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Does the causal relationship between renewable energy consumption, CO2 emissions, and economic growth exist in Thailand? An ARDL approach

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Abstract

This paper investigates the causal relationship between CO2 emissions, energy consumption, and income in Thailand using the data between 1986 and 2012 from the Energy Statistics of Thailand. We apply an Autoregressive distributed lag (ARDL) cointegration analysis in the estimation and test whether the Environmental Kuznets Curve (EKC) hypothesis exists in Thailand. The empirical results suggest that there is inverted-U-shaped relationship between CO2 emissions and income, which affirms the validity of Environmental Kuznets Curve (EKC) hypothesis in Thailand. The causality results indicate long-run relationship between CO2 emissions, energy consumption, and income. In the short run, there is bi-directional causality between CO2 emissions and income, and between CO2 emissions and energy consumption. However, there is no causal relationship between renewable energy consumption and CO2 emissions in the manufacturing sector as a result of government supporting policy on the use of renewable energy in this sector.

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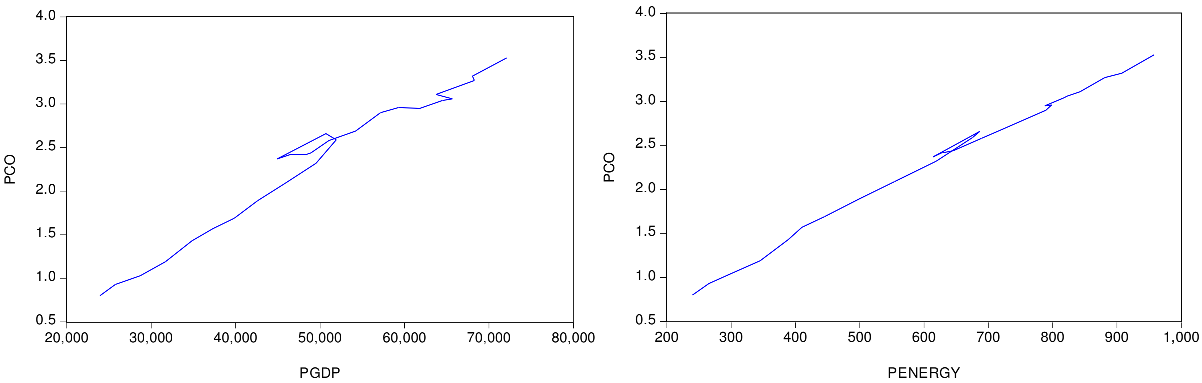
1. INTRODUCTION

Over the past thirty years, Thailand has experienced rapid economic growth; despite facing a huge crisis in 1997, the Thai economy has recovered and achieved high growth rate since 1999. Along with its expansion, the demand for energy has grown dramatically. This development has caused an increase in the demand for commercial energy which, in turn, led to higher carbon dioxide (CO_2) emissions. Figure I shows a positive relationship between CO_2 emissions and gross domestic product (GDP), and between emissions and energy consumption.

Figure I: The relationship between CO_2 emissions, GDP, and energy consumption in Thailand (1986-2012)



Source: The Energy Statistics of Thailand (2012)

There are several studies examining the relationship between these three variables. Kraft and Kraft (1978) first studied the relationship between energy consumption and economic growth (or output) and found unidirectional causality from gross national product (GNP) to energy consumption during 1947-1974 in the United States. Findings from the studies in the other countries are different. For example, Asafu-Adjaye (2000) found unidirectional causality from energy consumption to income in the case of India and Indonesia and bi-directional causality between energy consumption and income in the case of Thailand and the Philippines. Kaplan et al (2011) also found bi-directional causality between energy consumption and economic growth in Turkey.

By adding the pollution emissions into this relationship, Ang (2007) found that there exists a long-run relationship between CO_2 emissions, energy consumption, and output in France. Pao and Tsai (2010), Pao et al (2011), Pao and Tsai (2011), and Menyah and Wolde-Rufael (2010) also found the evidence consistently support this relationship in BRIC countries, Russia, Brazil, and South Africa, respectively. With regard to the direction, in the short run, Ang (2007) and Menyah and Wolde-Rufael (2010) found that there is unidirectional causality from energy consumption to economic growth in France and South Africa, respectively. On the other hand, Pao and Tsai (2010) found bi-directional causality between between energy consumption and output in BRIC countries. In addition, Pao and Tsai (2010) found bi-directional energy consumption and CO_2 emissions, while Menyah and Wolde-Rufael (2010) found unidirectional causality from energy consumption to CO_2 emissions.

