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CARBON DIOXIDE EMISSIONS, ENERGY CONSUMPTION, AND ECONOMIC GROWTH IN A TRANSITION ECONOMY: EMPIRICAL EVIDENCE FROM CAMBODIA

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Abstract

This study examines the inter-relationship among carbon dioxide (CO_2) emissions, energy consumption, and economic growth for a Mekong River Commission (MRC) country - Cambodia. The empirical results suggest that real gross domestic product (GDP), energy consumption, and CO_2 emissions are cointegrated. It needs 11 years to achieve a long-run equilibrium. There is a unidirectional causality from real GDP to energy consumption, and a bidirectional causality between real GDP, and CO_2 emissions. The CO_2 emissions are related to energy consumption through real GDP. This study is relevant and importance for Cambodia in formulating energy policies, for example, the revision of national energy efficiency policy.

JEL Classification: *C22, Q43, Q48.*
Keywords: *Cambodia; Causality; Cointegration; CO_2 emissions; Energy consumption; Economic growth.*

1. Introduction

The research issue inspires this study is the current phenomenon reported by the Phnom Penh Post that "Cambodia is suffering disproportionately from the impacts of greenhouse gas emissions from more developed nations, according to a new study published in the journal Nature on Friday... Cambodia is one of 36 countries "severely" affected by global climate change, as of 2010. If current trends continue, Cambodia's vulnerability will downgrade slightly to "acute" by 2030" (The Phnom Penh Post, 8 February 2016).[2] The Cambodia's power consumption is forecasted to rise to 3.4 TWh by the end of 2020 to achieve at

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[2] http://m.phnompenhpost.com/national/polluters-hurt-kingdom-study?utm_content=bufferd30f0&utm_medium=social&utm_source=facebook.com&utm_campaign=buffer (Accessed: March 1, 2016)

9.4% growth (Royal Government of Cambodia, 2013, p. 2). Meanwhile, the Royal Government of Cambodia (2013) has highlighted that the Cambodian annual electricity demand has increased about 16.3% from 2002 to 2011 and, the CO_2 emissions from energy consumption has amounted to nearly 4 million tonnes. More precisely, the primary energy consumption and CO_2 emission at least doubled over the past ten years – it is eventually a major challenge for the national energy policy. In fact, the overall policy goal of the Cambodian energy efficiency is to reduce the future national demand for energy by 20% at 2035, as well as national CO_2 emissions in 2035 by 3 million tonnes of CO_2 (Royal Government of Cambodia, 2013, p. 7).

Figure 1 (the top plot) shows that the Cambodian CO_2 emissions and real GDP increase substantially since 1995. They are closely correlated - higher real GDP causes more CO_2. The Cambodian real GDP 'takes off' in 1985 as a result of economic reforms since the past two decades from a command economy in the late 1980s to a free market economy in the recent (Tang and Chea, 2013). According to the United Nations (2003), Cambodia is one of the most open economies in the Southeast Asia region[3] and has been labelled as one of the new tiger economies of Asia, according to the forecast in the Asian Development Bank's Asian Development Outlook 2016.[4] The bottom plot shows the oil consumption increases since 1994 but drops drastically in 2008. It is consistent with the second structural shift of CO_2 emissions in 1995 (the first was in 1983) suggesting a positive correlation. Visual inspection of the plot shows that oil and electricity consumptions, CO_2 emissions, and real GDP are positively associated. The electricity used gradually increases since 2001, while the primary energy consumption is relative stable. The International Energy Statistics 2012 reports that in 2009 the CO_2 emissions from energy consumption amounted to 3.93 million tonnes that both figures the demand for primary energy, and CO_2 emissions at least doubled over the past ten years (Royal Government of Cambodia, 2013, p. 2). Hence, a case study of a Mekong River bordering country, Cambodia is gaining considerable interest among the researchers on the relationships among energy consumption, CO_2 emissions and economic growth.

The present issue in Cambodia is related to other countries from the previous studies, especially for the regional energy study of Association of Southeast Asian Nations (ASEAN). Cambodia joined the ASEAN on 30 April 1999. Cambodia plays a virtual role in terms of intra-regional co-operation that the ASEAN countries have an active agenda on many energy policy fronts, and they are together continuously to strive towards implementation of long-standing projects in order to establish interconnected grids for electricity and natural gas (namely

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[3] It is based on the economic freedom index compiled by the Heritage Foundation in the United States. Cambodia is ranked 35th among 170 countries for the year of 2003. The rankings for its neighbouring countries are 72nd for Malaysia, 99th for Indonesia, 135th for Vietnam, and 153rd for Lao People's Democratic Republic. Cambodia is ranked among the world's least developed countries (LDCs) at the very top in market-friendliness. Cambodia has offered a set liberal policies to investors. (United Nations, 2003).

[4] http://www.adb.org/news/features/here-comes-cambodia-asia-s-new-tiger-economy (Accessed: September 5, 2016)

the ASEAN Power Grid and the Trans-ASEAN Gas Pipeline) - but each country has its own key policies and targets.[5] Therefore, panel approach on the energy study with Cambodia such as Lee and Brahmasrene (2014) is infeasible. In fact, no study is available for a case study of Cambodia. This study contributes to the empirical literature on the empirical evidence of energy-CO_2-growth nexus for Cambodia.

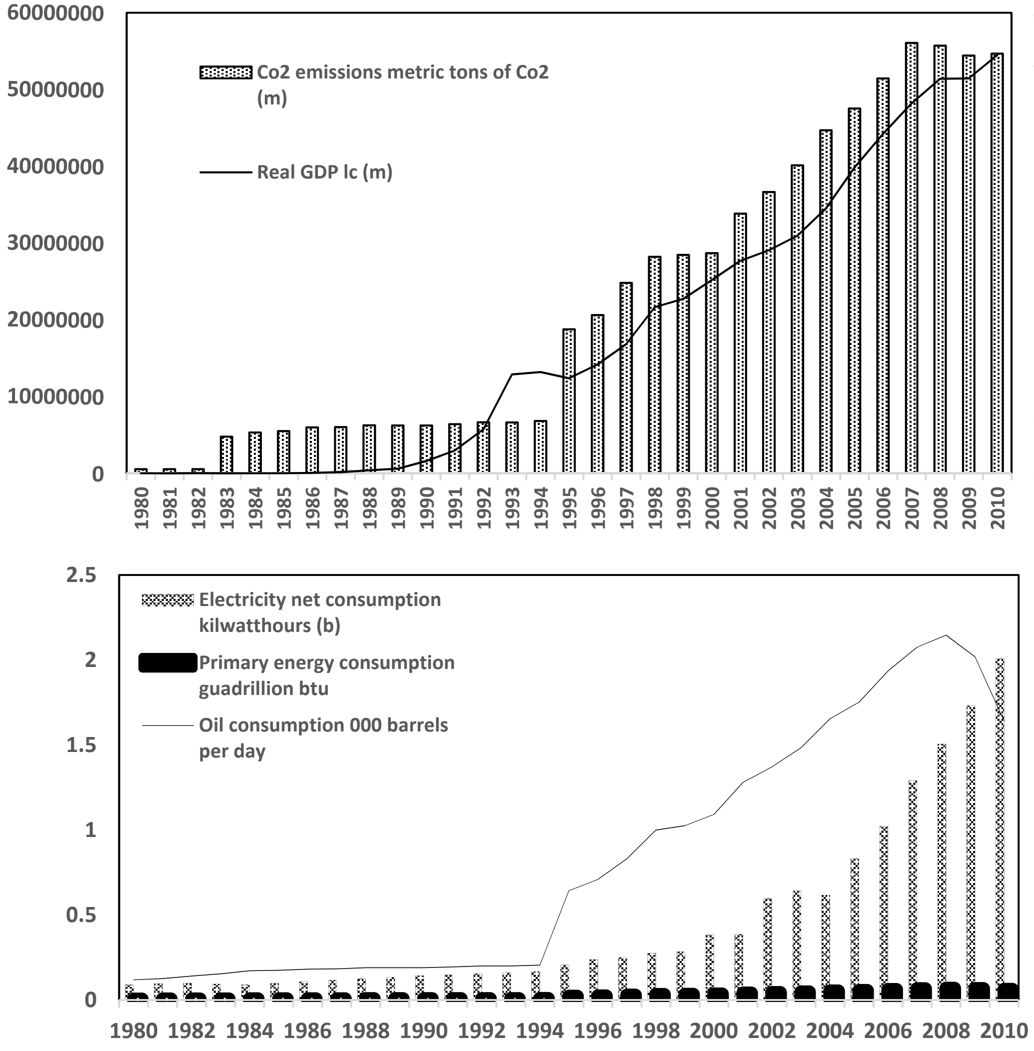

Figure 1: Plots of real GDP, CO_2 emissions, and energy consumption from 1980-2010.

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[5] See "Key energy policies, targets and objectives in ASEAN", in Table 1.5 (pages 32-33), Southeast Asia Energy Outlook – World Energy Outlook Special Report. https://www.iea.org/publications/freepublications/publication/SoutheastAsiaEnergyOutlook_WEO2013SpecialReport.pdf (Accessed: September 5, 2016).

