



## **An Application of Quadratic EKC model: Energy Use, Economic Development, and Environmental Quality for Thailand**

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### **ARTICLE INFO**

#### **Article History:**

Received: September 10, 2020

Revised: November 23, 2020

Accepted: December 27, 2020

Available Online: December 31, 2020

#### **Keywords:**

Environment quality

Energy used

Growth of the economy

Renewable energy

Non-renewable energy

ARDL

### **ABSTRACT**

This study examines the validation the relationship of environmental and energy for Thailand. Further this study examined the impact of economic growth, non-renewable and renewable energy and FDI on environment, with the help of time series data from 1990 to 2018 with ecological damage indicator, i.e., emission of carbon dioxide (CO<sub>2</sub>). This study applied Autoregressive (ARDL) Distributed Lag model for testing the cointegration in the model. In the long run, the results of this study confirm the existence of cointegration in the model. However, the negative effect of growth on the environment confirms the existence of the Kuznets Environmental Curve (EKC), which means that economic growth harms Thailand's environment. Renewable energy and foreign direct investment are the key aspects that reduce environmental degradation in Thailand during the study period. Therefore, the government must redouble its efforts to reduce carbon dioxide CO<sub>2</sub> emissions, perhaps through regulatory intervention or mandatory renewable energy applications for individual household and industrial segments. For example, the manufacturing sectors, iron, and steel must prioritize, reducing the high non-renewable energy consumption for those which are renewable. The government must introduce specific measures and campaigns for environmental protection for future generations as well as introduce taxes for polluters. Another relevant recommendation is to create an industry that relies on low energy consumption compared to high productivity levels.



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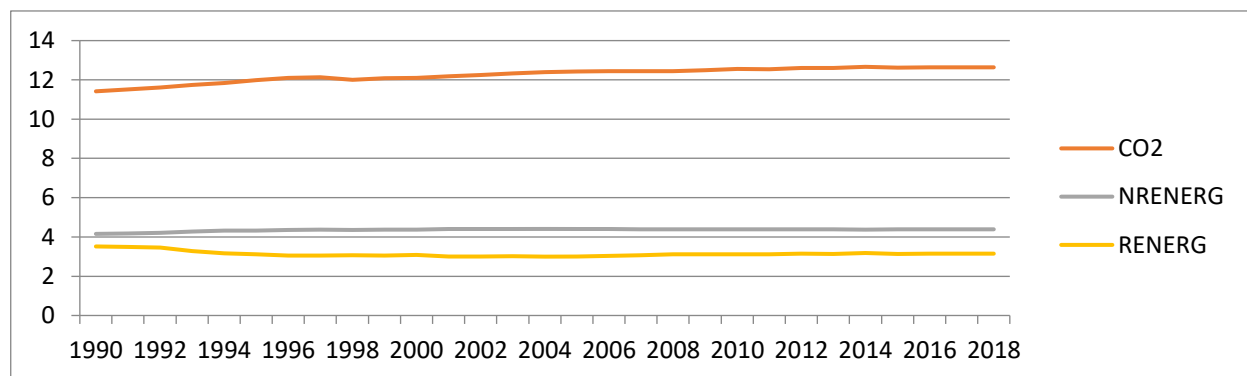
## **1. Introduction**

We could not reject the fact that our environment is continually altering in the global context. Environmental change is frequent, and therefore does the need to quickly recognize the issue as a vast and heavy inflowing of natural phenomena, cooling periods and global warming, varied types of weather conditions show, and much more. Although our planet is facing environmental changes which governments need to be aware of, every day governments are experiencing the lack of capital for existing and new financial challenges concerning the environment all across the world. It is roughly estimated that some challenges are small and bear few effects on the environment but at the same time, some are heavily affecting the environment. In the case of Thailand, the impact of climate change is increasingly known by everyone, and several policy procedures have been

established to lessen the impact of changing climates such as spreading the utilization of renewable energy and efficient energy. In terms of energy and climate, Thailand has recorded 12.62-kiloton in 2016 and 12.64 kilotons in 2015, an increase compared to 2015, so it concluded that with the passage of time carbon emission are increasing (World Bank, 2020). This specifies that Thailand’s EPI for energy and climate has developed for the last 5 to 10 years as recorded.