For Thailand, we find an empirical study by Asafu-Adjaye (2000) reporting bi-directional causality between energy consumption and income during 1971-1995. Lee and Chang (2008) also confirmed the existing relationship between energy consumption and Gross Domestic

Product (GDP) by using the World Development Indicator (WDI) during 1971-2002. Recently, Saboori and Sulaiman (2013) showed the existing long run relationship between CO_2 emissions, energy consumption, and income during 1971-2008. In addition, there is bi-directional causality between CO_2 emissions and income, and between energy consumption and CO_2 emissions in the short run.

Our paper will investigate the causal relationship between CO_2 emissions, energy consumption, and income in Thailand by using the Autoregressive distributed lag (ARDL) cointegration analysis in the estimation. We will also focus on the renewable energy consumption, and its relationship, as Saboori and Sulaiman (2013) did not investigate this, despite recent efforts by the Thai government to promote the use of renewable energy in the country (see the Alternative Energy Development Plan (AEDP) 2015 (Department of Alternative Energy Development and Efficiency, 2015)).

Furthermore, our paper will test whether Environmental Kuznets Curve (EKC) hypothesis existed in Thailand. The Environmental Kuznets Curve (EKC) hypothesis is a hypothesized relationship between economic growth and environmental degradation as inverted-U-shaped curve. This hypothesis describes an increase in income leading to an increase in pollution; however, when a country reaches a certain level of income, pollution start to decrease (Arouri et al, 2012). In an empirical test of the EKC hypothesis, the logarithm of the indicator is typically indicated as a form of quadratic or cubic function of the logarithm of income (Song et al, 2008). This hypothesis is supported by empirical evidence from various studies e.g., Grossman and Krueger (1991), Panayotou (2003), Shafik (1994), Moomaw and Unruh (1997), Selden and Song (1994), Roberts and Grimes (1997), and Cole et al (1997) (See Dinda (2004) for complete survey of literature).

We will extend our model by disaggregating the source of CO_2 emissions into four main categories including: power generation, industry, transportation, and other sectors in order to identify which source contributes significantly to the relationship. In addition, due to the strong relationship between renewable energy consumption and economic growth e.g., Yildirim et al (2012) and the Thai government policy in encouraging a development of the renewable energy sector, we will further study its relationship with CO_2 emissions. We divide the final energy consumption, which also includes renewable energy, into five economic sectors including: agriculture, manufacturing, resident, transportation, and other economic sectors.

This paper is organized as follows. Section 2 provides data used in the estimation. Section 3 presents the methodology and Section 4 shows the empirical results. Finally, the conclusion is in Section 5.

2. DATA

This study employs the annual data between 1986 and 2012 from the Energy Statistics of Thailand, Energy Policy and Planning Office (EPPO), Ministry of Energy, Thailand (EPPO, 2013). There are three main variables used in this study including: (1) carbon dioxide (CO_2) emissions from the use of energy, (2) energy consumption, and (3) income.

First, the CO_2 emissions mean the amount of CO_2 emissions from energy consumption, which are calculated from the use of all fuel types, based on the 2006 Guidelines of the Intergovernmental Panel on Climate Change (IPCC) (EPPO, 2013). We then classify the source of CO_2 emissions into four main categories including: power generation, industry, transportation, and other sectors (including the residential, agricultural and commercial sectors).

Energy consumption refers to the final modern energy consumption data. These consist of two sources of information. First, the final energy consumption, which excludes renewable energy variables, is from the Energy Policy and Planning Office (EPPO, 2013), Thailand. Second, the final energy consumption, which includes renewable energy, is divided into five economic sectors including: agricultural, manufacturing, resident, transportation and other economic sectors (including mining, construction, and commercial), is collected from the Department of Alternative Energy Development and Efficiency, 2012b).

Income refers to the Gross Domestic Product (GDP) per capita data, which are from the official report of the Office of the National Economic and Social Development Board (NESDB) (NESDB, 2015).

3. METHODOLOGY

We apply the Autoregressive distributed lag (ARDL) in cointegration analysis to examine the short-run and long-run relationship between CO_2 emissions, energy consumption, and income.

The ARDL approach consists of two steps in the estimation as follows:

- Step 1 - In order to check whether there is a relationship between these three variables in the long-run, we follow the bounds testing approach proposed by Pesaran et al (2001) and Narayan (2004).