Only Lee and Brahmasrene (2014)'s study considers Cambodia for a panel data (1991-2009) of 9 ASEAN countries, and they find that information communications technology (ICT), CO_2 emissions and economic growth are cointegrated. ICT has a significant positive impact on both economic growth and CO_2 emissions. Economic growth and CO_2 emissions have feedback causation. A recent study, Wang et al. (2016a) examine the effects of urbanisation on energy consumption, and carbon emission in the 8 ASEAN member countries, namely Singapore, Malaysia, Indonesia, Thailand, the Philippines, Brunei, Vietnam, and Myanmar. The panel cointegration tests suggest long-run relationship for 1980-2009. A 1% increases in urban population results in a 0.20% higher carbon emission. Urbanisation with energy use causes carbon emission in the long-run. In the short-run, urbanisation causes both energy use and carbon emission. Baek (2016) investigates the impact of inward foreign direct investment (FDI) on the CO_2, GDP, and energy consumption for 5 ASEAN countries (Indonesia, Malaysia, the Philippines, Singapore, and Thailand) for the period of 1981-2010. The inflow of FDI increases CO_2 emission. Income and energy consumption have a negative impact on reducing CO_2. Heidari et al. (2015) support environmental Kuznets curv*e* (EKC) for a panel of 5 ASEAN (Indonesia, Malaysia, the Philippines, Singapore, and Thailand) over the period of 1980-2008. The panel smooth transition regression (PSTR) shows energy consumption increases CO_2 if the GDP per capita is below 4686USD. Chandran and Tang (2013b) find cointegration between CO_2 emissions and other variables for Indonesia, Malaysia and Thailand for the period 1971-2008, and economic growth plays a greater role in CO_2. Inverted U-shape EKC is not supported in the case of Indonesia, Malaysia and Thailand.

Next section is the literature review with an update of 56 empirical studies between 2015 and 2016. Section 3 describes the data and their degree of integration. Time series testing methods are included in this section – autoregressive distributed lag (ARDL) approach. Section 4 reports the empirical results. Section 5 concludes the study.

2. Literature review - an update

Generally, two hypotheses are being tested empirically in the past studies, namely energy-growth nexus, and CO_2-energy-growth nexus. The most common Cobb–Douglas production function is being applied on the influence of energy consumption on output, while the EKC relates the pollution to output, and the Grey theory proposes a relationship between energy consumption and pollution. The other studies utilise the consumption theory which relates income and 'energy' variable(s) to consumption of goods and services. A seminal work by Kraft and Kraft (1978) documents that Gross National Product (GNP) does cause energy for the postwar period. Most of the past studies are summarised and reported by Ozturk (2010), Mohammadi and Parvaresh (2014), Chandran and Tang (2013a) and (2013b). They conclude that different findings when different sample countries, methods of analysis, and additional variables being considered.

This study summarises a total of 57 articles available between 2015 (29 articles) and 2016 (28 articles) (see Appendix A).[6]

The updated literature review gives several similarities are observed. Firstly, the studies are mainly to (re-)examine the cointegration and causality between economic growth, energy consumption, and pollutants (CO_2 emissions). 22 out of 28 articles published in 2016 test for cointegration and causality, except for Bae et al. (2016), Baek (2016), Fujii and Managi (2016), Kais and Sami (2016), Sumabat et al. (2016) and Wang et al. (2016b) on its effects of the variables. Secondly, they employ a multivariate framework than of bivariate framework by adding new variables such as energy prices, financial development, FDI, health quality, urbanisation, trade openness (international trade), tourism receipts, and so on. All of the studies in 2016 and 21 out of 29 studies in 2015 have considered additional variables, except for Apergis (2016). Thirdly, the single country study is still of the interest in energy study that almost half (28 articles) of the latest studies. The case study is, for example, Pakistan, Greek, Italy, Malaysia, and so on. Finally, the ARDL approach is a widely applied method for testing the cointegration.

3. Data, degree of integration and methods

This section describes the data, their degree of integration, $I(d)$, and testing methods. The four variables are real GDP (Y, in local currency, million), primary energy consumption (PEC, in btu), oil consumption (OC, in '000 barrels per year), electricity net consumption (ENC, in kilowatt-hours), and CO_2 emissions (metric tonnes). Real GDP data are from Tang and Chea (2013), while the energy data are taken from the U.S. Energy Information Administration (http://www.eia.gov/). The sample period is between 1980 and 2010 (annual data).[7] All of the variables are transformed into natural logarithm (*ln*).

Table 1 reports the augmented Dickey-Fuller (ADF) (Dickey and Fuller, 1979), Phillips-Perron (PP) (Phillips and Perron, 1988), and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) (Kwiatkowski et al., 1992) tests. Both of the ADF and PP tests consistently fail to reject the null hypothesis of a unit root for all candidate variables, but they reject the null hypothesis in the first-differenced transformation.[8] However, a more powerful test, KPSS method rejects the null hypothesis of stationary for all of the variables in levels, but none in first-differences suggesting $I(1)$, except for *ln*ENC which is $I(2)$ i.e. the null of the first-differenced stationary is rejected. Also, in panel (b), the KPSS tests show *ln*PEC, *ln*OC and $lnCO_2$ are stationary in levels, or $I(0)$ since the test statistics fail to reject null of trend stationary.

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[6] Other studies include Tang (2008; 2009), Tang and Tan (2012; 2013), Tang and Muhammad (2013), Tang and Tan (2014), and so on.

[7] The energy data for Cambodia are available until 2010. The Cubic interpolation has initially considered which generated 121 observations for the periods 1980Q4 – 2010Q4. However, a reservation is the underlying series are not smoothly trended resulting bias in interpolated series.

[8] If all variables are $I(1)$ as suggested, vector error correction model (VECM) can be used for short-run as well as long-run model, including causality tests.

Table 1: Unit root and stationary tests.

	ADF		PP		KPSS	
	Level	1st Difference	Level	1st Difference	Level	1st Difference
Panel (a) No Trend						
*ln*Y	-2.230	-2.700*	-1.730	-2.691*	0.645**	0.297
*ln*PEC	-0.550	-5.032***	-0.556	-5.032***	0.690**	0.112
*ln*OC	-0.773	-4.856***	-0.785	-4.856***	0.684**	0.128
*ln*ENC	2.996	-5.819***	4.822	-5.237***	0.698**	**0.636****
*ln*CO$_2$	-2.185	-5.481***	-2.412	-5.481***	0.710**	0.207
Panel (b) With Trend						
*ln*Y	0.058	-3.352*	-0.525	-3.248*	0.176**	0.104
*ln*PEC	-1.761	-4.930***	-1.900	-4.930***	0.100	0.112
*ln*OC	-1.561	-4.771***	-1.735	-4.771***	0.096	0.122
*ln*ENC	-1.087	-7.278***	-0.742	-19.249***	0.197**	**0.500*****
*ln*CO$_2$	-2.732	-5.805***	-2.505	-5.838***	0.114	0.082

Notes: For ADF test, Schwarz information criterion (SIC) is used to select the lag length. For PP test, the Barlett kernel is used for the spectral estimation method by using the Newey-West bandwidth. (***), (**) and (*) indicate 1%, 5% and 10% significance level, respectively. In panel (b), the italic statistics have non-significant trend component. The critical value of the finite sample KPSS critical values are obtained from Table 1 and Table 2 from Hornok and Larsson (2000).

This observation dissatisfies the application of the conventional cointegration such as Johansen multivariate cointegration method (Johansen and Juselius, 1990) which requires all underlying variables be *I*(1). The existence of *I*(1) variables allows the ARDL approach (Pesaran et al., 2001). The ARDL bounds test is applicable irrespective of whether the independent variables are stationary, *I*(0) or non-stationary, *I*(1). It avoids the pre-testing problems associated with conventional cointegration methods that require the degree of integration of the underlying variables either *I*(1) or *I*(0), see Pesaran and Pesaran (1997, pp. 302-3). The *ln*ENC variable is dropped from cointegration analysis since no cointegration among real GDP, ENC, and CO$_2$ emissions can be concluded.[9]

This study follows the empirical framework as employed by Tang et al. (2013), Tang and Salah (2014), Abdul (2014), Wolde-Rufael (2014), and Ruhul et al.

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[9] This procedure (ARDL) is applicable at most *I*(1) variables. Haldrup (1998) surveys the recent literature dealing with *I*(2) variables. Standard remedy of differencing the *I*(2) variable twice, may result in information loss. The Engle-Granger tests cannot reject the null hypothesis of the series are not cointegrated with a maximum lag of 3 (see the statistics below).

Dependent variable	tau-statistic	Prob.	*z*-statistic	Prob.
ENC	-0.661	0.985	-1.680	0.986
RGDP	-2.276	0.614	-13.240	0.300
CO2	-2.942	0.305	-11.187	0.443

(2014). The relations are lnY -$lnOC$ -$lnCO_2$, lnY –$lnPEC$ -$lnCO_2$, and lnY –$lnENC$ -$lnCO_2$. Following the ARDL modelling framework, a relation of lnY -$lnOC$ -$lnCO_2$, for example, can be written as equation (1).

$$\Delta lnY_t = \alpha_0 + \sum_{i=1}^{q} \beta_{1i} \Delta lnY_{t-i} + \sum_{j=0}^{q} \gamma_j \Delta lnOC_{t-j} + \sum_{k=0}^{q} \delta_k \Delta lnCO_{2t-k} + \theta_0 lnY_{t-1} + \theta_1 lnOC_{t-1} + \theta_2 lnCO_{2t-1} + e_t \tag{1}$$

