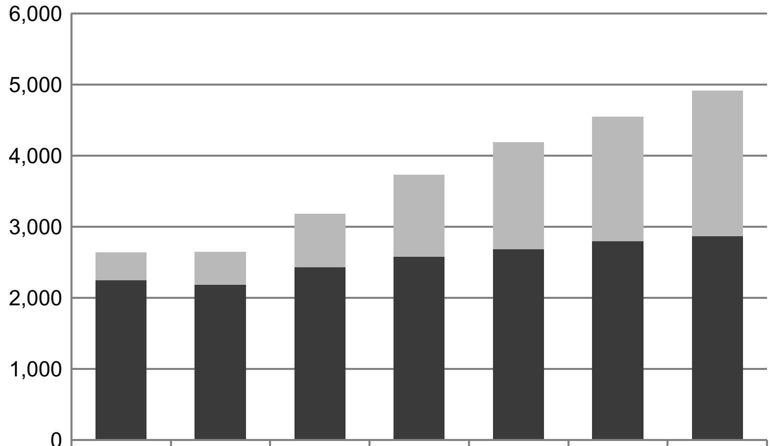
Keeping in mind the significance of nuclear energy consumption in economic growth and less/no GHG emissions generated by nuclear energy, this study validates its significance. Previous studies on the topic include panel (Apergis *et al.*, 2010) as well as time-series analysis (Menyah and Wolde-Rufael, 2010) of the causal relationship between the nuclear energy consumption, CO_2 emissions and economic growth.



	1990	2000	2008	2015	2020	2025	2030	2035
Non-OECD	155.1	171.5	260.5	323.1	358.9	401.7	442.8	481.6
OECD	198.6	234.5	244.3	250.4	260.6	269.8	278.7	288.2

Source: US Energy Information Administration, International Energy Outlook 2011

Figure 1.
World energy consumption, 1990-2035 (quadrillion Btu)



	2005	2010	2015	2020	2025	2030	2035
Non-OECD	393.0	462.0	748.0	1,154.0	1,508.0	1,747.0	2,043.0
OECD	2,246	2,186	2,430	2,576	2,680	2,799	2,873

Source: US Energy Information Administration, International Energy Outlook 2011

Figure 2.
World nuclear energy consumption, 2005-2035 (billion kilowatt hours)

This study, to the best of our knowledge, considers the largest panel (i.e. 25 countries) to-date and the only study that focuses on studying three different panels (complete dataset, developed countries, developing countries) in one study and applies the vector error correction mechanism to study the causal relationship between nuclear energy consumption, CO_2 emissions and economic growth. Most of the studies in this area are focused on developed countries, whereas this study also encompasses the case of developing countries in order to provide a roadmap to the policymakers in relation to their energy, GHG emissions control and growth planning.

2. Literature review

Energy economics has become a significant study area in recent times. Numerous studies have, empirically and theoretically, tried to establish relationships and causalities between energy components and their role in the enhancement of economic development of a country. Some of these studies have focused on the energy-growth relationship for a particular economy (Kraft and Kraft, 1978; Yu and Choi, 1985; Masih and Masih, 1996; Altinay and Karagöl, 2005) whereas, others have used panel data analysis to establish the relationship (Lee and Chang, 2008; Narayan and Smyth, 2008; Apergis and Payne, 2009; Lee and Lee, 2010; Noor and Siddiqi, 2010). However, results obtained as part of the research process have not reached a consensus. Researchers have shown that, at some instances, energy consumption causes economic growth (Lee and Chang, 2008). In other cases, there has been evidence of economic growth causing energy consumption (Kraft and Kraft, 1978; Yu and Choi, 1985; Aqeel and Butt, 2001). There has also been substantial support for bi-directional causalities (Masih and Masih, 1996; Lee and Lee, 2010) and no causality (Stern, 1993; Cheng, 1995) between these variables.

On similar grounds, the evidence for nuclear energy consumption and economic growth has been mixed. Although the nuclear energy consumption – economic growth literature has not been very old, still the studies conducted on the topic have yielded inconsistent results.

Apergis and Payne (2010) studied the relationship between nuclear energy consumption and economic growth for 16 countries over a time period 1980-2005 using panel co-integration and vector error correction model. Their results indicate bi-directional causality between nuclear energy consumption and economic growth in the short-run whereas uni-directional long-run causality moving from nuclear energy consumption to economic growth was found.