We first estimate these four equations below in order to get the coefficients (λ_i).

$$\Delta \ln co_t = \alpha_0^c + \lambda_1^c \ln co_{t-1} + \lambda_2^c \ln E_{t-1} + \lambda_3^c \ln Y_{t-1} + \lambda_4^c \ln Y_{t-1}^2 + \sum_{j=1}^{n} \gamma_{1j}^c \ln \Delta co_{t-j} + \sum_{j=0}^{n} \gamma_{2j}^c \Delta \ln E_{t-j} + \sum_{j=0}^{n} \gamma_{3j}^c \Delta \ln Y_{t-j} + \sum_{j=0}^{n} \gamma_{4j}^c \Delta \ln Y_{t-j}^2 + \varepsilon_t \quad (1)$$

$$\Delta \ln E_t = \alpha_0^E + \lambda_1^E \ln co_{t-1} + \lambda_2^E \ln E_{t-1} + \lambda_3^E \ln Y_{t-1} + \lambda_4^E \ln Y_{t-1}^2 + \sum_{j=0}^{n} \gamma_{1j}^E \ln \Delta co_{t-j} + \sum_{j=1}^{n} \gamma_{2j}^E \Delta \ln E_{t-j} + \sum_{j=0}^{n} \gamma_{3j}^E \Delta \ln Y_{t-j} + \sum_{j=0}^{n} \gamma_{4j}^E \Delta \ln Y_{t-j}^2 + \varepsilon_t \quad (2)$$

$$\Delta \ln Y_t = \alpha_0^Y + \lambda_1^Y \ln co_{t-1} + \lambda_2^Y \ln E_{t-1} + \lambda_3^Y \ln Y_{t-1} + \lambda_4^Y \ln Y_{t-1}^2 + \sum_{j=0}^{n} \gamma_{1j}^Y \ln \Delta co_{t-j} + \sum_{j=0}^{n} \gamma_{2j}^Y \Delta \ln E_{t-j} + \sum_{j=1}^{n} \gamma_{3j}^Y \Delta \ln Y_{t-j} + \sum_{j=0}^{n} \gamma_{4j}^Y \Delta \ln Y_{t-j}^2 + \varepsilon_t \quad (3)$$

$$\Delta \ln Y_t^2 = \alpha_0^{SY} + \lambda_1^{SY} \ln co_{t-1} + \lambda_2^{SY} \ln E_{t-1} + \lambda_3^{SY} \ln Y_{t-1} + \lambda_4^{SY} \ln Y_{t-1}^2 + \sum_{j=0}^{n} \gamma_{1j}^{SY} \ln \Delta co_{t-j} + \sum_{j=0}^{n} \gamma_{2j}^{SY} \Delta \ln E_{t-j} + \sum_{j=0}^{n} \gamma_{3j}^{SY} \Delta \ln Y_{t-j} + \sum_{j=1}^{n} \gamma_{4j}^{SY} \Delta \ln Y_{t-j}^2 + \varepsilon_t \quad (4)$$

Where α is constant term, CO_t is per capita CO_2 emissions at time *t* (measured in tons), Y_t is per capita GDP at time *t* (measured in baht), E_t is per capita energy consumption at time *t* (measured in tons of oil equivalents), and ε_t is error term.

Note that *j* denotes a lag length set at 0 and 1. Since we estimate the Vector Autoregressive (VAR) lag order selection criteria based on Schwarz's information criterion (SIC), ARDL (1,0,0,0) is the selected lag length for this model.

We are interested in a long-run coefficient (λ_i) and a short-run coefficient (γ_i).

We then proceed to using the Wald test for the bound testing the existence of long-run relationship among these variables. The null hypothesis for no cointegration between these variables are indicated in equations (5)-(8):

$$H_0 : \lambda_1^c = \lambda_2^c = \lambda_3^c = \lambda_4^c = 0 \quad (5)$$

$$H_0 : \lambda_1^E = \lambda_2^E = \lambda_3^E = \lambda_4^E = 0 \quad (6)$$

$$H_0 : \lambda_1^Y = \lambda_2^Y = \lambda_3^Y = \lambda_4^Y = 0 \quad (7)$$

$$H_0 : \lambda_1^{SY} = \lambda_2^{SY} = \lambda_3^{SY} = \lambda_4^{SY} = 0 \quad (8)$$

If the computed F-statistics is greater than the upper bound critical value, we will reject the null hypothesis. It means that there exists cointegration between these three variables.