**Table 1**  
**CO2 emission, GDP, Renewable and Non-renewable Energy in Thailand**

Years	GDP	FDI	CO2	NRENERG	RENERG
1990	7.319165	1.051943	11.41648	4.156348	3.51569
1991	7.447993	0.717927	11.51075	4.175805	3.496981
1992	7.564178	0.639687	11.60622	4.20269	3.460214
1993	7.700464	0.336241	11.73566	4.272962	3.274345
1994	7.820611	-0.0709	11.84337	4.319309	3.172531
1995	7.953875	0.200176	11.99011	4.330501	3.122339
1996	8.020922	0.243862	12.10213	4.354599	3.052277
1997	7.811236	0.952965	12.13306	4.367369	3.056302
1998	7.520685	1.861721	12.00974	4.363939	3.07505
1999	7.617394	1.572321	12.07895	4.365658	3.059291
2000	7.604763	0.979501	12.10775	4.366195	3.090503
2001	7.54606	1.437991	12.1787	4.396846	2.997511
2002	7.647876	0.911541	12.24684	4.405845	2.999073
2003	7.766042	1.23429	12.32196	4.407103	3.012805
2004	7.886128	1.220676	12.40159	4.407417	2.996965
2005	7.970416	1.467779	12.41903	4.40444	3.008273
2006	8.122534	1.391594	12.43737	4.401357	3.029503
2007	8.287282	1.188931	12.43896	4.396328	3.073214
2008	8.384726	1.077814	12.43894	4.389136	3.113119
2009	8.345931	0.822378	12.49726	4.383695	3.120485
2010	8.532346	1.463997	12.5494	4.38194	3.120375
2011	8.611069	-0.40483	12.53652	4.384447	3.124808
2012	8.676004	1.176982	12.60013	4.384051	3.148016
2013	8.727173	1.3327	12.61183	4.39033	3.133039
2014	8.691463	0.20004	12.66417	4.380012	3.182034
2015	8.672494	0.799616	12.62577	4.384807	3.129523
2016	8.695944	-0.38346	12.63417	4.385058	3.148488
2017	8.791515	0.569381	12.64151	4.383295	3.153585
2018	8.892002	0.964507	12.63384	4.384387	3.143919



**Figure 1: Time trend of Carbon emission with renewable and non-renewable energy in the case of Thailand.**

According to graph 1, CO2 emission has an increasing trend during the given years. They are also increasing in nonrenewable energy and renewable energy in Thailand. The use of nonrenewable energy (which is measured by fossils fuel energy of total energy) is higher than the renewables in Thailand according to WDI data (World Bank, 2020).

Over the last few years, the correlation association of conservational pollution and the growth of the economy is the main focus of the determined investigation. Therefore, inverse U-shaped affiliation among quality of the atmosphere and economic activities is rarely discussed in previous empirical studies; per capita income is used as an indicator for

economic growth. Hence, in the first step of growth and environment, income per capita rises cross beyond a rotating point. So, the association between income and the level of income disparity measured by Kuznets, so-called Environmental Kuznets Curve (EKC's).

Therefore, several empirical kinds of investigation on the economic effect and energy on the environmental quality were discussed by these studies (Akboştañcı, Türüt-Aşık, & Tunç, 2009; Ben Jebli, Ben Youssef, & Ozturk, 2013; Fodha & Zaghdoud, 2010; Jaunky, 2011; Nawaz, Azam, & Bhatti, 2019). To identify the relationships among the economic growth, energy utilization, and environment there used many linear and quadratic models to estimate the inverted U-shaped curve.

The current research uses the quadratic model in an equation to estimate the association between the use of energy and the environment for Thailand. For this purpose, this study employed the standard unit root test to authenticate the order of indicators then estimated the general model by Auto-Regressive Distributive lag (ARDL) model. This paper offers new researches into the growth of economy and energy utilization literature, and the study provides the vital tools to control the environment for research institutes, government, and international organizations to economic progression, control environment quality and energy used.

