**The relationship between $CO_2$ emissions, energy consumption, and income in Thailand: an ARDL approach**

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## Abstract

This paper investigates the causal relationship between $CO_2$ 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. The empirical results suggest that there is an existence of non-linear relationship between $CO_2$ emissions and income, which presents the validity of Environmental Kuznets Curve (EKC) hypothesis in Thailand. The causality results indicate a long-run causal relationship between $CO_2$ emissions, energy consumption, and income. In the short run, there exist bi-directional causality between energy consumption and $CO_2$ emissions and between income and $CO_2$ emissions.



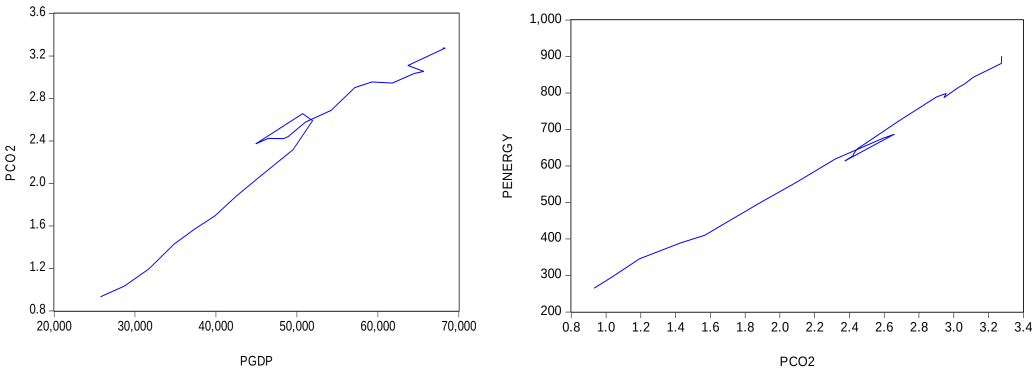
**Keywords:** Energy consumption, Pollution, Environmental Kuznets Curve, Thailand

**JEL Classification:** C32, Q43, O13

## INTRODUCTION

Over the past thirty years, Thailand has experienced a rapid economic growth; even Thai economy faced the huge crisis in 1997, the country has recovered and had a high growth rate since 1999. Along with an expansion of Thai economy, the demand for energy, which reflects from the domestic energy consumption, has grown dramatically. Furthermore, this development causes an increase in demand for commercial energy, in which it leads to a large produce of Carbon dioxide ($CO_2$) emissions to the society. The figure 1 shows a positive relationship between $CO_2$ emissions, Gross Domestic Product (GDP) and energy consumption from 1988-2011.

Figure 1: The relationship between $CO_2$ emissions, GDP, energy consumption in Thailand (1988-2011)




Source: The Energy Statistics of Thailand (2012)

There are several studies examining the relationship between these three factors. Kraft and Kraft first (1978) studied the situation between energy consumption and economic growth (or output) during 1947-1974 in the United States. Later then, there are several studies investigating this issue in the other countries: 4 Asian Countries [India, Indonesia, Philippines, and Thailand] (Asafu-Adjaya, 2000), 22 OECD Countries (Lee et al, 2008), Turkey (Kaplan and Ozturk, 2011). Furthermore, adding the pollution emissions into this situation, Ang (2007) found there exist a long-run relationship between $CO_2$ emissions, energy consumption and output in France; later, Pao and Tsai (2010) found in BRIC countries and Pao and Yu (2011), Pao and Tsai (2011), and Menyah and Wolde-Refael (2010) found in Russia, Brazil, South Africa, respectively.

For Thailand, we found only one empirical study by Asafu-Adjaya (2000) reporting bi-directional causality between energy consumption and income during 1971-1995. However, there is no empirical study investing the relationship between economic growth, energy consumption and $CO_2$ emissions in Thailand.

Our paper first intends to fill a gap in this area in Thailand by investigating the relationship between these three variables in the long run and short run during 1986-2012. We will apply Autoregressive distributed lag (ARDL) cointegration analysis in the estimation following the use of ARDL technique of Pesaran et al (2001) in empirical studies of other countries: Malaysia (Saboori et al, 2012) and Turkey (Halicioglu, 2009).

In addition, our paper also tests whether Environmental Kuznets Curve (EKC) hypothesis existed in Thailand following the approach used in the studies of 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).