Yoo and Ku (2009) investigated the causality between nuclear consumption and economic growth for six countries (Argentina, France, Germany, Korea, Pakistan and Switzerland) using time-series analysis covering time period of more than 20 years until 2005. Inconsistent results were obtained for the six countries. Bi-directional causality between nuclear energy consumption and economic growth was estimated for Switzerland. For Pakistan and France, economic growth affected nuclear energy consumption whereas reverse causality from nuclear energy consumption to economic growth was found in case of Korea. Argentina did not show any signs of causality evidence between the two variables.

Wolde-Rufael (2010) examined the relationship between economic growth and nuclear energy consumption for India over a period of 1969-2006 applying the bounds test co-integration approach, Toda and Yamamoto approach to Granger causality and variance decomposition approach. It was concluded that economic growth in India is dependent on nuclear energy consumption. Similar results were found by Yoo and Jung (2005) who investigated causality existing between nuclear energy consumption and economic growth for a Korean sample over the period 1977-2002 using co-integration and error correction modeling and found uni-directional causality running from nuclear energy consumption to economic growth.

Wolde-Rufael and Menyah (2010) tested the causal relationship between nuclear energy consumption and economic growth for nine developed countries over the time period 1971-2005 using Toda and Yamamoto's modified version of Granger causality test. Uni-directional causality running from nuclear energy consumption to economic growth was estimated for Japan, The Netherlands and Switzerland. Reverse causality running from economic growth to nuclear energy consumption was found for Canada and Sweden, whereas bi-directional causality evidence was collected for France, Spain, the UK and the USA.

Lee and Chiu (2011), in their panel data analysis for developed countries over the time period 1971-2006, found evidence of long-run causality running from economic growth to nuclear energy consumption whereas no evidence for short-run causality was estimated between the two variables.

Almost all of the above mentioned studies examined the relationship between economic growth and nuclear energy consumption by including some additional variables (for example, oil prices and oil consumption in Lee and Chiu, 2011; real gross fixed capital formation and labor force in Apergis and Payne, 2010; Wolde-Rufael, 2010; Wolde-Rufael and Menyah, 2010). Apergis *et al.* (2010) examined the relationship between nuclear energy consumption, renewable energy consumption CO_2 emissions and economic growth for 19 developed countries over a period of 1984-2007 using error correction mechanism. Negative association between nuclear energy consumption and CO_2 emissions was estimated in the long run. In the short run, nuclear energy consumption was observed to reduce CO_2 emissions. Bi-directional causality was estimated between economic growth and CO_2 emissions. In a similar study based on US sample covering a period 1960-2007, Menyah and Wolde-Rufael (2010) found uni-directional causality running from nuclear energy consumption to CO_2 emissions, whereas no causality was estimated between renewable energy and CO_2 emissions. Bi-directional causality was found between CO_2 emissions and economic growth.

3. Data and methodology

3.1 Data

Longitudinal (panel)annual data has been used in this study for 25 countries[4] over a period of 1993-2010. Countries and time period were selected on the basis of availability of data for each variable. Three different panels were formed for the study. The first panel contained all the 25 countries under study, the second panel contains the developed countries[5] and the third panel is formed for the developing countries[6]. *ln* (real GDP), *ln* (nuclear energy consumption) and *ln* (CO_2 emissions) are the three variables used in this study represented by the symbols *EG*, *NEC* and *CE*, respectively. GDP per capita (constant 2000 US$) data was obtained from World Bank world development indicators (WDI) online database. Data for nuclear energy consumption (million tonnes oil equivalent) and CO_2 emissions (million tonnes CO_2) was obtained from BP Statistical Review of World Energy (June 2011)[7]. Table I presents the descriptive statistics of the three variables for the panels under consideration.

3.2 Panel unit root tests

In order to test the co-integration and the causal relationship between economic growth (*EG*), nuclear energy consumption (*NEC*) and CO_2 emissions (*CE*), I use panel unit root tests (Baltagi, 2004). The methods proposed by Levin *et al.* (2002) and Im *et al.* (2003) are employed for testing unit roots. As additional checks, Fisher-ADF and Fisher-PP tests proposed by Maddala and Wu (1999) were also performed. The test proposed by Levin *et al.* (2002) is given as:

Variables	Obs.	Mean	SD	Minimum	Maximum
Panel A: all countries					
ln Real GDP (*EG*)	450	8.89	1.36	5.82	10.61
ln Nuclear energy consumption (*NEC*)	450	2.01	1.59	−4.42	5.26
ln CO_2 emissions (*CE*)	450	5.75	1.38	3.52	9.03
Panel B: developed countries					
ln Real GDP (*EG*)	270	9.79	0.67	8.19	10.61
ln Nuclear energy consumption (*NEC*)	270	2.59	1.40	−0.61	5.26
ln CO_2 emissions (*CE*)	270	5.57	1.42	3.52	8.78
Panel C: developing countries					
ln Real GDP (*EG*)	180	7.54	0.95	5.82	9.28
ln Nuclear energy consumption (*NEC*)	180	1.14	1.46	−4.42	3.65
ln CO_2 emissions (*CE*)	180	6.00	1.27	3.79	9.03

Table I.
Descriptive statistics

$$\Delta y_{xt} = \alpha_x + \delta_x y_{xt-1} + \sum_{z=1}^{p_x} p_x \Delta y_{xt-z} + \varepsilon_{xt} \quad (1)$$

where:

- Δ represents first difference operator.
- y_{xt} represents the dependent variable having observation for country x at time t.

The null hypothesis is $\delta_x = \delta = 0$ for all x.

The alternative hypothesis is $\delta_x = \delta < 0$ for all x.

- ε_{xt} represents the error term which is independently distributed normal for all x, t and has heterogeneous variances across panels.

The test given by Im *et al.* (2003) is an extension of the Levin *et al.* (2002) test, which allows for heterogeneity of δ value and relaxes the common autoregressive parameter assumption.

3.3 Panel co-integration tests

If the each variable in the panel is stationary of the order $I(1)$, panel co-integration tests are applied. This is done in order to check the long run relationship between the dependent and the independent variables. For this purpose, I employ Pedroni (2004) test, which is specified as:

$$EG_{xt} = \alpha_x + \delta_t + \beta_x NEC_{xt} + \gamma_x CE_{xt} + \eta_{xt} \quad (2)$$

$$NEC_{xt} = \alpha_x + \delta_t + \beta_x EG_{xt} + \gamma_x CE_{xt} + \mu_{xt} \quad (3)$$

$$CE_{xt} = \alpha_x + \delta_t + \beta_x EG_{xt} + \gamma_x NEC_{xt} + \nu_{xt} \quad (4)$$

where:

- EG_{xt}, NEC_{xt} and CE_{xt} represent economic growth, nuclear energy consumption and CO_2 emissions, respectively.
- x represents the countries in the panel.
- t represents time period.
- α_x represents the country specific effects.
- δ_t represents the deterministic time trends.
- η_{xt}, μ_{xt} and υ_{xt} represent the estimated residuals from equations (2)-(4), respectively.

Pedroni (2004) test allows for the variation of co-integration vector across different panel sections. As a check of robustness, Kao (1999) panel co-integration test is also performed.

3.4 Panel causality tests

After the implementation of panel co-integration, short and long causalities are checked for the variables. A two-step process is conducted in this regard. In the first stage, residuals are estimated from equations (2)-(4). In the second step, these residuals are fit in a dynamic error correction model (on the right side of the equation) specified as:

$$\Delta EG_{x,t} = \alpha_{1x} + \sum_{l=1}^{h} \delta_{11x,l}\Delta EG_{x,t-l} + \sum_{l=1}^{h} \delta_{12x,l}\Delta NEC_{x,t-l} + \sum_{l=1}^{h} \delta_{13x,l}\Delta CE_{x,t-l} + \gamma_{1x}\eta_{x,t-1} + \theta_{1x,t} \quad (5)$$

$$\Delta NEC_{x,t} = \alpha_{2x} + \sum_{l=1}^{h} \delta_{21x,l}\Delta EG_{x,t-l} + \sum_{l=1}^{h} \delta_{22x,l}\Delta NEC_{x,t-l} + \sum_{l=1}^{h} \delta_{23x,l}\Delta CE_{x,t-l} + \gamma_{2x}\mu_{x,t-1} + \theta_{2x,t} \quad (6)$$

$$\Delta CE_{x,t} = \alpha_{3x} + \sum_{l=1}^{h} \delta_{31x,l}\Delta EG_{x,t-l} + \sum_{l=1}^{h} \delta_{32x,l}\Delta NEC_{x,t-l} + \sum_{l=1}^{h} \delta_{33x,l}\Delta CE_{x,t-l} + \gamma_{3x}v_{x,t-1} + \theta_{3x,t} \quad (7)$$

where:

Δ	represents the difference operator.
$EG_{x,t}$, $NEC_{x,t}$ and $CE_{x,t}$	represent economic growth, nuclear energy consumption and CO_2 emissions, respectively, for country x at time t.
θ	represents the serially uncorrelated error term with zero mean.
γ_x	represents the adjustment speed.
h	represents the lag length determined using Akaike information criterion (AIC).