- Step 2 - We then estimate equations (9)-(12) to receive Error Correction Term (ECM). Note that several studies e.g., Saboori and Sulaiman (2013), Pao and Tsai (2010), and Menyah and Wolde-Rufael (2010) used ECM in investigating the existence of long-run and short-run relationship between these variables.

$$\ln co_t = \alpha_1^c + \delta_1^c \ln E_t + \delta_2^c \ln Y_t + \delta_3^c \ln Y_t^2 + \varepsilon_t \quad (9)$$

$$\ln E_t = \alpha_2^E + \delta_1^E \ln co_t + \delta_2^E \ln Y_t + \delta_3^E \ln Y_t^2 + \varepsilon_t \quad (10)$$

$$\ln Y_t = \alpha_3^Y + \delta_1^Y \ln co_t + \delta_2^Y \ln E_t + \delta_3^Y \ln Y_t + \delta_4^Y \ln Y_t^2 + \varepsilon_t \quad (11)$$

$$\ln Y_t^2 = \alpha_4^{SY} + \delta_1^{SY} \ln co_t + \delta_2^{SY} \ln E_t + \delta_3^{SY} \ln Y_t + \varepsilon_t \quad (12)$$

The coefficients received from the estimated equation (9) will indicate whether there is an existence of Environmental Kuznets Curve (EKC) hypothesis in Thailand. If there is an existence of EKC hypothesis, we expect an inverted-U-shaped relationship between income and CO_2 emissions (or $\delta_2^c > 0$ and $\delta_3^c < 0$) (Dinda, 2004).

Next, we impose ECM in the estimating equations (13)-(16) to obtain the short-run dynamic parameters and the speed of adjustment.

$$\Delta \ln co_t = \alpha_5^c + \vartheta^C ECM_{t-1}^c + \sum_{j=1}^{n} \rho_{1j}^c \Delta \ln co_{t-j} + \sum_{j=0}^{n} \eta_{2j}^c \Delta \ln E_{t-j} + \sum_{i=0}^{n} \sigma_{3j}^c \Delta \ln Y_{t-i} + \sum_{i=0}^{n} \psi_{4j}^c \Delta \ln Y_{t-i}^2 + \varepsilon_t \quad (13)$$

$$\Delta \ln E_t = \alpha_5^E + \vartheta^E ECM_{t-1}^E + \sum_{j=0}^{n} \rho_{1j}^E \Delta \ln co_{t-j} + \sum_{j=1}^{n} \eta_{2j}^E \Delta \ln E_{t-j} + \sum_{i=0}^{n} \sigma_{3j}^E \Delta \ln Y_{t-i} + \sum_{i=0}^{n} \psi_{4j}^E \Delta \ln Y_{t-i}^2 + \varepsilon_t \quad (14)$$

$$\Delta \ln Y_t = \alpha_5^Y + \vartheta^Y ECM_{t-1}^Y + \sum_{j=0}^{n} \rho_{1j}^Y \Delta \ln co_{t-j} + \sum_{j=0}^{n} \eta_{2j}^Y \Delta \ln E_{t-j} + \sum_{i=1}^{n} \sigma_{3j}^Y \Delta \ln Y_{t-i} + \sum_{i=0}^{n} \psi_{4j}^Y \Delta \ln Y_{t-i}^2 + \varepsilon_t \quad (15)$$

$$\Delta \ln Y_t^2 = \alpha_5^{SY} + \vartheta^{SY} ECM_{t-1}^{SY} + \sum_{j=0}^{n} \rho_{1j}^{SY} \Delta \ln co_{t-j} + \sum_{j=0}^{n} \eta_{2j}^{SY} \Delta \ln E_{t-j} + \sum_{i=0}^{n} \sigma_{3j}^{SY} \Delta \ln Y_{t-i} + \sum_{i=1}^{n} \psi_{4j}^{SY} \Delta \ln Y_{t-i}^2 + \varepsilon_t \quad (16)$$

Where ECM_{t-1} is error correction terms in the previous period (or lagged ECM terms), ρ, η, σ, ψ are the short run dynamic coefficients, and ϑ is the speed of adjustment.

The negative sign of ϑ indicates the existence of the causal relationship in the long-run; while the short run dynamic coefficients (ρ, η, σ, ψ) show the existence of the short-run causality among these variables.

4. RESULTS

First, we have to check if the variable is either integrated of order one $I(1)$ or integrated of order zero $I(0)$ by using Augmented Dickey-Fuller (ADF) Test. Table I shows the results of the Augmented Dickey-Fuller (ADF) Test for unit root, we found that variables used in the estimation are integrated of order one $I(1)$ and integrated of order zero $I(0)$. Total energy consumptions (including renewable energy) and income are $I(0)$; while total energy consumptions (excluding renewable energy) and total CO_2 emissions are $I(1)$.

Pesaran et al (2001) suggest the Autoregressive distributed lag (ARDL) approach, "*a relatively new cointegration technique*", that does not require the variables used in the estimation to be posed in the same order of integration as the conventional cointegration approach e.g., Engle and Granger (1987) (Saboori and Sulaiman, 2013, p.815). Therefore, in order to investigate of the existence of cointegration among CO_2 emissions, energy consumption, and income, the ARDL approach is applied in the estimated equations (1)-(4).