The computed *F*-statistic is a restriction of the estimated coefficients of the level variables, lnY_{t-1}, $lnOC_{t-1}$ and $lnCO_{2t-1}$ to zero, or to test the null hypothesis of $H_0: \theta_0 = \theta_1 = \theta_2 = 0$ (i.e. no long-run relationship between the underlying variables). This test statistic has a non-standard distribution irrespective of whether lnY, $lnOC$, and $lnCO_2$ are $I(0)$ or $I(1)$. If the *F*-statistic falls outside the upper-bound critical values, the null hypothesis can be rejected. It suggests a long-run relation. No long-run relation can be concluded given that the *F*-statistic is below the lower-bound critical values. Inconclusive inference is delivered, if the *F*-statistic falls between the lower-and upper-bound critical values and it depends on whether the underlying variables are $I(0)$ or $I(1)$ (Pesaran and Pesaran, 1997, p. 304). The remaining ARDL specifications with energy consumption $lnOC$ can be re-arranged as equations (2) and (3). Similar testing procedure (as equation 1) is applied.

$$\Delta lnOC_t = \alpha_0 + \sum_{i=0}^{q} \beta_{1i} \Delta lnY_{t-i} + \sum_{j=1}^{q} \gamma_j \Delta lnOC_{t-j} + \sum_{k=0}^{q} \delta_k \Delta lnCO_{2t-k} + \theta_0 lnY_{t-1} + \theta_1 lnOC_{t-1} + \theta_2 lnCO_{2t-1} + e_t \tag{2}$$

$$\Delta lnCO_{2t} = \alpha_0 + \sum_{i=0}^{q} \beta_{1i} \Delta lnY_{t-i} + \sum_{j=0}^{q} \gamma_j \Delta lnPEC_{t-j} + \sum_{k=1}^{q} \delta_k \Delta lnCO_{2t-k} + \theta_0 lnY_{t-1} + \theta_1 lnPEC_{t-1} + \theta_2 lnCO_{2t-1} + e_t \tag{3}$$

Once a cointegration is suggested, an error correction model (ECM) can be estimated by ordinary least squares (OLS) estimator (Engle & Granger, 1987). It is a restricted version of ARDL equations (1)-(3) in which an error correction term, ecm_{t-1} replaces the lagged one level variables, where $ecm_{t-1} = lnY_{t-1} - \theta_1 lnOC_{t-1} - \theta_2 lnCO_{2t-1}$ as in equation (1). The quations (1)-(3) are rewritten in ECM form, i.e. equations (1'), (2') and (3').

$$\Delta lnY_t = \alpha_0 + \sum_{i=1}^{q} \beta_{1i} \Delta lnY_{t-i} + \sum_{j=0}^{q} \gamma_j \Delta lnOC_{t-j} + \sum_{k=0}^{q} \delta_k \Delta lnC - \gamma_0 ecm_{t-1} + e_t \tag{1'}$$

$$\Delta lnOC_t = \alpha_0 + \sum_{i=0}^{q} \beta_{1i} \Delta lnY_{t-i} + \sum_{j=1}^{q} \gamma_j \Delta lnOC_{t-j} + \sum_{k=0}^{q} \delta_k \Delta lnCO_{2t-k} - \gamma_0 ecm_{t-1} + e_t \tag{2'}$$

$$\Delta lnCO_{2t} = \alpha_0 + \sum_{i=0}^{q} \beta_{1i} \Delta lnY_{t-i} + \sum_{j=0}^{q} \gamma_j \Delta lnPEC_{t-j} + \sum_{k=1}^{q} \delta_k \Delta lnCO_{2t-k} - \gamma_0 ecm_{t-1} + e_t \qquad (3')$$

On the other hand, Granger non-causality test (Granger, 1988) is employed in order to identify the directions of causality between the variables. According to Engle and Granger (1987, p. 251), "*An individual economic variable, viewed as a time series, can wander extensively and yet some pairs of series may be expected to move so that they do not drift too far apart. Typically economic theory will propose forces which tend to keep such series together*". Toda and Yamamoto (1995) method is used in this study because it allows non-causality test without pre-testing cointegration either the underlying variables are cointegrated or non-cointegrated of an arbitrary order. Also, it permits a mixture integration of the variables whether a series is $I(0)$, $I(1)$ or $I(2)$ such as the case of this study that *ln*ENC is $I(2)$. The details of this widely applied method are available from Toda and Yamamoto (1995). It involves two steps; (i) determine the true lag length of k and the maximum order of integration (d_{max}) of the underlying variables in the system, and an *augmented* VAR($k + d_{max}$) is then estimated by OLS estimator; and (ii) compute the standard Wald tests to the first kth VAR coefficient matrix only or to test for restrictions on the parameters of the VAR(k) model in order to reject the null hypothesis of 'x does not Granger-cause y'. The test statistic follows an asymptotic chi-squared distribution with k degrees of freedom in the limit when a VAR($k + d_{max}$) is estimated.

4. Empirical results

This section reports the empirical results. Table 2 presents the computed F-statistics of the ARDL specifications (a) - (f) for cointegration and their critical values that consider a small sample of 30 observations. As noted in the previous section, *ln*ENC is I(2), and no cointegration. The F-statistics of all specifications, except for CO_2 equations (c) and (f) exceed the upper bound of the critical value, 3.695 at 10% significance level. Hence, the null hypothesis of 'there exists no long-run relationship between real GDP, energy consumption, and CO_2 emissions' can be rejected, irrespective of the order of their integration I(0) or I(1). It suggests that energy consumption, real GDP, and CO_2 emissions are cointegrated with the following relations, i.e. *ln*Y -*ln*OC -*ln*CO_2, *ln*Y -*ln*PEC -*ln*CO_2, *ln*OC -*ln*Y -*ln*CO_2, and *ln*PEC -*ln*Y -*ln*CO_2.[10]

The estimated relations (a) – (f) are reported in Table 3 by the ARDL approach. They pass a set of diagnostic checking for serial correlation, function form, normality, and heteroscedasticity. The two key relations (a) and (d) show both energy consumption and CO_2 emissions are statistically insignificant to explain real GDP in the long-run. An increase in oil consumption (0.970) and primary energy consumption (0.971) results in higher CO_2 emission (equations (c) and (f)). A one-percent increase in the CO_2 emissions leads to a one-percent

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[10] As shown in Table 2, *ln*OC and *ln*PEC are endogenous. Hence, both variables are dropped. The F-statistic of ARDL bounds test (with 3 lags) is 15.591, which rejects the null of no cointegration.

(1.1 and 1.0) increase in energy consumption of oil (*ln*OC) and primary electricity (*ln*PEC), respectively (equations (b) and (e)). This study caters the endogeneity in the independent variables (Table 2), the estimates of fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) are computed and reported in Appendix B. In general, their estimates are robust to the ARDL estimator, especially the FMOLS.

Table 4 presents the estimated ECM of ARDL equations (a), (c) and (d) as suggested by augmented production function (i.e. *ln*Y –*ln*OC -*ln*CO_2, and *ln*Y-*ln*PEC -*ln*CO_2), and CO_2 emission equation (i.e. *ln*CO_2 –*ln*OC –*ln*Y). The remaining ARDL specifications (b), (e) and (f) are not covered since the dynamic lag structure is ARDL (0,0,0) indicating no short-run shocks. Both equations (a') and (d') suggest that the one and two years lagged CO_2 emissions growth lead to reduce the Cambodian economic growth, in the short-run. Their estimated short-run elasticities are ranged between -0.199 and -0.391. The CO_2 equation shows, a 1% of OC increases will lead 0.85% additional CO_2 emissions to Cambodia. Again, the estimated error correction terms (ECT_{t-1}) which measure the speed of adjustment to equilibrium, are significant and in an expected sign. It further confirms the existence of a long-run relationship among real GDP, energy consumption, and CO_2 emissions. The estimated value of -0.093 (or -0.091) suggests a speed of convergence to equilibrium of about 9% per year or approximately 11 years to equilibrium. The *ECT* of CO_2 equation (c') is statistically insignificant further supporting the finding of no cointegration as obtained from the bound test (Table 2). Figure 2 presents the CUSUM and CUSUMQ plots for *ECM* equations. The CUSUM tests suggest stability (within 5% critical bounds), while the CUSUMQ of equations (c') and (d') reveal unstable the estimated coefficients.

The Toda and Yamamoto's (1995) testing method is used because the underlying variables are non-stationary, or mixture in their degree of integration, *I*(d).[11] Table 5 presents the empirical results, which takes into account the statement of '*the cause occurs before the effect…*' by Granger (1988). In panel I, the test statistic, 9.758 (or 12.61) does reject the null hypothesis of *ln*Y does not Granger cause *ln*OC (or *ln*CO_2) at 5%. Also, the null hypothesis of *ln*CO_2 does not Granger cause *ln*Y is rejected (see the last column). The remaining test statistics are statistically insignificant. It shows that the causality is unidirectional which runs from real GDP to oil consumption. There is no reversed causality. This finding is in line with the standard consumption function that relates energy consumption to income (real GDP). A bidirectional causality is confirmed between real GDP and CO_2 emissions. It supports the EKC hypothesis that relates the pollution (CO_2) to output. Similar findings are obtained on primary energy consumption, *ln*PEC as the test statistics reported in panel II. The real GDP does

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[11] This method has been widely employed by researchers. Given the finite annual observations in this study, the critical values of the causality tests are obtained by using the bootstrap modified Wald statistics critical values by Hacker and Hatemi-J (2006). Therefore, the reported results do not suffer the finite sample issue. The VECM can be applied for robustness check if the assumption that all variables are non-stationary, or *I*(1).

Granger cause the primary energy consumption. A bidirectional causality is obtained between real GDP and CO$_2$ emissions. In panel III, no causality between the electricity net consumption (*ln*ENC) and real GDP. Again, bidirectional causality is obtained between real GDP and CO$_2$ which is consistent with panels I and II. Real GDP is an 'intermediator' from CO$_2$ emissions to energy consumption. In general, the entire empirical results are diagrammatically in Figure 3.

Table 2: ARDL bound *F*-test for cointegration.