4. Empirical results and discussion

4.1 Panel unit root tests

Tables II(a)-(c) report the results of the panel unit root tests conducted for the three variables economic growth (*EG*), nuclear energy consumption (*NEC*) and CO_2 emissions (*CE*) using Levin *et al.* (2002) and Im *et al.* (2003), Fisher-ADF and Fisher-PP methodologies. All the four unit root test statistics confirm that the three series (*EG*, *NEC* and *CE*) are integrated of the order of the *I*(1) for all the three panels.

4.2 Panel co-integration tests

Since each of the variables in all the three panels is stationary at *I*(1), I applied panel co-integration tests. Table III specifies the results of the Pedroni's panel co-integration test. In order to confirm the existence of co-integration between the three variables, Kao's panel co-integration test (Table IV) is also used. The results clearly indicate the rejection of null hypothesis of no co-integration. So, it can be said that the three series (economic growth, nuclear energy consumption and CO_2 emissions) move together in the long run for the cross-section of countries under consideration for all the three panels.

Variables	Trend	Levin, Lin and Chu	Im, Pesaran and Shin	Fisher-ADF	Fisher-PP
a. Panel unit root test results for complete panel					
EG	Individual effects	−0.658	2.326	2.587	2.700
	Individual effects and linear trends	2.103	2.201	2.599	5.047
NEC	Individual effects	−3.172***	−2.538***	−2.434***	−3.341***
	Individual effects and linear trends	−0.746	−0.355	−0.048	−1.325*
CE	Individual effects	−0.823	−0.948	−0.521	−0.780
	Individual effects and linear trends	−2.638***	−1.737**	−1.304*	−0.172
ΔEG	Individual effects	−8.091***	−6.922***	−6.882***	−7.378***
	Individual effects and linear trends	−5.556***	−3.792***	−3.931***	−5.421***
ΔNEC	Individual effects	−14.409***	−14.616***	−12.142***	−19.440***
	Individual effects and linear trends	−13.059***	−13.722***	−11.275***	−15.238***
ΔCE	Individual effects	−13.763***	−13.931***	−12.173***	−12.686***
	Individual effects and linear trends	−10.235***	−9.686***	−9.083***	−11.421***
b. Panel unit root test results for developed countries					
EG	Individual effects	−6.007***	−0.893	−0.740	−1.294*
	Individual effects and linear trends	2.777	1.916	2.252	5.302
NEC	Individual effects	−3.412***	−2.100**	−2.052**	−2.374***
	Individual effects and linear trends	−1.683**	0.096	0.499	0.695
CE	Individual effects	−2.813***	−2.300**	−1.779**	−1.411*
	Individual effects and linear trends	−2.291**	−0.994	−0.593	0.549
ΔEG	Individual effects	−6.717***	−6.076***	−6.000***	−5.809***
	Individual effects and linear trends	−5.831***	−4.547***	−4.700***	−4.582***
ΔNEC	Individual effects	−11.862***	−10.802***	−9.201***	−14.534***
	Individual effects and linear trends	−11.311***	−10.558***	−8.700***	−11.325***
ΔCE	Individual effects	−11.929***	−12.615***	−10.613***	−11.208***
	Individual effects and linear trends	−10.886***	−11.010***	−9.512***	−10.989***
c. Panel unit root test results for developing countries					
EG	Individual effects	3.161	5.261	5.276	5.855
	Individual effects and linear trends	0.392	1.049	1.115	1.488
NEC	Individual effects	−0.508	−0.966	−0.926	−2.374***
	Individual effects and linear trends	−1.463*	−2.031*	−2.068**	−2.946***
CE	Individual effects	0.519	1.425	1.443	0.495
	Individual effects and linear trends	−2.237**	−2.234**	−2.066**	−0.944
ΔEG	Individual effects	−5.801***	−4.495***	−4.470***	−4.551***

(*continued*)

Table II.

Variables	Trend	Levin, Lin and Chu	Im, Pesaran and Shin	Fisher-ADF	Fisher-PP
	Individual effects and linear trends	−4.221***	−1.456*	−1.625*	−2.960***
ΔNEC	Individual effects	−18.593***	−14.971***	−12.817***	−12.937***
	Individual effects and linear trends	−17.153***	−14.519***	−8.949***	−10.224***
ΔCE	Individual effects	−7.471***	−6.456***	−6.024***	−6.332***
	Individual effects and linear trends	−5.580***	−3.581***	−3.491***	−4.600***

Table II.