Next, we test the null hypothesis of no cointegration as stated in equations (5)-(8). If the null hypothesis is rejected (or, all values of the calculated F-statistic are higher than the bound critical value (Narayan, 2005)), there is the existence of cointegration among these variables. The results in Table II indicate that there exists cointegration among total CO_2 emissions, total energy consumptions (both including and excluding renewable energy) and income.

We further extend our model by disaggregating the source of CO_2 emissions into four main categories including: power generation, industry, transportation, and other sectors. We find that there exists cointegration among three main variables in only the power generation sector, representing the existence of long-run relationship in this sector. However, in the industry sector, cointegration exists only in the case of total energy consumption (excluding renewable energy), but not in the case of total energy consumption (including renewable energy). Furthermore, these three main variables are not cointegrated in the transportation and other sectors, indicating non-existence of long-run relationship in these sectors.

We then test EKC hypothesis by estimating equation (9). Table III shows the estimated long-run results of EKC equations, classified by source of CO_2 emissions. We find significant positive and negative coefficients on income (lnY) and income squared ($\ln Y^2$), respectively, indicating the existence of EKC hypothesis in the long run in all sources of CO_2 emissions, except in the industry sector.

Table IV shows the estimated long-run results of EKC equations, classified by types of energy consumption in five economic sectors. The signs of coefficients on income (lnY) and income squared ($\ln Y^2$) support the existence of EKC hypothesis in all economic sectors, except the other economic sectors. The other economic sectors, which are mining, construction, and commercial sectors, have positive linear relationship between CO_2

emissions and income, and between CO_2 emissions and energy consumption. These sectors use less energy, releasing less pollutions, compared to the agriculture, manufacturing, resident, and transportation sectors based on the statistical evidence reported in the Thailand Energy Efficiency Situation 2012 (Department of Alternative Energy Development and Efficiency, 2012b).

In addition, if we focus on the long-run relationship between renewable energy consumption and CO_2 emissions, there is the existence of the long-run relationship in the resident, transportation, and other sectors. However, the coefficients on energy consumption and CO_2 emissions in agriculture and manufacturing sectors are not statistically significant, indicating that there is no impact of energy consumption on CO_2 emissions in these two sectors. These sectors have been supported by the government to use the renewable energy e.g., solid biomass and biogas. For example, based on Thailand Energy Balance 2012 (Department of Alternative Energy Development and Efficiency, 2012c), the manufacturing sector has used more renewable energy compared to the other sectors in the economy.

Table I: The Augmented Dickey-Fuller (ADF) Test for Unit Root

Variables	**Intercept (AIC)**	
	Level	First Difference
Y	0.0508** (-2.9736)	0.0383** (-3.1143)
Y^2	0.0804*** (-2.7441)	0.0319** (-3.2017)
E **(excluding renewable energy)**	0.1398 (-2.4473)	0.0992*** (-2.6371)
E **(including renewable energy)**	0.0063* (-3.9084)	0.0536*** (-2.9522)
E **(including renewable energy in agriculture sector)**	0.0696*** (-2.8178)	0.0473** (-3.0332)
E **(including renewable energy in manufacturing sector)**	0.5202 (-1.4951)	0.0012* (-4.6088)
E **(including renewable energy in resident sector)**	0.0000* (8.1783)	0.2018 (-2.2336)
E **(including renewable energy in transportation sector)**	0.4180 (-1.6987)	0.0327* (-3.2149)
E **(including renewable energy in other economic sectors)**	0.0359** (3.1459)	0.0062* (-3.9447)
CO **(Total CO_2 emissions)**	0.1182 (-2.5418)	0.0764*** (-2.7736)
CO **(CO_2 emission - power generation)**	0.0001* (-5.5617)	0.0097* (-3.7373)
CO **(CO_2 emission - industry)**	0.1976 (-2.2416)	0.0486** (-3.0005)
CO **(CO_2 emission - transportation)**	0.0093* (-3.8215)	0.0640*** (-2.874)
CO **(CO_2 emission – other sectors)**	0.8607 (-0.5715)	0.0001* (-5.5934)

Note:

(a) The number in bracket is the t-statistic.
(b) *,**, and *** indicate the significance level at 1%, 5%, and 10%.