## **2. LITERATURE REVIEW**

### **2.1. Theoretical Literature**

The best suitable measure of the environment or ecological influence on the growth of the economy is the Environmental Kuznets curve (EKC's) theory that has a U-shaped affiliation. The theory explains that when a country experienced the early stage of growth, it required more CO<sub>2</sub> emission growth and intensive consumption of energy. Conversely, when development status attained, consumption of energy declines with social awareness and better technology on protecting the environment.

### **2.2. Empirical Works of literature**

The causal relation between the emission of CO<sub>2</sub> and other variables discussed in various studies from different economies. Ben Jebli et al. (2013) explored the Environmental Kuznets Curve (EKC) hypothesis to determine unidirectional causality relationship existence of GDP, trade openness, non-renewable energy & renewable energy, and CO<sub>2</sub> productions. Therefore, long-run evaluations revealed that trade openness and non-renewable energy positively affect the emission of CO<sub>2</sub> and renewable energy negatively affects CO<sub>2</sub> emission. While this influences are statistically insignificant when imports are used in the model. Fodha and Zaghdoud (2010) for Tunisia, explored the connections between the income per capita as a measure of environment and growth (CO<sub>2</sub>, and SO<sub>2</sub> emissions), for cointegration investigation by using time series analysis. Therefore, the research determined the association between GDP (gross domestic product) and SO<sub>2</sub> radiations in the existence of U-shaped connections, therefore the affiliation is monotonically increasing between GDP and emission of CO<sub>2</sub>. Therefore, SO<sub>2</sub> emissions and gross domestic products (GDP) have unidirectional causality in the short/long run.

Many experimental studies review a single country or more than one country known as a balanced panel in the Environmental Kuznets curves hypothesis. Some studies observe the dynamic relation among environmental quality and economic growth such as (Akboştañcı et al., 2009; Bakhtyar, Kacemi, & Nawaz, 2017; Jaunky, 2011; Narayan & Narayan, 2010), while others researches among environment, growth, and energy (Apergis & Payne, 2009; Sadorsky, 2009). Several empirical studies take trade openness as a useful variable and measure its dynamic relation with productivity, CO<sub>2</sub> releases, and non-renewable energy (Halicioğlu, 2009; Jalil & Mahmud, 2009; Jayanthakumaran, Verma, & Liu, 2012; Shahbaz, Ozturk, Afza, & Ali, 2013). Ben Jebli et al. (2013) identified that for interest, most essential variables are renewable energy, the study inspects vigorous association between output, foreign and trade liberalization, CO<sub>2</sub> emissions and non-renewables for OECD nations panel.

Ang (2007) examined the vigorous association among energy used, level of output, and CO<sub>2</sub> emissions per capita for France. Hence, the study disclosed that the existence of

the long-run causality of growing energy use as of economic progression for carbon dioxide emissions growth. Thus, the study also proved that the growth in output causes massive use of energy and causation effect in the short-run; however, the U-shaped environmental Kuznets curve (EKC's) hypothesizes tested logically and clearly. Arouri, Youssef, M'henni, and Rault (2012) explored the association among emission of CO<sub>2</sub> per capita to check the environmental degradation, real GDP, and energy used for the 12 North African nations along with the Middle East. The study determined that there is a quadratic association among GDP and emission of CO<sub>2</sub>. At the same time, the energy used has a increasing effect on the per capita emission of carbon emanation for the whole regions of study area. United Arab Emirates (UAE), Tunisia and Morocco don't second with the assumptions of EKC's curve in long run income elasticity.

Halicioğlu (2009) discussed the dynamic fundamental relations among energy used per capita emission of CO<sub>2</sub>, international trade, and productivity for Turkey, using the ARDL co-integration bounds test technique. Hence, results provide proof of co-integration existence in the long run. The relations explained that emission of CO<sub>2</sub> is provided by the income, massive energy used, and international trade in the long run. Consequently, the long-run association defines the country's level of income, determined the country's energy used, CO<sub>2</sub> emissions and international trade. Additionally, income is an important variable to check the emission of CO<sub>2</sub> in Turkey, observed by international trade and energy used.