		F-statistics
(a)	F(*ln*Y| *ln*OC, *ln*CO$_2$)	18.417***
(b)	F(*ln*OC|*ln*Y, *ln*CO$_2$)	4.496**
(c)	F(*ln*CO$_2$| *ln*OC, *ln*Y)	3.252
(d)	F(*ln*Y|*ln*PEC, *ln*CO$_2$)	17.982***
(e)	F(*ln*PEC|*ln*Y, *ln*CO$_2$)	4.826**
(f)	F(*ln*CO$_2$| *ln*PEC, *ln*Y)	3.397

Narayan's (2005) critical values bound of the *F*-statistics:

Intercept and no trend (T=30, k=2)	Lower bound, *I*(0)	Upper bound, *I*(1)
90%	2.915	3.695
95%	3.538	4.428
99%	5.155	6.265

Notes: Asymptotic critical bound are obtained from Narayan (2005). Here, the '*k*' is the number of regressors. The (***) and (**) denote significance levels at 1% and 5%, respectively. Given a sample of 31 observations (1980-2010), a lag length of 3 is implemented or ARDL (3,3,3). Enders (2014) proposed a lag length that is maximally $T^{1/3}$ where T is the number of observations.

Table 3: ARDL long-run elasticities.

ARDL	(a) *ln*Y| *ln*OC, *ln*CO$_2$	(b) *ln*OC|*ln*Y, *ln*CO$_2$	(c) *ln*CO$_2$| *ln*OC, *ln*Y	(d) *ln*Y|*ln*PEC, *ln*CO$_2$	(e) *ln*PEC|*ln*Y, *ln*CO$_2$	(f) *ln*CO$_2$| *ln*PEC, *ln*Y
Intercept	1.910 (0.974)	-7.292*** (0.000)	6.488*** (0.000)	-252.3 (0.263)	-11.46*** (0.000)	11.145*** (0.000)
*ln*CO$_2$	3.878 (0.651)	1.105*** (0.000)	-	24.71 (0.226)	1.028*** (0.000)	-
*ln*Y	-	-0.009 (0.248)	-0.009 (0.907)	-	-0.001 (0.830)	0.001 (0.714)
*ln*OC	-4.476 (0.572)	-	0.970*** (0.001)	-	-	-
*ln*PEC	-	-	-	-25.11 (0.216)	-	0.971*** (0.000)
Diagnostic Chi-squared test statistics - Lagrange Multiplier (LM) Version						
Serial correlation	1.151	4.229**	0.127	3.348*	0.261	0.256
Functional form	6.737***	3.601*	0.000	5.065**	2.019	2.666*

Table 3 (*continued*).

ARDL	(a) $lnY \mid lnOC, lnCO_2$	(b) $lnOC \mid lnY, lnCO_2$	(c) $lnCO_2 \mid lnOC, lnY$	(d) $lnY \mid lnPEC, lnCO_2$	(e) $lnPEC \mid lnY, lnCO_2$	(f) $lnCO_2 \mid lnPEC, lnY$
Diagnostic Chi-squared test statistics - Lagrange Multiplier (LM) Version						
Normality	1.111	163.13^{***}	96.97^{***}	1.980	0.300	0.295
Heteroscedasticity	0.073	2.004	1.716	0.039	3.067^{*}	2.715^{*}

Notes: $lnY|lnOC$, $lnCO_2$ is interpreted as lnY being influenced by $lnOC$ and $lnCO_2$ and the same applies to the rest of the equations. The estimated coefficients are reported with the *p*-values in parenthesis. (***) (**) and (*) denote significance levels at 1%, 5% and 10%, respectively. The sample periods are 1984-2010 for equations (a), (b) and (d), and 1985-2010 for equations (c), (e) and (f) after initial ARDL (3,3,3) computed by Microfit.

Table 4: Error correction model (ECM) for the selected ARDL model.

Independent variables	(a') ARDL($lnY \mid lnOC, lnCO_2$) ARDL (1,0,3)	(c') ARDL($lnCO_2 \mid lnOC, lnY$) ARDL (1,1,0)	(d') ARDL($lnY \mid lnPEC, lnCO_2$) ARDL (1,0,3)
Intercept	0.177 (0.973)	0.902 (0.749)	-23.089 (0.234)
$\Delta lnCO_2$	0.039 (0.963)	-	1.875 (0.272)
$\Delta lnCO_{2t-1}$	-0.217^{**} (0.030)	-	-0.199^{**} (0.037)
$\Delta lnCO_{2t-2}$	-0.391^{***} (0.000)	-	-0.383^{***} (0.000)
$\Delta lnOC$	-0.417 (0.569)	0.850^{***} (0.000)	-
$\Delta lnPEC$	-	-	-2.297 (0.177)
ΔlnY	-	-0.001 (0.876)	-
ECT_{t-1}	-0.093^{***} (0.004)	-0.139 (0.743)	-0.091^{***} (0.004)

Notes: The estimated coefficients are reported with the *p*-values in parenthesis. (***) and (**) denote significance levels at 1% and 5%, respectively. The lag structures of the ARDL (.) equation are selected by Schwarz Bayesian criteria (SBC) for the short-run dynamic. The first-differenced variable (denoted as Δ) is the difference between current value and lagged one value, e.g., $\Delta lnCO_2 = lnCO_{2t} - lnCO_{2t-1}$. The *ECT* for equations (a), (c) and (d) are $ecm\_1 = lnY + 4.476*lnOC - 3.878*lnCO_2 - 1.91$, $ecm\_3 = lnCO_2 - 0.970*lnOC + 0.009*lnY - 6.488$, and $ecm\_4 = lnY + 25.106*lnPEC - 24.709*lnCO_2 + 252.336$, respectively.

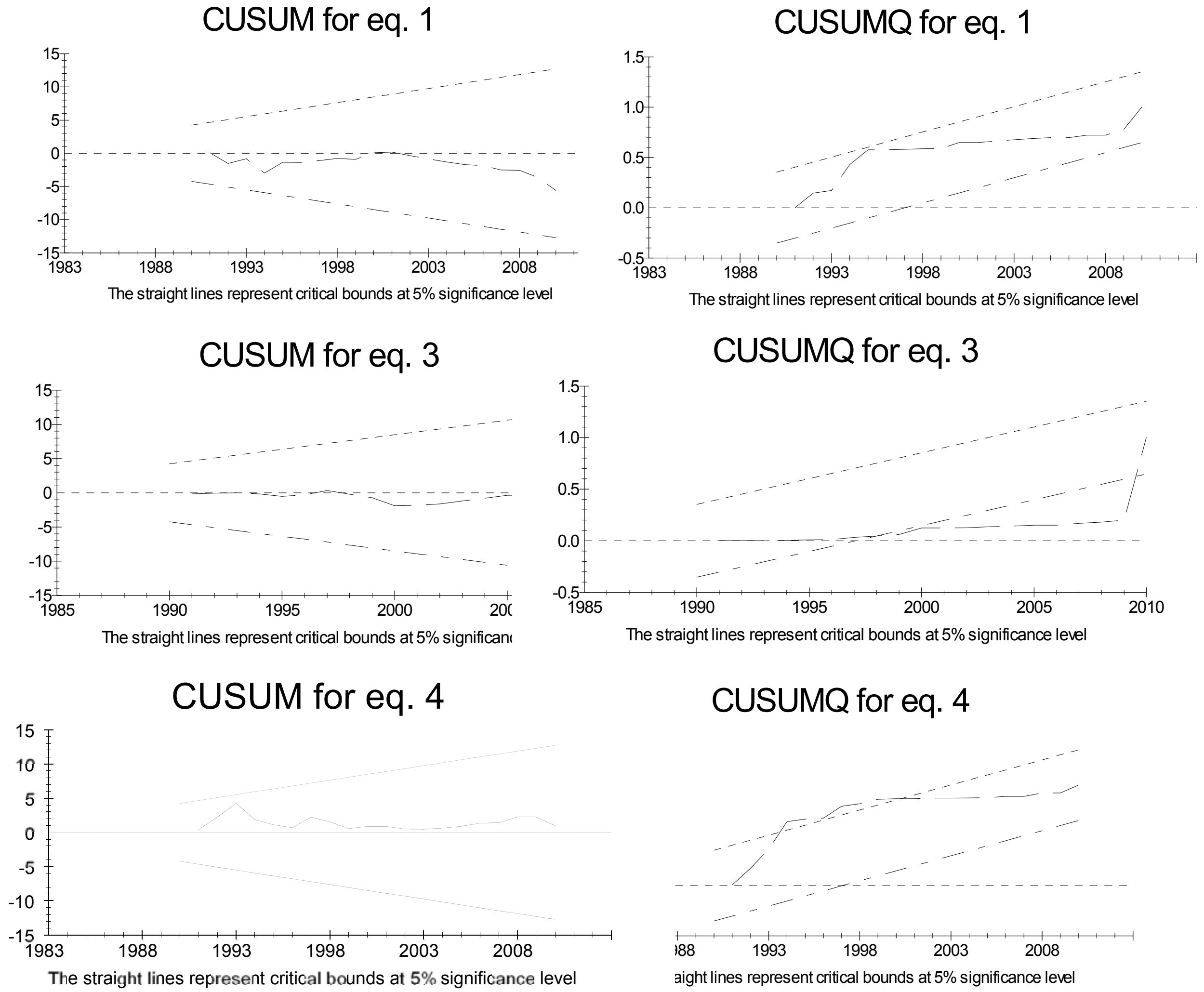


Figure 2: CUSUM and CUSUMQ tests.