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 and discussion. Finally, section 5 is a conclusion.

## 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. 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 per capita.

First, the $CO_2$ emissions are calculated from the use of energy in Thailand following the criteria of the 2006 Guidelines of the Intergovernmental Panel on Climate Change (IPCC). Therefore, $CO_2$ emissions mean the amount of $CO_2$ emission from energy consumption, in which it covers in 4 major economic sectors including power generation, transportation, industry and other economic sectors (including the residential, agricultural and commercial sectors).

Second, the energy consumption refers to the final modern energy consumption data, which comes from four main source including (1) solid fossil fuel (coal and lignite), (2) petroleum products (gasoline, diesel, fuel oil, liquefied petroleum gas, jet petroleum and kerosene), (3) natural gas in industry, and (4) electricity (power generation from Small Power Producers).

Finally, the Gross Domestic Product (GDP) per capita data are collected from the Office of the National Economic and Social Development Board (NESDB).

## METHODOLOGY

To serve two main purposes of our study, we first apply Autoregressive Distributed Lag (ARDL) in cointegration analysis to examine the short-run and long-run relationship between $CO_2$ emissions, energy consumption, and GDP per capita, and then employ a simple Ordinary Least Squares (OLS) regression to check whether there is an existence of Environmental Kuznets Curve (EKC) in Thailand.

### Mathodology Part 1: Investigating the long-run and short-run relationship

We apply an Autoregressive distributed lag (ARDL) in cointegration analysis in the estimation. The ARDL approach consists of two steps in the estimation:

- Step 1: In order to check whether there is a relationship of 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 ( $\lambda_i$ ):

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

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

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

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

Where $\alpha$ 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 (baht as a unit), $E_t$ is per capita energy consumption at time t (measured in tons of oil equivalents), and $\varepsilon$ is error term.

Note that j denotes a lag length set at 0 and 1 (Since we have a limited number of observations, the lag length we use will restrict to 1).

We are interested in $\lambda_i$ which is a long run coefficient and $\gamma_i$ which is a short run coefficient.

We then proceed on using a F-test for testing the existence of long-run relationship.

The null hypothesis for no cointegration among these variables 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 F-test is greater than the upper bound critical value, we rejected the null hypothesis.

It means that there exists long-run relationship among these three variables.

- Step 2: We first estimate equations (9)-(12) to receive Error Correction Term (ECM).

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

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

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

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

Then, we impose ECM in the estimating equations (13)-(16) to obtain the short run dynamic parameters.

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

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

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

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

Where $ECM_{t-1}$ is error in the previous period, $\rho, \eta, \sigma, \psi$ are the short run dynamic coefficients, $\vartheta$ is the speed of adjustment.

## Methodology Part 2: Testing Environmental Kuznets Curve (EKC) hypothesis

This section will test whether there is an existence of Environmental Kuznets Curve (EKC) hypothesis in Thailand by employing an ordinary Least Squares (OLS) regression on the equation (17).

$$\ln CO_t = \alpha + \beta_1 \ln Y_t + \beta_2 \ln Y_t^2 + \beta_3 \ln E_t + \varepsilon_t \qquad (17)$$

Where $CO_t$ is $CO_2$ emissions per capita at time t (measured in tons), $Y_t$ is GDP per capita at time t (measured in baht), $E_t$ is energy consumption per capita at time t (measured in kg of oil equivalent ), and $\varepsilon_t$ is the standard error term.

If there is an existence of EKC in Thailand, we expect $\beta_1 > 0$ and $\beta_2 < 0$ (or an inverted U-Shaped relationship).

## RESULTS

In order to investigate the existence long run relationship between Co2 emission, income and energy consumption, the ARDL approach is estimated as equations (1)-(4) by ordinary least squares (OLS). The results show there exist long run relationship between $CO_2$ emission, income and energy consumption as in table 1.