Chindo, Abdulrahim, Waziri, Huong, and Ahmad (2015) inspected the connection between GDP, emission of carbon discharge and energy utilization, and GDP in Nigeria. The study used the ARDL technique to co-integration; the study provides an analysis of the long-run affiliation amongst the mentioned indicators. Hence, emission of CO<sub>2</sub> in the long and short-run has an increasing and significant impression on GDP, although in short-run energy used to establish a significantly negative effect on GDP.

(Alkathlan & Javid, 2013) explored the affiliation among CO<sub>2</sub> releases, economic development, and use of energy at the increasing positive multiple periods in Saudi Arabia from the time period of 1980-2011. Consequently, the findings of the analysis are long run that CO<sub>2</sub> emissions to income elasticity are positive and significant as well as higher than anticipated in short-run income elasticity. Therefore, the outcomes of the study indicate that a rise in income growth per head leads to higher CO<sub>2</sub> releases, which supports the confidence that there is increasing monotonically association between income growth and CO<sub>2</sub> releases as well as planned in addition to the consume of fuel to the consumption of energy models. Furthermore, the models of gases, both in the long and short-run elasticity of income and carbon productions, are negatively related.

Ben Jebli et al. (2013) reported the co-integration panel method for analyzing the causation relation among energy used, renewable and non-renewable, trade liberalization, and per capita CO<sub>2</sub> productions for a panel of 25 OECD nations. Meanwhile, in the long run Granger causation used to examine the causal relationship between renewable and non-renewable, per capita output, trade liberalization to per capita CO<sub>2</sub> releases. Though, the long run assessments disclose that trade and renewable energy used per capita negatively influence per capita emission of CO<sub>2</sub>, and EKC's U-shaped hypothesis statements are valid. Correspondingly, by present research (Rafindadi, Muye, & Kaita, 2018) exposed in Gulf Cooperation Council (GCC) economies over the period 1990 to 2014, in a reduction in CO<sub>2</sub> emissions FDI (Foreign Direct Investment) used as instrument variable. In contrast, consumption of energy use to raise it.

### **3. Methodology**

#### **3.1. Data and variable measurement**

Annual time series data was used in this study for the periods from 1990 to 2018 and come from WDI (World Bank, 2020). The data relates to the following variables: per capita emission of CO<sub>2</sub> (and are used as an endogenous variable and also as environmental degradation indicator with respect to the rest of the explanatory variables), GDP represents GDP per capita, RENERG represents renewable energy utilization in metric tons unit, NRENERG represents a non-renewable utilization of energy worthy even in metric tons per inhabitant, FDI represents foreign direct investments.

### 3.2. Model Specification

Initially, a stationary test is used to test the unit-root of the data (to avoid false/spurious regression). Therefore, the unit-roots of the indicators are verified for both "trends" and "first differences" using the Dickey-Fuller stationarity test (ADF). Hence, a combination of stochastic procedures is used when variables' integration order is committed (i.e., at the level  $I(0)$  or the first difference  $I(1)$  from the outcomes of the unit root testing). If the results indicate that data has a unit root, then we move towards the ARDL methodology. This procedure has been frequently mentioned in the current empirical literature. It is more preferred than Johansen's cointegration technique, as it has the elasticity to modify lengths or lags intervals (which can modify and calculate by AIC and SIC criteria). Therefore, in order to escape endogeneity and validate even with smaller samples in order to obtain healthier results. Therefore, the mathematical illustration of the general model is as follows:

$$G_t = f(C_t, E_t) \tag{1}$$

Following publications such as Ang (2007); Halicioglu (2009); Jayanthakumaran et al. (2012) used the Autoregressive Distribution lag model (ARDL) which help to find out the effect of energy used, economic development and quality of the environment in Thailand as follows:

$$CO_2 = \delta_0 + \delta_1 ECON + \delta_2 GDP + \delta_3 GDPSQ + \epsilon_t \tag{2}$$