Table II: F-Statistics of the Null Hypothesis

Dependent Variable f($CO\|E,Y,Y^2$)	Total Energy Consumption (excluding renewable energy) F-Statistic	Results	Total Energy Consumption (including renewable energy) F-Statistic	Results
Total CO_2 emission	7.9473	Cointegration	3.0519	Cointegration
- Power generation	12.5519	Cointegration	17.3376	Cointegration
- Industry	4.3181	Cointegration	2.8674	No- Cointegration
- Transportation	0.7635	No-Cointegration	1.1465	No-Cointegration
- Other sectors	0.9457	No- Cointegration	0.9301	No-Cointegration
Lower-bound critical value at 5%	3.710			
Upper-bound critical value at 5%	5.018			
Lower-bound critical value at 10%	3.008			
Upper-bound critical value at 10%	4.150			

Note: Lower and Upper bound critical value are taken from Table case III (Narayan, 2005, p.1988)

Table III: Estimated Results of the EKC Equations Classified by Source of CO_2 Emissions

Dependent f($CO\|E,Y,Y^2$)	$CO\|E$ (excluding renewable energy)			$CO\|E$ (including renewable energy)	
	Total CO_2 emissions	Power generation	Industry	Total CO_2 emission	Power generation
Constant	-36.035*	-67.1709*	-29.9629**	-63.9448*	-90.6783*
ln*E*	1.0082*	0.9929*	0.7962*	0.87*	1.1725*
ln*Y*	5.6493*	11.055*	3.8235	10.7797*	15.3603*
lnY^2	-0.2624*	-0.5032*	-0.1472	-0.4933*	-0.7139*
Shape	Inverted U-Shaped	Inverted U-Shaped	-	Inverted U-Shaped	Inverted U-Shaped
Diagnostic test statistics					
R^2	0.9984	0.9876	0.99	0.993	0.9879
F-statistic	4798.815	615.5930	942.098	1085.609	627.82

Note: *,**, and *** indicate the significance level at 1%, 5%, and 10%.

Table IV: Estimated results of the EKC equations classified by types of energy consumption

Dependent f($CO|E,Y,Y^2$)	constant	ln$Y$	lnY^2	ln$E$	Shape	Diagnostic test statistics	
						R^2	F-statistic
CO|E **(excluding renewable energy)**	-36.035*	5.6493*	-0.2624*	1.0082*	Inverted U-Shaped	0.9984	4798.815
CO|E (including renewable energy)	-63.9449*	10.7797*	-0.4932 *	0.8700 *	Inverted U-Shaped	0.9930	1085.609
- Agriculture	-72.5217*	12.3929*	-0.5185*	0.0655	Inverted U-Shaped	0.9864	556.057
- Manufacturing	-74.4864*	12.8651*	-0.5479*	0.1388	Inverted U-Shaped	0.9872	590.265
- Resident	-46.6251*	7.8333*	-0.3150*	-0.3305*	Inverted U-Shaped	0.9929	1077.51
- Transportation	-44.0145*	7.0081*	-0.2737*	0.4303*	Inverted U-Shaped	0.9936	1189.761
- Other Economic Sectors	-12.3320*	1.0739*	0.1306	0.5907*	linear	0.9910	844.1332

Note: *,**, and *** indicate the significance level at 1%, 5%, and 10%.

After we estimate equations (9)-(12) in order to get error correction term (ECM), we then impose the lagged ECM term (ECM_{t-1}) in the estimated equations (13)-(16). Table V and VI present the short run dynamic coefficients and the lagged ECM term coefficients. The short-run coefficients indicate the existence of the short-run causality among these variables. The coefficients of ECM_{t-1} express the speed of adjustment and how fast variables adjust to long-run equilibrium (Saboori et al, 2012).

The coefficients on ECM_{t-1} are negative and statistically significant in the cases of total energy consumption (excluding renewable energy) (= -0.757) and of total energy consumption (including renewable energy) (= -0.790). The significant negative coefficient on ECM_{t-1} affirms the existence of a long-run relationship between these three variables in Thailand. The value of coefficients mean that any departures from the equilibrium between variables will reach the long-run equilibrium at speed of 75.7% and 79.0% annually, respectively.

Overall, the short run dynamic coefficients on total energy consumptions (ΔlnE) (both excluding and including renewable energy (= 0.822 and 0.697)), are statistically significant, indicating significant trade-off between CO_2 emissions and energy consumptions in the short run in Thailand. Then, if we focus on particular sectors, the short run dynamic coefficients in agriculture, manufacturing, and power generation sectors are not statistically significant, but statistically significant in resident, transportation, and other sectors. Therefore, there is trade-off between CO_2 emissions and energy consumptions in only resident, transportation, and other economic sectors in the short run.

Table V shows that there is non-existence of short-run relationship between CO_2 emissions and income in only industry sector. However, Table VI presents that there are significant positive and negative coefficients of income (ΔlnY) and income squared ($\Delta(\ln Y)^2$), respectively. This result supports the existence of EKC hypothesis in the short run for all economic sectors, except in other economic sectors.