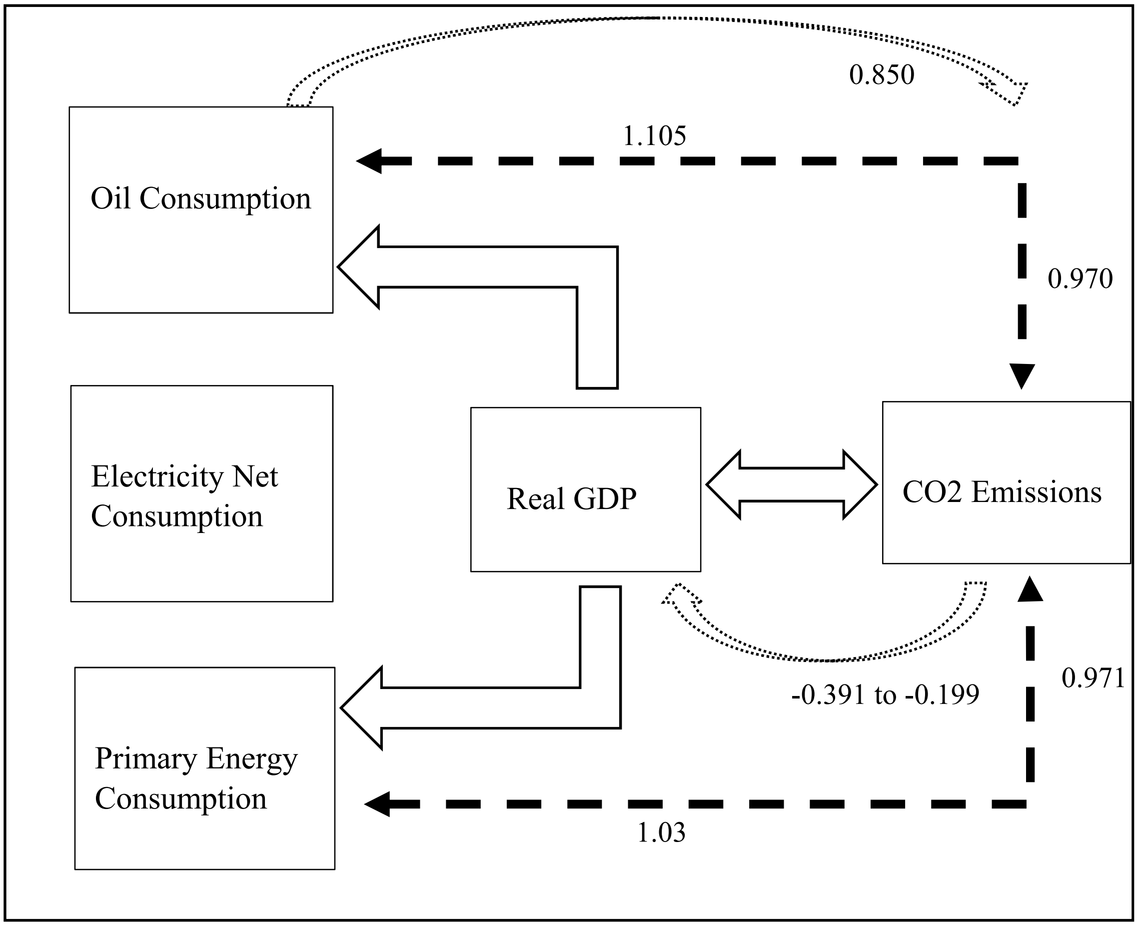
Table 5: Toda and Yamamoto (1995) non-causality test with the bootstrap approach.

	Independent variables		
Panel I	*ln*Y	*ln*OC	*ln*CO_2
*ln*Y	-	1.970	9.795^{**}
*ln*OC	9.758^{**}	-	2.000
lnCO_2	12.610^{**}	2.127	-
Panel II	*ln*Y	*ln*PEC	*ln*CO_2
*ln*Y	-	1.700	9.470^{**}
*ln*PEC	10.666^{**}	-	2.839
lnCO_2	10.685^{**}	1.183	-

Table 5 (*continued*).

	Independent variables		
Panel III	*ln*Y	*ln*ENC	*ln*CO_2
*ln*Y	-	0.322	6.287*
*ln*ENC	2.472	-	1.882
lnCO_2	6.958*	0.183	-

Notes: The reported value are the Wald statistics. (**) and (*) indicate 5%, and 10% significance levels based on the bootstrap modified Wald statistic (Hacker & Hatemi-J, 2006). The critical values obtained for 1%, 5% and 10% significance levels are 17.888, 10.4992 and 7.892, respectively. If the variables are significant, the column variable Granger causes the row variable. The selected lag, *k* are based on the SBC values suggested. Panels I and II follows the VAR(k + d_{max}) structure of VAR(2 +1). For panel III, the VAR(*ln*Y= 1 +1, *ln*CO_2 = 1 +1, *ln*ENC = 1 +2) since the *ln*ENC is $I(2)$.



Notes: The solid line represents the Granger non-causality results from the Toda-Yamamoto method. The bold dash line represents the effects in the long-run; the small dash line represents the short-run effect.

Figure 3: Summary of inter-linkages among energy consumption, real GDP, and CO_2 emissions.

5. Concluding remarks

This study contributes to the existing literature by delivering fresh evidence of the energy-growth-CO_2 nexus for a transition economy of MRC countries, Cambodia. This study finds that:

a) There is, at least a long-run relationship (cointegration) among GDP, energy consumption (oil consumption and primary energy consumption), and CO_2 emissions. Oil and primary energy consumptions respectively increase CO_2 emissions. Both energy consumption and CO_2 emissions have no impact on the Cambodian GDP in the long-run.
b) The CO_2 variable has negative short-run implication on GDP, while oil consumption results in additional CO_2 emissions. The speed of adjustment is approximately 11 years in order to achieve a long-run equilibrium among the variables.
c) GDP does Granger cause energy consumption. A bidirectional causality between GDP and CO_2 emissions. The identified transmission channel for CO_2 emissions to energy consumption (oil and primary) is through GDP.

These findings are relevant for policy implication. As projected that Cambodia's energy consumption is growing at an average of 5.2% per year between 2009 and 2035 that the Cambodian energy consumption can be reduced to 4.3% with an overall reduction of future energy demand of 20% by 2035.[12] Hence, energy policies to cut the consumption of primary and oil energy can be implemented in order to lower the CO_2 emissions, in the long-run 3 million tonnes of CO_2 in 2035. The time cost of energy and CO_2 mismanagement is 11 years (i.e., the speed of adjustment) to the Cambodian government to allow the national energy efficiency policy in results.

From the non-causality finding, energy policies of reducing either oil or primary energy consumption can be implemented without deteriorating the country's output. The Cambodian demand for energy is caused by GDP that the recent high growth (approximately 7%) scenario requires more energy inputs to support the core growth sectors. In this context, a wider understanding of these sectors is needed on their CO_2 emissions and their strategy towards green energy. The national energy efficiency policy is currently under development. Therefore, reduction in oil and primary energy consumption can be achieved by substitution of renewable energy or clean energy. Government and private sectors are suggested to employ advanced technology - carbon-free power, and renewable energy for achieving environmental friendly and promoting economic development in the future. The tax credit can be implemented for those industries using renewable energy. According to Sarraf et al. (2013, p. 228), Cambodia is categorised as one of the richest economies with natural energy resources such as solar, wind, biomass, and hydropower among the developing countries. The Cambodian renewable energy resources can generate up to 67,388 GWh energy

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[12] See http://www.phnompenhpost.com/business/move-lift-energy-efficiency-cambodia (Accessed July 2, 2014).

per year. They also found that the best option for rural electrification is renewable energy resources.

A few of concerns are necessary for further study in the field. Ozturk (2010) suggested that new approaches and perspectives are important for further study rather than by simply applying traditional econometric methods, adding new variables, using different countries, and different time intervals.

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Appendix A: Summary of the Most Recent Studies (2015-2016).

No.	Study	Country	Variables	Methods	Main Findings
1.	Abbasi and Riaz (2016)	Pakistan 1971-2011	CO_2 emissions, GDP per capita, financial intermediation development, stock market development, and FDI.	Cointegration (ARDL - bounds test) and VECM.	Per capita CO_2 emissions were cointegrated with financial development indicators and per capita GDP. GDP per capita had a significant impact on CO_2. *Long-run:* economic growth increased energy consumption. The financial sector contributed to CO_2 increases. *Short-run*: growth in per capita incomes was associated with a rise in the CO_2. FDI --> CO_2. Private sector credit and stock market turnover --> CO_2.
2.	Jiranyakul (2016)	Thailand 2001Q1-2014Q2	Electricity consumption, energy price, and GDP.	Cointegration (ARDL - bounds test) and VECM.	The three variables were cointegrated. *Long-run:* GDP --> electricity consumption. *Short-run*: GDP <--> electricity consumption.
3.	Ahmed et al. (2016)	Brazil, India, China, South Africa (BICS) 1970-2013	CO_2 emissions, GDP, trade openness, and energy consumption (per capita).	Panel cointegration, pairwise Granger causality and innovative account approach.	The variables were cointegrated. CO_2 <--> energy consumption. Trade openness --> CO_2, energy consumption and economic growth. Economic growth --> CO_2. Trade openness and economic growth reduced CO_2 emissions in the long-run - support EKC hypothesis.
4.	Al-Mulali et al. (2016)	Kenya 1980-2012	CO_2 emissions, GDP, renewable electricity, fossil fuel electricity, financial development, trade openness, urban population ratio.	Cointegration (ARDL-bounds test) – long-run and short-run.	A long-run relationship between these variables. Fossil fuel energy consumption, GDP, urbanisation and trade openness increased air pollution mutually in the long-run and short-run. Renewable energy consumption mitigated air pollution. Financial development reduced air pollution only in the long-run. EKC was supported.