Whereas CO<sub>2</sub> corresponds to carbon dioxide emissions (calculated in kilograms per inhabitant); ECON is the consumption of energy with the unit - kg of oil equivalent per capita; GDP is income, GDPSQ is square of income, and is the end of the regression error. The parameters  $\delta_1, \delta_2$  and  $\delta_3$  are the long-term elasticity of production of CO<sub>2</sub> concerning the utilization of energy, per capita real GDP & square per capita GDP respectively, therefore, symbol  $\delta_1$  should be positive, under environmental Kuznets, the assumption of the curve  $\delta_2$  should be positive during the sign  $\delta_3$  should be negative. The statistical insignificance of  $\delta_3$  suggests a monotonous increase in the emission of CO<sub>2</sub> and income relationship.

$$CO_{2t} = f(GDP_t, GDPSQ_t, RENERG_t, NRENERG_t, FDI_t) \tag{3}$$

However, the study also transmuted our research model by studying the variables in the quadratic equation of the Kuznets environment to perceive the long run affiliation amongst the variables as mentioned above, as shown in equation 4;

$$CO_{2t} = \theta_0 + \theta_1 GDP_t + \theta_2 GDPSQ_t + \theta_3 RENERG_t + \theta_4 NRENERG_t + \theta_5 FDI_t + \epsilon_t \tag{4}$$

In equation (4), CO<sub>2</sub> per capita emission of CO<sub>2</sub> (as an endogenous variable), GDP represents per capita income, GDPSQ represents the quadratic form of the model and represents the effect of income square, RENERG represents use of renewable energy from the total use of energy, NRENERG represents consumption of non-renewables from the total, FDI represents foreign direct investment and t represents the time period. For the subsequent stages of the cointegration test, there are numerous approaches available for computing results and analysis. Henceforth, an Engle-Granger method of (Engle & Granger, 1987), Johansen cointegration method of Johansen and Juselius, 1990 and ARDL bounds testing method by (Pesaran, Shin, & Smith, 2001). This investigation employed the ARDL bounds testing techniques because it evades the difficulties of endogeneity as well as the study produces improved results for smaller data sets and adds to assessment the coefficients, in the long run, using these equations.

$$CO_{2t} = \theta_0 + \sum_{i=1}^p \theta_1 \Delta CO_{2t-1} + \sum_{i=0}^p \theta_2 \Delta GDP_{t-1} + \sum_{i=0}^p \theta_3 \Delta GDP^2_{t-1} + \sum_{i=0}^p \theta_4 \Delta RENERG_{t-1} + \sum_{i=0}^p \theta_5 \Delta NRENERG_{t-1} + \theta_6 CO_{2t-1} + \theta_7 GDP_{t-1} + \theta_8 GDP^2_{t-1} + \theta_9 RENERG_{t-1} + \theta_{10} NRENERG_{t-1} + \epsilon_t \tag{5}$$

Where  $\epsilon_t$  represents IID error term,  $\theta_0$  shows an intercept, and  $\Delta$  represents a difference operator. From  $\theta_1$  to  $\theta_5$  indicate short-term parameters and long-term parameters are designated from  $\theta_6$  to  $\theta_{10}$ . Akaike information criteria (AIC) were used to select the optimal lag length and to check the co-integration presence between the variables mentioned above, and Bound test F-testing was used. The non-cointegration hypothesis is

$H_0: \theta_6 = \theta_7 = \theta_8 = \theta_9 = \theta_{10} = 0$  against the hypothesis of the existence of a co-integration relation among the indicators  $H_1: \theta_6 \neq \theta_7 \neq \theta_8 \neq \theta_9 \neq \theta_{10} \neq 0$ . al., Narayan and Narayan (2010) provided critical upper and lower limit values for both types of samples (30 to 80), respectively. If the higher critical value limit is less than the F-value, then the cointegration exists between variables while if the F-value falls under the lower critical bond limit, then the cointegration will not exist between variables. Nevertheless, the inference of inconclusiveness occurs if the F-value lies in between both limits.