**Table 1: F-statistics of the null-hypothesis**

| Dependent Variable | F-statistic | Results |
|---|---|---|
| $F(Co_2 \mid E, Y, Y^2)$ | 7.9473 | Cointegration |
| $F(E \mid Co_2, Y, Y^2)$ | 4.3105 | Cointegration |
| $F(Y \mid Co_2, E, Y^2)$ | 38.5974 | Cointegration |
| $F(Y^2 \mid Co_2, E, Y)$ | 38.9114 | 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 values are taken from Table Case III (Narayan, 2005 p.1988)

The null hypothesis of no cointegration is rejected. In other words, all values of the calculated F-test are higher than the bound critical value (Narayan , 2005). As a result, we conclude that there exist long run relation between $CO_2$ emissions, energy consumption, and income.

Then, after we estimate equations (9)-(12) in order to get ECM, in which these are long-run coefficients as indicated in table 2.

**Table 2: Estimated long-run coefficients**

| **Dependent Variable** | **Constant** | **ln(Co$_2$)** | **ln(E)** | **ln(Y)** | **ln(Y$^2$)** | **R-Square** |
|---|---|---|---|---|---|---|
| ln(Co$_2$) | -36.0350* (-7.28) | - | 1.0082* (13.17) | 5.6493* (6.11) | -0.2624* (-6.43) | 0.9984 |
| ln(E) | 27.0391* (4.36) | 0.8757* (13.17) | - | -4.1119* (-3.74) | 0.1976* (4.07) | 0.9984 |
| ln(Y) | 5.9889* (57.55) | 0.1096* (6.11) | -0.0918* (-3.74) | - | 0.0455* (78.70) | 0.9999 |
| ln(Y$^2$) | -131.4031* (-58.28) | -2.4498* (-6.43) | 2.1245* (4.08) | 21.8985* (78.70) | - | 0.9999 |

*Significant at 5%

Then, we impose ECM in the equations (13)-(16), we later then obtain short-run coefficients and speed of adjustment as indicated in table 3. The causality results indicate there exists bi-directional causality between energy consumption and $CO_2$ emissions and between income and $CO_2$ emissions in the short-run.

## Table 3: Estimated short run coefficients

| Dependent Variable | Short run independent | | | | Speed of Adjustment | Diagnostics | | |
|---|---|---|---|---|---|---|---|---|
| | $\Delta\ln(CO_2)$ | $\Delta\ln(E)$ | $\Delta\ln(Y)$ | $\Delta\ln(Y^2)$ | ECM | $X^2_{AUTO}$ | $X^2_{ARCH}$ | $X^2_{NORM}$ |
| $\Delta\ln(Co_2)$ | - | 0.8220* (6.91) | 6.2945* (3.07) | -0.2879* (-3.04) | -0.7577* (-3.65) | 0.0573 | 0.4933 | 0.9574 |
| $\Delta\ln(E)$ | 0.7855* (7.18) | - | -2.2099 (-1.00) | 0.1127 (1.11) | -0.6111* (-2.74) | 0.1825 | 0.5801 | 0.8996 |
| $\Delta\ln(Y)$ | 0.0401* (3.05) | -0.0076 (-0.50) | - | 0.0457* (98.11) | -0.4633* (-3.75) | 0.1086 | 0.4285 | 0.8047 |
| $\Delta\ln(Y^2)$ | -0.8733* (-2.99) | 0.2191 (0.65) | 21.8190* (97.40) | - | -0.4560* (-3.6766) | 0.0990 | 0.5109 | 0.7293 |

*significant 5%,

Finally, we estimated equation (17) and found that there exists a validity of Environmental Kuznets Curve (EKC) hypothesis in Thailand.

## CONCLUSION

This paper first intends to investigate the causal relationship between $CO_2$ emissions, energy consumption, and income in Thailand using the data between 1986 and 2012 from the Energy Statistics of Thailand, Energy Policy and Planning Office (EPPO), Ministry of Energy, Thailand. By applying an Autoregressive distributed lag (ARDL) cointegration analysis following Pesaran et al (2001) and Narayan (2004) in the estimation, we found a long-run causal relationship between $CO_2$ emissions, energy consumption, and income. In the short run, there exist bi-directional causality between energy consumption and $CO_2$ emissions and bi-directional causality between income and $CO_2$ emissions. In addition, we also test whether there is an existence of non-linear relationship between $CO_2$ emissions and income following Dinda (2004) and Ang (2007). We found an existence of inverted U-curve between $CO_2$ emissions and income, which presents the validity of Environmental Kuznets Curve (EKC) hypothesis in Thailand.

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