5.	Apergis (2016)	15 countries 1960-2013	GDP and CO_2	Panel cointegration.	Panel cointegration tests were inconclusive. EKC held in 12 out of the 15 countries.
6.	Bae et al. (2016)	15 post-Soviet Union countries 2000-2011	CO_2, GDP, corruption index, FDI, energy intensity, population density, EU dummy, trade openness, alternative and nuclear energy consumption.	Multiple-equation generalised method of moment (GMM).	GDP influenced CO_2 directly, and indirectly through its impact on corruption. Corruption affected CO_2 directly and indirectly through GDP. Political democracy and economic freedom increased CO_2 indirectly through economic growth. Improved energy efficiency and the EU climate policy reduced CO_2. FDI inflows tended to increase CO_2.
7.	Baek (2016)	5 ASEAN countries 1981-2010	CO_2, GDP, energy consumption, and inward FDI.	Dynamic panels - pooled mean group (PMG).	FDI increased CO_2, supporting pollution haven hypothesis. Income and energy consumption had a detrimental impact on reducing CO_2.
8.	Balaguer and Cantavella (2016)	Spain 1874-2011	CO_2, GDP, population, and international oil prices (crude oil).	Cointegration (ARDL-bounds test)	A cointegrating relationship among CO_2, GDP, GDP squared, and prices. EKC hypothesis was supported. Real oil prices were a valuable indicator of pollutant energy consumption.
9.	Bento and Moutinho (2016)	Italy 1960-2011	CO_2, GDP, non-renewable and renewable electricity production, and international trade.	Cointegration (ARDL-bounds test) and Granger causality (Toda-Yamamoto (TY)).	Cointegration among the variables with structural breaks. EKC held. Renewable electricity production reduced CO_2 in the short-run and long-run. International trade --> CO_2 and non-renewable electricity production (rep). Output --> rep. Non-rep --> rep.
10.	Dogan and Seker (2016)	23 top countries listed in Renewable Energy Country Attractiveness Index 1985-2011	CO_2, GDP, electricity power – (1) renewable sources, (2) non-renewable sources, trade openness, and financial development.	Panel cointegration - bootstrap approach.	The variables were cointegrated. FMOLS and DOLS – increases in renewable energy consumption, trade openness and financial development decreased CO_2. Increases in non-renewable energy consumption contributed to CO_2. EKC was

					supported for the top renewable energy countries.
11.	Dogan and Turkekul (2016)	US 1960-2010	CO_2, GDP, energy consumption, urbanisation, trade openness, and financial development.	Cointegration (ARDL-bounds test)	The variables were cointegrated. *Long-run:* energy consumption and urbanisation increased environmental degradation. Trade leads to environmental improvements. EKC was not supported. CO_2 <--> GDP. CO_2 <--> energy consumption. CO_2 <--> urbanisation. GDP <--> urbanisation. GDP <--> trade openness. GDP --> energy consumption. Financial development --> output. Urbanisation --> financial development.
12.	Fujii and Managi (2016)	39 countries and 14 industries 1995-2009	Eight air pollutants (CO_2, CH_4, N_2O, NOX, SOX, CO, NMVOC and NH_3), GDP, population and policy variable.	Panel regression analysis.	At least ten individual industries rejected EKC (in 8 pollutants). The key industries that dictated EKC relationship existed in CO_2, N_2O, CO, and NMVOC.
13.	Javid and Shari (2016)	Pakistan 1972-2013	CO_2, total energy use, GDP, financial development, and trade openness.	Cointegration (ARDL-bounds test) and Granger causality.	The variables were cointegrated. EKC held both short- and long-term. The key factors to CO_2 were income, energy consumption and financial development. Openness had no the case.
14.	Jebli et al. (2016)	25 OECD countries 1980-2010	Renewable and non-renewable energy consumption, CO_2, GDP, real exports and real imports.	Panel cointegration and Granger causality.	There was cointegration between the variables. *Short-run*: Renewable energy consumption <--> imports. Renewable energy <--> non-renewable energy. Non-renewable energy <--> trade. Exports --> renewable energy. Trade --> CO_2. Output --> renewable energy. *Long-run:* Bidirectional causalities between all the variables. Inverted U-shaped EKC found. Increasing non-renewable energy increased CO_2.

					Increasing trade or renewable energy reduced CO_2.
15.	Kais and Sami (2016)	58 countries 1990-2012	CO_2, energy use, GDP, urbanisation, and trade openness. (Total data are used than per capita))	Panel data model.	Energy use had a positive impact on the CO_2 for all panels. Per capita GDP had a positive impact on carbon. The presence of an inverted U-shaped curve between CO_2 and GDP per capita.
16.	Katrakilidis et al. (2016)	Greek 1960-2012	CO_2, health quality, and GDP per capita.	Cointegration (Johansen and ARDL-bounds test), VECM, and Granger causality.	Economic growth led to CO_2 emissions and had a positive effect on health quality. Environmental degradation negatively affected health quality. Environmental degradation and economic activity systematically affected health quality.
17.	Khan et al. (2016)	Pakistan 1975-2012	CO_2, energy consumption, and water resources.	Cointegration, ECM, and VAR Granger causality.	A long-run relationship between the variables. Energy consumption and water resources had a positive relationship with air pollution. Total natural resources rent had the least contributor to air pollution.
18.	Lee and Chong (2016)	U.S. building sector 1973-2012	Residential and commercial sectors: total energy resource consumption, energy prices, and the total amount of CO_2 emissions.	Granger causality (TY) and generalised impulse response function.	*Long-run:* Natural gas prices --> natural gas consumption (residential and commercial sectors). Electricity prices --> electricity consumption (commercial sector). Electricity and coal consumption --> CO_2 (residential and commercial sectors). *Short-run:* Natural gas consumption was the most sensitive towards changes in natural gas price in the residential sector. Electricity consumption was the most sensitive towards electricity prices in the commercial sector. Commercial sector's energy consumption generated greater

					influence on CO_2 than the residential sector.
19.	Li et al. (2016)	China - 28 provinces 1996-2012	Environmental pollution, GDP, energy consumption, trade openness, urbanisation.	Dynamic panel model - GMM and ARDL.	EKC hypothesis was well supported. Positive effects of energy consumption on various pollutant emissions. Trade and urbanisation might deteriorate environmental quality in the long-run, albeit not in the short-run.
20.	Saidi and Hammami (2016)	58 1990-2012	GDP, energy consumption, CO_2, capital stock, FDI, financial development, population, trade openness, and urbanisation.	Dynamic simultaneous-equation panel – GMM estimator.	Energy consumption <--> economic growth. Energy consumption <--> CO_2 for the four panels. CO_2 --> economic growth (Latin American and the Caribbean), which implies that environment degradation had a negative impact on growth.
21.	Saidi and Mbarek (2016)	19 emerging economies 1990-2013	CO_2, financial development, trade openness, GDP, and urbanisation.	Panel cointegration (system GMM panel).	Positive monotonic relationship between income and CO_2. No support of EKC. Financial development had long-run negative impact on CO_2. Urbanisation decreases CO_2.
22.	Sumabat et al. (2016)	Philippine 2000-2010	Net fuel consumption, electricity consumption, population, and GDP.	Accounting CO_2, and index decomposition analysis.	Negative impacts of economic growth and a higher standard of living to CO_2. The contribution of economic activity and energy intensity to CO_2 offset each other.
23.	Wang et al. (2016a)	8 ASEAN 1980-2009	Total energy use, total carbon emissions, and urbanisation.	Panel cointegration and Granger causality.	A long-run equilibrium relationship between the variables. A 1% rise in urban population resulted in a 0.20% increase in carbon emissions. *Short-run:* Urbanisation --> energy use. Urbanisation --> carbon emissions. *Long-run:* Urbanisation with energy use --> carbon emissions.
24.	Wang et al. (2016b)	Provinces of China. 1990-2012	Sulphur dioxide emissions, population, energy use, GDP, and urbanisation.	Semi-parametric panel fixed effects regression.	The inverted U-shaped curve was supported between economic growth and sulphur dioxide emissions, but little

					evidence for urbanisation and sulphur dioxide emissions.
25.	Yorucu (2016)	Turkey 1960-2010	CO_2 (fuel consumption, transport, and electricity heating), foreign tourist arrivals, and electricity consumption.	Cointegration (ARDL-bounds test)	Long-run equilibrium relationships existed. Foreign tourists and electricity consumption were significant factors of a long-run equilibrium relationship with CO_2 from electricity and heat production and CO_2 from transport, respectively. *Long-run:* Foreign tourist arrivals and electricity consumption --> CO_2. *Short-run:* significant dynamic relationships between CO_2, electricity consumption and tourist arrival.
26.	Zaman et al. (2016a)	Brazil, Russia, India, China, South Africa (BRICS) 1975-2013	Environmental, energy, health, and GDP per capita.	Panel cointegration.	Environmental variables had a deleterious effect on the BRICS economic growth. Energy sources significantly increased economic growth. Health expenditures and infrastructure were important for health issues.
27.	Zaman et al. (2016b)	34 countries 2005-2013	Tourism (expenditures, receipts, and arrivals), energy use, CO_2, GDP, gross fixed capital formation and health expenditures.	Panel two stage least square, and principal component analysis for tourism development.	Invested U-shaped between CO_2 and income. Causal relationships: Tourism induced CO_2, energy induced CO_2, investment induced CO_2, growth led tourism, investment led tourism and health led tourism.
28.	Zhang and Gao (2016)	China – 30 provinces 1995-2011	Tourism receipts, energy consumption, and CO_2 emissions.	Panel cointegration and Granger causality.	A cointegration relationship among the variables in all regions. Tourism-induced EKC did not exist in central China, and weakly supported in eastern and western China. Tourism had a negative impact on CO_2 in the eastern region. Causality of both short- and long-runs was mixed among regions.