## 4. Empirical results

### 4.1. Unit Root Tests

Before estimate cointegration with ARDL, a stationarity test is needed for all variables to control the degree of integration and confirmed by the statistical method of the increased Dickey-Fuller (ADF) test. Refer to Table 1 for the root unit test results.

**Table 2**  
**Augmented Dickey-Fuller test**

Order Variables	Critical value	Level	Prob.	First Difference		
		Cal. value		Critical value	Cal. value	Prob.
CO2	-2.97185	-3.83816**	0.007			
FDI	-3.58062	-3.76577**	0.0341			
GDP	-3.6032	-2.68025	0.252	-3.22923	-3.31687*	0.0849
GDPSQ	-3.58753	-2.10925	0.5179	-3.22923	-3.31778*	0.0847
NRENERG	-2.97185	-5.58974**	0.0001			
RENERG	-3.58062	-2.56178	0.2988	-3.58753	-4.33598**	0.0101

Note: \*\*\*,\*\* and \* show 1%, 5% and 10% level of significance respectively.

The outcomes of the Augmented Dickey-Fuller (ADF) test indicate that some variables are stationary at the level, and some are at the first difference. Consequently, some variables are integrated into a level  $I(0)$  range and some are first difference  $I(1)$ , so the next step is the beginning of the ARDL for the cointegration test of the model.

### 4.2. Cointegration Results

To inspect the co-integration within the indicators, this study uses the ARDL bound test (Narayan & Narayan, 2010), and the F-stat value is given in table 3. F-stat value is 8.58, which is higher than the lower and upper bound of 1% significance value which is 2.82 and 4.21. Results indicate that there exists the cointegration in the above non-linear equation.

**Table 3**  
**ARDL bond test**

F-statistic	Critical Value Bounds	
Sig. level	$I_0$ Bound	$I_1$ Bound
5%	2.14	3.34
1%	2.82	4.21

Table 3 shows the ARDL estimators' results according to the mentioned level of significance, respectively. One can see that the level of significance is 1%, or 5%, for mention coefficients. However, long run relationship is also verified by ARDL bond test. A further move to the long-run estimates of the model, which is analyzed by the ARDL and are given in table 4 and short-run estimates, are given in table 5.

As the natural logarithm is applied on the dataset of annual data analysis, the coherent long-run estimation of GDP, square of GDP, RENERG, NRENERG, TRAD, and FINDEV are economically equal to the CO2 elasticities in accordance with income, the square of income, consumption of renewable energy, use of nonrenewable energy, trade liberalization, & financial expansion. The estimation signs for the income and its square are positive and negative, respectively. Furthermore, GDP's marginal impact on the emission of CO2 shows that there is an increasing effect of emission of CO2 and its production, but in the long run, it has a decreasing effect and eventually becomes negative.

### 4.3. ARDL Long-run results

**Table 4**  
**Long run ARDL results**

Variable	Coeff.	SE	t-stats	Prob.
GDP	3.2972***	0.6023	5.4745	0.0009
GDPSQ	-0.2183***	0.0346	-6.3096	0.0004
RENERG	-0.9877**	0.2565	-3.8510	0.0063
NRENERG	4.9462***	0.4302	11.4979	0.0000
FDI	-0.0079	0.0121	-0.6500	0.5365

Note: \*\*\*,\*\* and \* show 1%,5% and 10% level of significance respectively.

It means the environment will be improved when a country increases the income from the specific threshold. By taking a look at these results, it is obvious that the EKC theory is valid for the countries using renewable energy. The presence of the EKC theory conforms to (Acaravci & Ozturk, 2010; Al-Mulali & Ozturk, 2016; Al-Mulali, Solarin, & Ozturk, 2016; Al-Mulali, Weng-Wai, Sheau-Ting, & Mohammed, 2015; Ang, 2007; Baek, 2015; Balaguer & Cantavella, 2016; Chiu & Chang, 2009; Heidari, Katircioğlu, & Saeidpour, 2015; Lean & Smyth, 2010; Nasir & Rehman, 2011; Pao & Tsai, 2011; Saboori & Sulaiman, 2013; Shahbaz, Khraief, Uddin, & Ozturk, 2014; Sulaiman, Azman, & Saboori, 2013; Tang & Tan, 2015).