Table V: Estimated Long-run and Short-run Effect of CO_2 Emissions Classified by Source of CO_2 Emissions

Dependent $f(CO_2\|E,Y,Y^2)$	**Total Exclude Renewable Energy**			**Total Include Renewable Energy**	
	Total CO_2 emissions	Power generation	Industry	Total CO_2 emissions	Power generation
Constant	0.0059	0.0284**	-0.0096	0.0068	0.0350**
ΔlnE	0.8220*	-0.2299	1.6949*	0.6968*	-0.2427
ΔlnY	6.2945*	19.2175*	-3.875	8.3272**	21.2967*
ΔlnY^2	-0.2879*	-0.8455*	0.1713	-0.3751**	-0.9520*
ECM_{t-1}	-0.7577*	-0.7744*	-0.4656*	-0.7903**	-0.7851*
Diagnostic test statistics					
R^2	0.9448	0.7445	0.91	0.8751	0.7684
F-test(prob)	89.88	19.23	53.96	36.7953	17.42

Note: *,**, and *** indicate the significance level at 1%, 5%, and 10%.

Table VI: Estimated Long-run and Short-run Effect of CO_2 Emissions Classified by Types of Energy Consumption

Dependent $f(CO_2\|E,Y,Y^2)$	**Total Energy Consumption (excluding renewable energy)**	**Total Energy Consumption (including renewable energy)**	**Agriculture**	**Manufacturing**	**Resident**	**Transportation**	**Other Economic Sectors**
Constant	0.0059	0.0069	0.0165**	0.0162***	0.0185**	0.0153**	0.0140
ΔlnE	0.8220*	0.6968*	0.0376	-0.0233	-0.1954**	0.1712*	0.2417*
ΔlnY	6.2945*	8.3271**	12.5193*	12.3745*	12.5198*	10.1919*	0.9275*
ΔlnY^2	-0.2879*	-0.3751**	-0.5441*	-0.5356*	-0.5510*	-0.4366*	-0.0877
ECM_{t-1}	-0.7577*	-0.7903**	-0.8956*	-0.8823**	-0.9802**	-0.8879*	-0.6613
Diagnostic test statistics							
R^2	0.9448	0.8751	0.8197	0.8198	0.8506	0.8637	0.8056
F-test(prob)	89.8788	36.7953	23.8728	23.8797	29.8964	33.2578	21.7517

Note: *,**, and *** indicate the significance level at 1%, 5%, and 10%.

Table VII: Estimated Long-run and Short-run Relationship between CO_2 Emissions, Energy Consumption, and Income Classified by Types of Energy Consumption

Variables	Long Run	Short Run				Diagnostic test statistics	
	ECM_{t-1}	$\Delta lnCO_2$	ΔlnE	ΔlnY	ΔlnY^2	R^2	F-test
Total Energy Consumption (excluding renewable energy)							
$\Delta lnCO_2$	-0.7577*	-	0.8220*	6.2945*	-0.2879*	0.945	89.9
ΔlnE	-0.6110**	0.7855*	-	-2.2099	0.1127	0.932	72.1
ΔlnY	-0.4632	0.0401*	-0.0076	-	0.0457*	0.999	8840.2
ΔlnY^2	-0.4560*	-0.8733*	0.2191	21.8190*	-	0.999	8223.7
Total Energy Consumption (including renewable energy)							
$\Delta lnCO_2$	-0.7903**	-	0.6968*	8.3271**	-0.3751**	0.875	36.8
ΔlnE	-0.1669	0.3578*	-	1.4564	-0.0434	0.870	35.3
ΔlnY	-0.3371**	0.0243**	0.0120	-	0.0456*	0.999	7466.2
ΔlnY^2	-0.3367**	-0.4998**	-0.2112	21.8304*	-	0.999	6919.3
Agriculture							
$\Delta lnCO_2$	-0.8956**	-	0.0376	12.5193*	-0.5441*	0.820	23.9
ΔlnE	-1.2956*	0.3920**	-	-1.7853	0.0710	0.705	12.5
ΔlnY	-0.3396*	0.0271*	0.0158***	-	0.0457*	0.999	6608.0
ΔlnY^2	-0.3263**	-0.5452*	-0.3512***	21.8116*	-	0.999	6160.3
Manufacturing							
$\Delta lnCO_2$	-0.8823**	-	-0.2333	12.3745*	-0.5356*	0.820	23.9
ΔlnE	-0.4935*	-0.1701	-	-12.6852	0.6720***	0.653	9.9
ΔlnY	-0.2851**	0.3182*	-0.0023	-	0.0457*	0.999	7382.4
ΔlnY^2	-0.2669**	-0.6405*	0.0673	21.7684*	-	0.999	6946.1
Resident							
$\Delta lnCO_2$	-0.9802**	-	-0.1954**	12.5198*	-0.5510*	0.851	29.9
ΔlnE	-0.3145***	-0.8393**	-	7.0429	-0.3198	0.441	4.1
ΔlnY	-0.3078**	0.0336*	-0.0016	-	0.0454*	0.999	7331.4
ΔlnY^2	-0.2843**	-0.6840*	0.0391	21.9367*	-	0.999	6716.7
Transportation							
$\Delta lnCO_2$	-0.8879**	-	0.1712**	10.1919*	-0.4366*	0.864	33.2
ΔlnE	-0.7746*	1.2515*	-	3.5353	-0.2259	0.573	7.0
ΔlnY	-0.2732**	0.0342*	-0.0008	-	0.0454*	0.999	6957.6
ΔlnY^2	-0.2549**	-0.6806*	0.0009	21.9108*	-	0.999	6492.1
Others							
$\Delta lnCO_2$	-0.6613	-	0.2417*	0.9275*	-0.0877	0.806	21.7
ΔlnE	-0.7647*	1.3107*	-	-1.3057*	0.2307	0.588	7.5
ΔlnY	-0.3150***	0.7652*	-0.1746**	-	0.0269	0.782	18.9
ΔlnY^2	-0.5397*	-0.1050	0.0454	0.0343	-	0.353	2.8