29.	Robalino-Lopez et al. (2015)	Venezuela 1980-2025	CO_2, energy consumption, and GDP.	Kaya identity and GDP formation approach – cointegration.	EKC did not hold including a coming future under different economic scenarios.
30.	Ajmi et al. (2015)	G7 (excluding Germany) 1960-2010	GDP, energy consumption, and CO_2 (per capita).	Granger causality – classical and time-varying.	GDP <--> Japan energy consumption. GDP --> Italy energy consumption. Energy consumption --> Canada's GDP. Energy consumption <--> US CO_2. Energy consumption <--> France CO_2. GDP --> Italy and Japan CO_2. No support to EKC for Italy and Japan.
31.	Al-Mulali et al. (2015a)	99 countries 1980-2008	Ecological footprint, GDP, energy consumption, trade openness, and financial development.	Panel regression (fixed and random effects models).	EKC held for upper middle- and high-income countries. Energy consumption, urbanisation, and trade openness increased environmental damage through their positive effect ecological footprint. Financial development reduced environmental degradation.
32.	Al-Mulali et al. (2015b)	Vietnam 1981-2011	Electricity consumption, GDP, capital, labour force, export and import.	Cointegration (ARDL-bounds test)	Pollution haven hypothesis held. Imports increase pollution. Fossil fuel energy consumption increased pollution. Renewable energy consumption had no effect in reducing pollution. Labour force reduces pollution. EKC did not exist.
33.	Al-Mulali et al. (2015c)	23 European countries 1990-2013	Five disaggregated renewable electricity production, GDP, trade openness, financial development, and CO_2.	Panel cointegration, and VECM Granger causality.	All variables were cointegrated. GDP growth, urbanisation, and financial development increase CO_2 in the long-run, while trade openness reduced it. Renewable electricity had a negative long-run effect on CO_2. GDP growth --> CO_2.
34.	Al-Mulali (2015)	16 major biofuel energy producing and consuming countries. 2000-2010	Biofuel energy consumption, Biofuel energy production, GDP growth, CO_2, consumer price	Panel cointegration, and Granger causality – VECM.	The long-run relationship was presented. Biofuel energy increased GDP growth and reduced the level of pollution. It increased both agriculture

			food index, and total crop production index.		production and agriculture crop prices.
35.	Alshehry and Belloumi (2015)	Saudi Arabia 1971-2010	Energy consumption, GDP, energy prices, and CO_2.	Cointegration (Johansen), and Granger causality.	A long-run relationship among the variables. *Long-run:* Energy consumption --> economic growth and CO_2. CO_2 <--> economic growth. Energy price --> economic growth and CO_2. *Short-run:* CO_2 --> energy consumption and economic output. Energy price --> CO_2. Energy-led growth held.
36.	Asongu (2015)	24 African countries 1982-2011	GDP, energy consumption, and CO_2.	Panel cointegration (ARDL), and Granger causality.	A long-run relationship among the variables in 24 countries. *Long-run:* GDP and CO_2 --> energy consumption. CO_2 (and energy consumption) <--> GDP.
37.	Bastola and Sapkota (2015)	Nepal 1980-2011	GDP, CO_2, and primary energy consumption.	Cointegration (Johansen and ARDL-bounds), and Granger causality.	Two cointegrating vectors i.e., energy consumption and carbon emissions equations. *Long-run:* Energy consumption <--> CO_2. Economic growth --> CO_2 and energy consumption.
38.	Begum et al. (2015)	Malaysia 1970-1980	CO_2, GDP, energy consumption, and population growth.	Cointegration (ARDL-bounds).	Cointegration existed among the variables. CO_2 decreased with increasing per capita GDP. EKC was not supported. Energy consumption and GDP has long-term positive impacts with CO_2. Growth might have an adverse effect on CO_2 (long-run).
39.	Burke et al. (2015)	189 countries 1961-2010	CO_2 and GDP.	Panel approach - OLS and generalised least squares (GLS) estimators	No strong support that emissions-income elasticity is larger during individual years of economic expansion as compared to the recession. Economic growth increased emissions in the same year and subsequent years. Emissions tended to grow more quickly after booms and slowly after recessions. Economic

					growth and emissions had been more tightly linked in fossil-fuel rich countries.
40.	Farhani and Ozturk (2015)	Tunisia 1971-2012	CO_2, GDP, energy consumption, financial development, trade openness, and urbanisation.	Cointegration (Johansen and ARDL-bounds), and Granger causality.	One cointegration relationship. Financial development had a positive sign with CO_2. A positive monotonic relationship between GDP and CO_2 – rejected EKC. *Long-run:* GDP, energy consumption, financial development, trade openness and urbanisation --> CO_2. CO_2, GDP, energy consumption, trade openness, and urbanisation --> financial development. *Short-run:* GDP, energy consumption and urbanisation --> CO_2. CO_2, GDP, energy consumption and trade openness --> financial development. CO_2, GDP, energy consumption and urbanisation --> trade openness.
41.	Georgiev and Mihaylov (2015)	30 OECD 1990-2005	Sulphur oxides, nitrogen oxides, carbon monoxide, volatile organic compounds, carbon dioxide, greenhouse gases, GDP, and population density.	Panel and cross-section - Spatial econometric analysis.	EKC existed only for CO, VOC and NO_x, and for CO_2 the curve is monotonically increasing. GHG supported EKC. SO_x followed a U-shaped curve.
42.	Hao and Liu (2015)	China – 29 provinces 1995-2011	FDI, trade, CO_2, GDP, domestic capital stock, and population growth.	Two-equation model – GMM.	FDI on CO_2 was negative (direct), and it dominates the positive indirect effect through FDI's influence on per capita GDP. Foreign trade on CO_2 was insignificant with potential endogeneity and dynamics introduced.
43.	Haseeb and Azam (2015)	Pakistan 1975-2013	Energy consumption, CO_2, and growth.	Cointegration and Granger causality.	Long-run relationship among the variables. CO_2 <--> growth. Energy consumption --> CO_2.

44.	Heidari et al. (2015)	ASEAN 1980-2008	CO_2, GDP, and energy consumption.	Panel smooth transition regression (PSTR).	Rejected the null hypothesis of linearity. First regime (GDP per capita below 4686USD), environmental degradation increases with economic growth while the trend was reversed in the second regime. Energy consumption with either first or second regime increased CO_2. EKC was supported.
45.	Jammazi and Aloui (2015a)	6 Gulf Cooperation Council (GCC) 1980-2013	CO_2, energy consumption, and economic growth.	Wavelet windowed cross-correlation (WWCC)	Energy consumption <--> economic growth. Energy consumption --> CO_2. The intensity of the co-movements reached its zenith at coarser scales (long-run). Supported neighborhood-effect.
46.	Jammazi and Aloui (2015b)	6 GCC countries 1980-2012	CO_2, energy consumption, and economic growth.	WWCC – Granger causality.	Energy consumption <--> economic growth. Energy consumption --> CO_2. Economic growth <--> CO_2.
47.	Jebli and Youssef (2015)	Tunisia 1980-2009	CO_2, renewable and non-renewable energy consumption, GDP, and international trade.	Cointegration (ARDL-bounds), and VECM Granger causality	A long-run relationship among variables. *Short-run:* Trade, GDP, CO_2 and non-renewable energy --> renewable energy. *Long-run:* Non-renewable energy and trade had a positive impact on CO_2. EKC was not supported.
48.	Kasman and Duman (2015)	15 countries 1992-2010	Primary energy consumption, GDP, CO_2, trade openness, and urbanisation.	Panel cointegration and Granger causality.	The variables were cointegrated. Supported EKC. *Short-run:* Energy consumption, trade openness and urbanisation --> CO_2. GDP --> energy consumption. GDP, energy consumption and urbanisation --> trade openness. Urbanisation --> GDP. Urbanisation --> trade openness.
49.	Long et al. (2015)	China 1952-2012	GDP, CO_2, labour, capital stock, and energy consumption.	Cointegration, Granger causality, etc.	At least one cointegration relationship among the variables. Coal had a dominant impact on economic growth and CO_2. GDP <--> CO_2, coal, gas,

					and electricity consumption.
50.	Omri et al. (2015)	12 Middle East and North Africa (MENA) 1990-2011	GDP, CO_2, financial development, trade openness, capital stock, energy consumption, urbanisation, inflation, and FDI.	Panel cointegration, and simultaneous-equation panel data.	Variables included were not cointegrated. CO_2 <--> economic growth. Economic growth <--> trade openness. Trade openness <--> financial development. Financial development --> economic growth. Trade openness --> CO_2. Verified EKC.
51.	Saidi and Hammami (2015)	58 countries 1990-2012	Energy consumption, CO_2, capital stock, labour force, FDI, and GDP.	Dynamic panel (GMM).	Energy consumption had a positive impact on economic growth. CO_2 emissions had a negative impact on economic growth.
52.	Salahuddin et al. (2015)	6 GCC countries 1980-2012	CO_2, electricity consumption, GDP, and financial development.	Panel cointegration, Granger causality, etc.	The long-run relationship was found. Electricity consumption and economic growth had a positive long-run relationship with CO_2. The negative relationship between CO_2 and financial development. Economic growth <--> CO_2. Electricity consumption --> CO_2.
53.	Tang and Tan (2015)	Vietnam 1976-2009	CO_2, GDP, energy consumption, and FDI.	Cointegration, and VECM Granger causality.	All variables were cointegrated. Supported EKC. CO_2 <--> income. FDI <--> CO_2. Energy consumption --> CO_2. Energy consumption, FDI, and income were the key determinants of CO_2.
54.	Yu et al. (2015)	China - iron and steel industry 1990-2010	CO_2, GDP growth rate, investment and technology expenditure.	VAR, Granger causality, and impulse response function.	Technology expenditure significantly reduced CO_2. Investment negatively impacted CO_2.
55.	Yuan et al. (2015)	China 2000-2012	Air pollutants emissions (regional level), energy consumption, and GDP.	Resource and environmental performance index, REPI.	Economic development had negative impact on energy consumption and air environment, but it could be favourable if reasonable energy and industrial structure, improved energy efficiency, and strict environmental policies were put in place.