The environment is infected by the use of energy, and it depends upon the sources of energy used. If the consumption of renewable energy increases, then it will reduce the emission of CO<sub>2</sub>. While nonrenewable energy consumption is directly proportional to the emission of CO<sub>2</sub>. However, the emission of CO<sub>2</sub> decreased by 0.9877%, with an increase in the 1% RENERG. Furthermore, the emission of CO<sub>2</sub> age increased to 4.96262% with an increase in 1% NREC. These results are similar through the already published researches (Al-Mulali et al., 2016; Bento & Moutinho, 2016; Bölük & Mert, 2015; Chiu & Chang, 2009; Jebli, Youssef, & Ozturk, 2016; López-Menéndez, Pérez, & Moreno, 2014; Shafiei & Salim, 2014; Sulaiman et al., 2013) which suggest that the environment will be improved if the country uses renewable energy. (Al-Mulali & Ozturk, 2016; Al-Mulali, Saboori, & Ozturk, 2015; Bento & Moutinho, 2016; Farhani & Shahbaz, 2014) show that environmental degradation occurs with the use of non-renewable energy sources. There is an insignificant in the negative impression of financial growth on the emission of CO<sub>2</sub>.

As previously explained for long-term elasticity, the model is statistically jointly significant. The quadratic model outcomes show that in the short term, a coefficient for GDP and NRENERG is more positive than in the long term. As with short-term elasticity, as expected, the RENERG and FDI coefficients are negatively associated with the emission of CO<sub>2</sub>. In summary, to see the renewables impact of on emission of CO<sub>2</sub>, it is perhaps more precise and appropriate to use the quadratic model that is best able to grasp the relation of growth, financial development and the use of new technologies (renewable) with CO<sub>2</sub> productions are reduced.

The error correction term is used to confirm the long-run association in-between the exogenous and endogenous indicators. So, ECM must be significant and negative for the presence of a long-run affiliation in the model, and it also tells the speed of adjustment of the model. According to the result of ECM from table 5, there exists the cointegration in the model, with the speed of adjustment of 1.304% annually. Which means that the model will come to its equilibrium condition for less than a year.

### 4.4. Short-run results

**Table 5**  
**Short run ARDL results**

Variable	Coeff.	SE	t-stats	Prob.
D (CO <sub>2</sub> (-1))	0.4832**	0.2030	2.3800	0.0489
D (CO <sub>2</sub> (-2))	0.3418	0.2121	1.6119	0.1510
D (GDP)	3.0087*	1.3379	2.2488	0.0593
D (GDP(-1))	2.8677	1.7591	1.6302	0.1471
D (GDP(-2))	0.2400*	0.1110	2.1627	0.0673
D (GDPSQ)	-0.1636*	0.0839	-1.9507	0.0921

D (GDPSQ(-1))	-0.2013*	0.1077	-1.8690	0.1038
D (RENERG)	0.3120	0.4273	0.7302	0.4890
D (RENERG(-1))	0.0913	0.4826	0.1891	0.8554
D (RENERG(-2))	-1.0138**	0.3753	-2.7010	0.0306
D (NRENERG)	-0.1608	1.4700	-0.1094	0.9160
D (NRENERG(-1))	-0.1394	2.0292	-0.0687	0.9471
D (NRENERG(-2))	-4.9345**	1.4746	-3.3465	0.0123
D (FDI)	-0.0103	0.0158	-0.6480	0.5376
ECM(-1)	-1.3024***	0.2264	-5.7518	0.0007

Note: \*\*\*,\*\* and \* show 1%,5% and 10% level of significance respectively.