Note: Significant at: *10, **5, and ***1 percent levels

Trend	Panel v	Panel rho	Panel PP	Panel ADF	Group rho	Group PP	Group ADF
Panel A: all countries							
No deterministic trend	−1.83*	1.99*	1.01	−0.32	3.65***	2.09**	−2.05**
Deterministic intercept and trend	5.52***	2.79***	1.32	−1.25	4.15***	1.66	−3.98***
Panel B: developed countries							
No deterministic trend	−1.66*	1.60	0.84	0.36	3.00***	1.84*	0.22
Deterministic intercept and trend	8.46***	1.82*	0.65	−0.53	3.04***	1.21	−2.77***
Panel C: developing countries							
No deterministic trend	−0.78	1.16	0.54	−1.13	2.10**	1.06	−2.49**
Deterministic intercept and trend	0.90	1.98*	1.08	−1.42	2.84***	1.14	−2.98***

Table III.
Pedroni panel co-integration test results

Notes: Significant at: *10, **5 and ***1 percent levels; EG is the dependent variable

	ADF test statistics
Panel A: all countries	−3.58**
Panel B: developed countries	−1.93*
Panel C: developing countries	−3.00**

Table IV.
Kao panel co-integration test results

Notes: Significant at: *5 and **1 percent levels; EG is the dependent variable

4.3 Panel causality tests

Table V reports the results of the short-run and long-run causality tests for the three panel data sets.

Panel A (all countries) of Table V indicates only two short-run relationships between the variables where CO_2 emissions cause nuclear energy consumption and economic growth is observed to cause CO_2 emissions. This means that an increase in the CO_2 emissions may lead to a case for higher nuclear energy consumption. Short-run causality running from economic growth to CO_2 emissions indicates that enhanced growth boosts up CO_2 emissions and emphasizes the fact that economic growth has to be sacrificed in

Table V.
Panel causality test results

Dependent variable	Sources of causation (independent variables) Short run ΔEG	ΔNEC	ΔCE	Long run ECT[a]	Strong causality ΔEG, ECT	ΔNEC, ECT	ΔCE, ECT
Panel A: all countries							
ΔEG	–	0.34	1.09	5.95**	–	3.23**	3.82**
ΔNEC	1.27	–	3.65*	0.15	0.66	–	2.32
ΔCE	21.01***	2.21	–	32.54***	24.19****	17.92***	–
Panel B: developed countries							
ΔEG	–	1.17	2.87*	1.03	–	1.23	2.01
ΔNEC	0.67	–	0.73	1.64	1.16	–	1.13
ΔCE	1.74	0.39	–	5.77**	3.58**	3.10**	–
Panel C: developing countries							
ΔEG	–	0.13	0.09	0.49	–	0.31	0.31
ΔNEC	0.05	–	2.47	0.0004	0.03	–	1.67
ΔCE	6.79***	1.50	–	12.11***	9.14***	7.05***	–

Notes: Significant at: *10, **5 and ***1 percent levels; [a]ECT represents the coefficient of the error correction terms; Wald *F*-statistics are reported

order to reduce CO_2 emissions or, otherwise, alternate means of energy consumption need to be developed in order to keep economic growth intact and to move it along with the cutback on CO_2 emissions. The long-run estimates suggest that economic growth and CO_2 emissions respond to deviations from long-run equilibrium. Joint tests for strong causality indicate that nuclear energy consumption causes economic growth whereas economic growth and CO_2 emissions have bi-directional causal relationship. This offers an insight into the matter that economic growth causes CO_2 emissions and increased CO_2 emissions are also associated with enhanced growth. Therefore, one has to sacrifice economic growth in order to cope with the responsibility to keep CO_2 emissions under check. Our estimates approve the findings of Apergis *et al.* (2010) and Menyah and Wolde-Rufael (2010) who found bi-directional causality between CO_2 emissions and economic growth. The fact that nuclear energy consumption causing economic growth suggests that any energy conservation measures undertaken may impact the growth capabilities of the economy. The joint tests also indicate causality running from nuclear energy consumption to CO_2 emissions which is in-line with the findings of Menyah and Wolde-Rufael (2010) for US sample.