56.	Zhang and Da (2015)	China 1996-2010	GDP, added value of primary, secondary and tertiary industries, final consumption.	Log mean Divisia index (LMDI), and decoupling index.	Economic growth increased CO_2. Energy intensity and final energy consumption played significant roles in decreasing CO_2 and carbon emission intensity.
57.	Ziaei (2015)	25 countries 1989-2011	CO_2, energy consumption, and financial development	Panel VAR, and impulse response function.	The strength of energy consumption shock on stock return rate in European countries was greater than East Asian and Oceania countries. Conversely, shocks to stock return rate influence energy consumption in the long horizon for East Asia and Oceania countries.
58.	Mohammadi and Parvaresh (2014)	14 Oil-exporting countries 1980-2007	GDP, energy consumption, urbanisation, CO_2 emissions and real exports.	Panel cointegration and ECM.	Energy consumption and output for 14 oil-exporting countries were cointegrated. Energy consumption <--> growth.
59.	Araç and Mübariz (2014)	Turkey 1960–2010	Energy consumption and GDP per capita.	Cointegration (Johansen and ARDL-bounds test), smooth transition vector autoregressive model, etc.	The variables were not cointegrated. Asymmetric effects of positive versus negative and small versus large energy consumption shocks on output growth, and vice versa. Negative energy shocks had a greater effect on output growth than positive energy shocks, and that big negative energy shocks affected output much more than small negative energy shocks. Positive output shock had a greater impact on energy consumption whereas negative shocks had almost no effect on energy consumption.
60.	Onafowora and Oluwole (2014)	Brazil, China, Egypt, Japan, Mexico, Nigeria, South Korea, and South Africa 1970-2010	CO_2 emissions, GDP, energy consumption, trade, and population density.	Cointegration (ARDL-bounds test) and variance decomposition.	A long-run relationship among CO_2 and its determinants for all countries. Inverted U-shaped EKC hypothesis held in Japan and South Korea. Other six countries, N-shaped trajectory between

					economic growth and CO_2 in the long-run. CO_2 --> output growth (Brazil, Japan, Egypt, Nigeria and South Africa). Output growth to CO_2 (China and South Korea). Economic growth <--> CO_2 (Mexico). Energy consumption --> both CO_2 and economic growth (all countries).
61.	Ruhul et al. (2014)	29 OECD countries 1980-2011	GDP, industrial output, capital, labour force and renewable and non-renewable energy consumption.	Panel cointegration and Granger causality.	A long-run relationship among the variables. Industrial output <--> renewable and non-renewable energy consumption. GDP growth <--> non-renewable energy consumption. GDP growth --> renewable energy consumption.
62.	Abdul (2014)	29 net energy importer and 19 net energy exporter countries 1970-2012	GDP, capita stock, the level of employment, total energy consumption, and trade openness.	Panel cointegration and Granger causality.	Long-run relationship between energy consumption and economic growth. Energy consumption, capita stock, investment flows, the level of employment and trade openness had a positive impact on economic growth of both groups. The existence of cross section dependence among the countries.
63.	Wolde-Rufael (2014)	15 transition economies 1975–2010	Electricity consumption, and GDP.	Bootstrap panel causality.	Causality from electricity consumption to economic growth for Belarus and Bulgaria. Causality from economic growth to electricity consumption for Czech Republic, Latvia, Lithuania and the Russian Federation. Bi-directional causality for Ukraine.
64.	Chandran and Tang (2013a)	China and India 1965-2009	CO_2 emissions, GDP and coal consumption	Time series cointegration and Granger causality.	Three variables were cointegrated. China: Economic growth --> CO_2. Economic growth <--> coal consumption. CO_2 <--> coal consumption. India: Economic growth

					--> coal consumption. Economic growth <--> CO_2. CO_2 <--> coal consumption.
65.	Chandran and Tang (2013b)	ASEAN-5 1971-2008	CO_2 emissions, energy consumption for road transportation sector, FDI, and GDP.	Time series cointegration and Granger causality.	CO_2 and other variables were cointegrated for Indonesia, Malaysia and Thailand – income and transport energy consumption significantly influence CO_2 (FDI was not the case). Economic growth contributed to CO_2. *Long-run:* economic growth <--> CO_2 (Indonesia and Thailand). Economic growth --> CO_2 (Malaysia). Bi-directional causality between transport energy consumption, FDI and CO_2 in Thailand and Malaysia.
66.	Al-Mulali and Tang (2013)	GCC countries 1980-2009	CO_2 emissions, FDI, energy consumption, and GDP (per capita).	Panel cointegration and panel Granger causality.	The four variables were cointegrated. FMOLS: energy consumption and GDP growth increase CO_2 emission; FDI inflows had a long-run negative relationship with CO_2. Granger causality: FDI had no short-run causal relationship with CO_2 and energy consumption; energy consumption and GDP growth were positively caused by CO_2. The pollution haven hypothesis was rejected. Energy-led growth hypothesis was valid.
67.	Alam (2013)	A panel of 25 countries 1993-2010	GDP, nuclear energy consumption and CO_2 emissions.	Panel cointegration and panel Granger causality.	The three series were cointegrated. *All countries:* CO_2 --> nuclear energy consumption. Economic growth --> CO_2. Nuclear energy consumption --> CO_2. Economics growth <--> CO_2. Nuclear energy consumption --> CO_2. *Developed countries:* CO_2 --> economics growth. Economics growth --> CO_2 and nuclear energy

					consumption --> CO_2. *Developing countries:* Economics growth --> CO_2.
68.	Liew et al. (2012)	Pakistan 1980-2007	Energy consumption, and outputs.	Cointegration (Johansen's) and Granger causality.	Energy consumption, agriculture and services outputs were cointegrated. Energy consumption <--> agriculture output. Services and industrial output --> energy consumption.
69.	Ang (2007)	France 1960-2000	CO_2 emissions, energy consumption, and GDP.	Cointegration (ARDL-bounds test) and vector ECM.	The long-run relationship was found. Growth influenced energy consumption, and CO_2 (long-run). Energy consumption --> output growth (short-run).
70.	Asafu-Adjaye (2000)	India and Indonesia 1973-1995 Thailand and Philippines 1971-1995	Commercial energy use, GDP and consumer price index (CPI).	Cointegration (Johansen's) and ECM.	Energy, income and prices variables were cointegrated. Energy consumption --> income for India and Indonesia. Energy consumption <--> income for Thailand and the Philippines. Energy, income and prices were mutually causal. Only Indonesia and India that energy and income were neutral.

Notes: --> refers to "does Granger-cause"; -/-> refers to "does not Granger-cause"; <--> refers to bidirectional causation.

Appendix B: FMOLS and DOLS Estimates.

Dep. Var.	(a) *ln*Y		(b) *ln*OC		(c) *ln*CO_2		(d) *ln*Y		(e) *ln*PEC		(f) *ln*CO_2	
	FMOLS	DOLS	FMOLS	DOLS	FMOLS	DOLS	FMOLS	DOLS	FMOLS	DOLS	FMOLS	DOLS
C	-11.184**	-35.40	-1.896	-4.330**	5.046***	3.48***	-8.775	117.7	-6.352***	-8.7***	9.012***	9.25***
	(0.027)	(0.554)	(0.176)	(0.018)	(0.000)	(0.001)	(0.277)	(0.629)	(0.000)	(0.000)	(0.000)	(0.000)
lnCO_2	1.679**	5.352	0.687***	0.952***	-	-	1.631**	-9.692	0.637***	0.89***	-	-
	(0.035)	(0.551)	(0.000)	(0.000)			(0.038)	(0.657)	(0.000)	(0.000)		
*ln*Y	-	-	0.036	-0.043	0.150**	0.042	-	-	0.037	-0.038	0.151**	0.039
			(0.579)	(0.207)	(0.014)	(0.378)			(0.545)	(0.271)	(0.016)	(0.427)
*ln*OC	0.375	-3.011	-	-	0.801***	1.16***	-	-	-	-	-	-
	(0.680)	(0.714)			(0.000)	(0.000)						
*ln*PEC	-	-	-	-	-	-	0.412	11.39	-	-	0.853***	1.24***
							(0.667)	(0.591)			(0.000)	(0.000)
AR^2	0.739	0.793	0.822	0.970	0.857	0.900	0.739	0.797	0.819	0.969	0.854	0.896
S.E.	1.535	1.306	0.449	0.182	0.479	0.356	1.536	1.295	0.426	0.173	0.485	0.363

Notes: (***) and (**) denote significance levels at 1% and 5%, respectively. The DOLS estimates are based on one lead and one lag. The estimated coefficients are reported with the *p*-values in parenthesis. AR^2 is adjusted R-squared.