#### 4.5. Diagnostic Tests Results

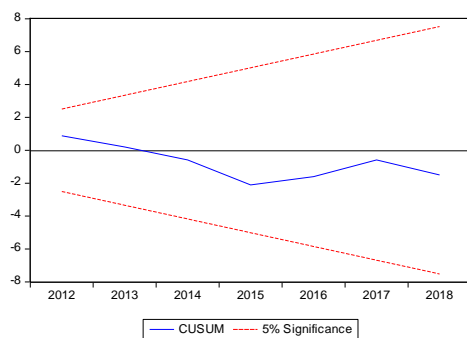
The summary results of the diagnostic tests are shown in Table 6. The outcomes of the diagnostics test are considered satisfactory in all aspects like serial-correlation, functional form, normality, and heteroskedasticity. That confirms the validity of the estimates. The LM test shows that the value of Prob. The value for serial correlation and heteroskedasticity is superior than 5% of the critical value, while the value for a functional form is significant at 5%. We can assume that we accept  $H_0$  = no series correlation = correct functional form = no heteroskedasticity. Refer to Table 5 for diagnostic tests.

**Table 6**  
**Model Diagnostics**

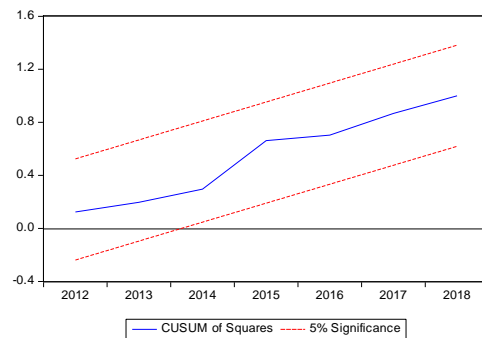
Tests	Prob.
R-square	0.9985
Adj. R-square	0.9945
DW	2.5586
Serial Correlation	0.2274
Heteroskedasticity	0.8260
Normality	0.0946
Ramsey RESET	0.4017

#### 4.6. CUSUM and CUSUMSQ Test of Stability

CUSUM and CUSMSq test used to check the constancy of the estimates of the estimated equation and also used to measure the consistency of the estimates of the equation. They confirm that the model and estimates are steady because both the two graphs remained in the critical limit. The result is that a graphical representation of these two tests is provided in Figures 1 and 2:



**Figure 2: CUSUM stability test**



**Figure 3: CUSUMSQ Stability test**

### 5. Conclusion and Policy Recommendation

This research explores the affiliation between the use of energy and development of the economy, as well as the link between the degradation of the environment and FDI as further explanatory variables. Therefore, the study used the ARDL cointegration test to inspect the presence of the EKC theory. The quadratic functional form model is used in this study because it is widely used for the EKC theory. ARDL method with bound test confirms that there occurs a long-run association in the model. Overall, long-run estimates show that income and use of nonrenewable energy factors boosts the emission level of CO2 while the



square of income and use of renewable energy minimize the emission of CO<sub>2</sub> in Thailand. So, it is confirmed that there exists an EKC hypothesis in the case of Thailand because the elasticities of income in the short-run are positive, and in long run, it becomes harmful. We also noted that the coefficient for the two variables became smaller in the long run than in the short run, which could reflect the EKC theory. Furthermore, renewable energies and FDI are inversely proportional to the emission of CO<sub>2</sub> as expected and also a higher long-term negative coefficient than in the short-term. As such, we can see that the quadratic model is more precise and more appropriate to find out the influence of the level of economic extension and the effect of renewable energies on the emission of CO<sub>2</sub>.

Based on the quadratic model, this study concludes that there are favorable impacts of renewables and FDI on reducing CO<sub>2</sub> emissions. Therefore, the government should redouble its efforts to reduce CO<sub>2</sub> emissions of carbon dioxide, perhaps through regulatory intervention or the mandatory application of renewable energy for individual segments of households and industries. For example, the manufacturing, iron and steel sectors should place greater importance on reducing their high use of non-renewable energy to renewable ones. The government should introduce specific measures and campaigns to protect the environment for future generations, as well as introduce taxes for polluters. Another relevant recommendation is to inaugurate industries that are based on low consumption of energy but high efficiency similar to those adopted by the Tigers of China and Asia.

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