Panel B (developed countries) of Table V provides evidence of short-run causality running from CO_2 emissions to economic growth meaning that any policies to reduce CO_2 emissions would hamper economic growth in the short term. Long-run estimates indicate the response of CO_2 emissions to long-run deviation of the system from equilibrium. Joint tests for strong form of causality indicate the dependence of CO_2 emissions on economic growth. This provides a healthy sign for the developed countries for the reason that adherence to the Kyoto protocol and other CO_2 emissions reduction policies would not impact the growth of the economy in the long run, although some shocks may be felt in the short run. Similar to the finding for the complete panel, nuclear energy consumption is seen to impact CO_2 emissions with a positive sign. This implies that nuclear energy also may not be a CO_2 free source of energy and its use may also result in the increase of the emissions for various reasons that are beyond the scope of this paper. This study contradicts the findings of

Lee and Chiu (2011) who, in their panel data analysis for developed countries, found evidence of long-run causality running from economic growth to nuclear energy consumption although they found no evidence for short-run causality between the two variables as is the case in this paper.

Panel C (developing countries) of Table V presents similar results to that of the complete panel. Both the short-run and strong-form causality estimates indicate that economic growth impacts CO_2 emissions without feedback effect implying that any CO_2 emissions reduction policies will not affect economic growth in the short or long run for developing countries. CO_2 emissions respond to the long-run deviation of the system from equilibrium position.

5. Conclusion

One of the most important issues that the policymakers, today, have to deal with is the increasing demand for energy and the need for enhancement and development of alternate sources of energy that can provide consistent energy along with the reduction of GHGs. This study provides an insight into one of the available sources of energy, i.e. nuclear energy and its impact on economic growth and CO_2 emissions. The rationale of this study was to unearth causality relationships between economic growth, nuclear energy consumption and CO_2 emissions for three different panels (complete dataset of 25 countries, developed countries and developing countries). Short- and long-run causalities were estimated using error correction models.

For the complete panel of 25 countries, CO_2 emissions were seen to cause nuclear energy consumption ($CO_2 \rightarrow NEC$) and economic growth was observed to cause CO_2 emissions ($EG \rightarrow CO_2$). Joint tests for strong causality indicated that nuclear energy consumption caused economic growth ($NEC \rightarrow CO_2$), economic growth and CO_2 emissions have bi-directional causal relationship ($EG \leftrightarrow CO_2$) and nuclear energy consumption caused CO_2 emissions ($NEC \rightarrow CO_2$). For developed countries, short-run causality running from CO_2 emissions to economic growth ($CO_2 \rightarrow EG$) was estimated, whereas strong form of causality indicated the dependence of CO_2 emissions on economic growth ($EG \rightarrow CO_2$) and nuclear energy consumption was seen to impact CO_2 emissions ($NEC \rightarrow CO_2$). For developing countries, both the short-run and strong-form causality estimates indicated that economic growth causes CO_2 emissions ($EG \rightarrow CO_2$).

Related to the policy implication of the study, developing countries can safely adopt CO_2 cut-back policies as they are not found to impact economic growth. For developed countries, such policies may impede growth in the short run but in the long run these policies do not affect the economic growth. In general, policymakers from both developed and developing countries need to devise alternate sources of energy in order to keep the growth capabilities intact and at the same time adhere to reduced GHG emissions. Since, none of the panels of the study significantly validates the impact of nuclear energy consumption on the economic growth; policies aimed at nuclear dependency need to be re-evaluated and re-addressed.

Notes

1. CO_2 emissions (related to energy consumption) augment from 30.2 billion metric tonnes in 2008 to 35.2 billion metric tonnes in 2020 and 43.2 billion metric tonnes in 2035 (US Energy Information Administration, International Energy Outlook 2011).

2. Refer to Figure 1 for analyzing the trend of world energy consumption for a period of 1990-2035.
3. The Kyoto protocol asks its signatories to ensure that green-house gas emissions in 2012 are in level with the total emissions in 1990.
4. Argentina, Brazil, Bulgaria, Canada, China, Czech Republic, Finland, France, Germany, Hungary, India, Japan, Mexico, The Netherlands, Pakistan, Russia, Slovakia, South Africa, South Korea, Spain, Sweden, Switzerland, Ukraine, the UK, the USA.
5. Canada, Czech Republic, Finland, France, Germany, Hungary, Japan, The Netherlands, Slovakia, South Korea, Spain, Sweden, Switzerland, the UK, the USA.
6. Argentina, Brazil, Bulgaria, China, India, Mexico, Pakistan, Russia, South Africa, Ukraine.
7. www.bp.com/statisticalreview

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Corresponding author
Abdullah Alam can be contacted at: abdullah_alam@yahoo.com