Note: *,**, and *** indicate the significance level at 1%, 5%, and 10%.

Table VIII: The Summary of Short-Run Causality Results

	$CO_2 \leftrightarrow$ Energy	$CO_2 \leftrightarrow$ Income	$CO_2 \leftrightarrow$ Income Squared	Energy$\leftrightarrow$ Income
1. Total Energy Consumption (excluding renewable energy)	bi-directional	bi-directional	bi-directional	no relationship
2. Total Energy Consumption (including renewable energy)	bi-directional	bi-directional	bi-directional	no relationship
- Agriculture	one-directional	bi-directional	bi-directional	no relationship
- Manufacturing	no relationship	bi-directional	bi-directional	no relationship
- Resident	bi-directional	bi-directional	bi-directional	no relationship
- Transportation	bi-directional	bi-directional	bi-directional	no relationship
- Other Economic Sectors	bi-directional	bi-directional	no relationship	bi-directional

Note: the significance level at 5%

Table VII presents the estimated long-run and short-run relationship between CO_2 emissions, energy consumption, and income by using ARDL approach. Table VIII explicitly summarizes the estimated results from Table VII in order to present the short-run causality results. To sum up, the relationship between CO_2 emissions and energy consumption is bi-directional causality overall, except in agriculture and manufacturing sectors. There is unidirectional causality running from CO_2 emissions to energy consumption in the agriculture sector. However, there is no causal relation in manufacturing sector as a result of government supporting policy on the use of renewable energy in this sector. Finally, we find no bi-directional causality between energy consumption and income in all sectors, except in other economic sectors.

5. CONCLUSION

This paper intends to investigate the causal relationship between CO_2 emissions, energy consumption, and income and to test whether there is an existence of the Environmental Kuznets Curve (EKC) hypothesis in Thailand. By applying an Autoregressive distributed lag (ARDL) cointegration analysis following Pesaran et al (2001), Narayan (2004), Pao and Tsai (2010), Menyah and Wolde-Rufael (2010), and Saboori and Sulaiman (2013), our findings show the existence of EKC hypothesis in the short run and in the long run.

Then, we extend our model by classifying by the source of CO_2 emissions and by the type of energy consumption. The results indicate no significant relationship between energy consumption and CO_2 emissions in agriculture and manufacturing sectors. In addition, our main findings confirm long-run relationship between CO_2 emissions, energy consumption, and income in Thailand. The short run dynamic results show trade-off between CO_2 emissions and energy consumption overall. However, there is no trade-off in agriculture, manufacturing, and power generation sectors due to the high usage of renewable energy consumption in these sectors.

This finding confirms the success of government policy on promoting the use of renewable energy, which leads to a constantly increase in domestic renewable energy consumption in the country, especially in agricultural and manufacturing sectors (Department of Alternative Energy Development and Efficiency, 2012a). The Thai government has provided an incentive to the private sector to use renewable energy in power generation since 1992 (Energy Policy and Planning Office, 2011). Furthermore, the National Energy Policy Council (NEPC) has implemented the national plan and policy regarding energy conservation in order to encourage these two sectors to use more renewable energy in the production process since 2006. For example, the campaign on promoting the use of gasohol and biodiesel in agriculture sector and the incentive provision for the establishments in manufacturing sector to produce clean energy and preserve environment (Energy Policy and Planning Office, 2006).

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