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Determinants of Environmental Degradation in Thailand: Empirical Evidence from ARDL and Wavelet Coherence Approaches

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ABSTRACT: This paper explores long-run and causal effects of financial development, real growth, urbanization, gross capital formation and energy consumption on CO_2 emissions in Thailand by utilizing recent econometric techniques. The study employs ARDL technique to examine the long and short run interconnection between CO_2 emissions and the regressors. Furthermore, we employ the FMOLS, DOLS and CCR as a robustness check to the ARDL long-run estimator. The study use time-series data spanning from 1971 to 2016. The study also utilizes the wavelet coherence technique to collect information on the association and causal interrelationship among these economic variables at different frequencies and timeframes in Thailand. The study objectives are structured to answer the following questions: (a) does the selected macroeconomic indicators impact CO_2 emissions in Thailand? (b) if so, why? Findings reveal; (i) Negative and insignificant link between CO_2 emissions and urbanization. (ii) GDP growth affects CO_2 emissions positively. (iii) The interconnection between CO_2 emissions and energy usage is positive. (iv) Gross capital formation impact CO_2 emissions positively. (v) Positive interconnection exists between financial development and CO_2 emissions in Thailand. Additionally, the wavelet coherence result provides a supportive evidence for the ARDL long run result. Based on these findings, policy directions were suggested.

Keywords: Environmental Pollution; Energy consumption; Economic growth; Thailand.

INTRODUCTION

One of the most critical issues confronting the globalized world is global warming and its major adverse effects on the environment. The consequence of human activities, especially CO_2 emissions, has been known to be one of the key causes leading to climate change in recent decades (IPCC, 2007). It is also important to recognize conditions that encourage CO_2 emissions. Nonetheless, rising CO_2 emissions levels are actually detrimental to the environment with a large degree of air contamination. Environmental policy-makers will take a deeper look at the above problem as a consequence of the greenhouse gas emissions (GHGs) impact and climate change. Due to the massive rise in greenhouse gas (GHG) levels over the past few decades, environmental degradation has been one of the major global problems. As a consequence, a variety of

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nations, including Thailand, have ratified the Kyoto Protocol, which contains binding obligations. Several efforts have been made, including the Kyoto Protocol, accompanied by the Paris Agreement. Advanced nations are required to limit their GHG emissions under 5% of their 1990 levels as agreed upon by the Kyoto, which is accompanied by the Paris Agreement, which seeks to constrain the universal average temperature increase by 2^0C by the dawn of the century.

Environmental pollution is the most complex issue facing the advanced nations. Recently, it has started to encroach developing economies. Large greenhouse gas (GHG) emissions have an effect on developed and non-industrialized nations all over the world. Environmental pollution is triggered by fire in the forest, flooding in various nations are the main factors that cause environmental problems. The activities mentioned above are causing damage to facilities, ecological systems, farm land and the most precious human life. These occurrences are the prime issue of economic and environmental experts. Environmental pollution is a global issue, and terrorizations arising from the worsening of environmental quality are impacting the entire globe, which is the major issue of nation that release GHGs.

According to World Bank (2017), CO_2 emissions is an eye-catching indicator of GHGs; China emits 21.6% of the world's CO2 emissions; the USA emits 14.36% of the world 's emissions; the EU emits 9.66% of the overall CO_2 emissions; India emits 17%, Russia emits 5% and Brazil emits 2.33% of global CO_2 emissions. Primarily, it rests on top greenhouse gas emitters nations to decrease the level of global CO_2 emissions; nevertheless, GHGs emitting nations encounter issues as CO_2 emissions are triggered by energy generation as industrial growth can be accomplished by effective sources of energy. Under these cases, a decrease in the rates of CO_2 emissions will have a detrimental effect on the growth of the economy, which governments are very hesitant to pursue. A nation that seeks to achieve the maximum economic growth by international exchange and investment, achieving the highest economic growth by industrialization and urbanization, causes environmental deterioration that has an impact on environmental quality of each region, due to the acceleration of conventional energy resource utilize for business activities, like industrial production.

Thailand's economy relies on exports (machinery, foods and wood, chemicals and plastics, automobiles and parts, stone and glass, textiles, and furniture), contributing to more than two-thirds of the nation's GDP. Thailand itself is an emerging economy with GDP and GDP per capita of US$505 billion and US$7,273.56, respectively, in 2018 (World Bank, 2020). Thailand's economy is the 8th largest in Asia, with a population of 69.43million in 2018 (World Bank, 2020). Thailand's current level of GHGs in 2014 was roughly 337 $MtCO_2$. The increase in the GDP of Thailand will in no doubt accelerate the urbanization of the country. Urbanization increase is a threat to a country sustainable development (Odugbesan & Rjoub, 2020), because it will increase the energy consumption, hence, the escalation of CO_2 emission (Anwar et al. 2020). In this respect, Thailand’s national GHGs accounted for just 0.84% of global emissions in 2012 and 0.64% of global emissions in 2015. Furthermore, between 1990 and 2012, Thailand's share of cumulative emissions was 0.75 percent. In Thailand, CO_2 emissions per capita for was 4.06 metric tons in 2018. In 1999, CO_2 emissions per metric tons was 2.75 metric, which increased to 4,06 metric tons in 2018, rising at the rate of 2.13% annually. The CO_2 has received a considerable attention among scholars being a major determinant of greenhouse effect. The absence of policy measures will encourage the increasing trend of the emission owing to the increased global energy demand, and fossil fuels being the main determinant of greenhouse emission will have an adverse impact on the environment.

Most of empirical studies has established the relationship between GDP and CO_2 (Adebayo et al. 2020; Koc & Bulus, 2020); urbanization and CO_2 (Haseeb et al. 2018; Odugbesan & Rjoub, 2020; Ozatac et al. 2017); energy consumption and CO_2 (Bukhari et al. 2017; Liu, 2016; Odugbesan & Rjoub, 2020; Adebayo, & Akinsola, 2021); and recently, financial development was suggested as a significant determinant for CO_2 (Tariq et al. 2016; Yadzi & Shakouri, 2014), which some author opined that the omission could result to an erroneous empirical findings (Shahbaz et al. 2013; Tamazian et al. 2009). Meanwhile, the findings from these empirical studies have been mixed and conflicting. The conflicting results could be avoided according to Odugbesan & Rjoub (2020) if authors could employ a novel analytical technique. In view of these, this study first contribute to literature on environmental research within the context of Thailand, and secondly employ a novel analytical techniques (wavelet coherence) which has not been previously used within the context of Thailand to investigate the determinant of environmental degradation in the country. The technique of wavelet coherence has the capability of overcoming the limitation of "Fourier transform" in the analysis of nonstationary time series.

The study tends to examine the linkage between CO_2 emissions and financial development, real growth, urbanization, gross capital formation and energy consumption by asking the fundamental question; Does these macroeconomic variables impact CO_2 emissions in Thailand? If so, why? Furthermore, the wavelet coherence was used to simultaneously to investigate the correlation and causality between CO_2 emissions and its determining factors. The investigator used ARDL to ascertain the long-run and short-run relationship. Furthermore, the FMOLS, DOLS and CCR estimators were deployed as a robustness check to the ARDL long-run estimation. Also, in order to capture the correlation and causality simultaneously, the study used the wavelet coherence technique. To the author's knowledge, the use of wavelet coherence method to collect information on correlation and/or causality between CO_2 emissions and financial development, energy use, gross capital formation, urbanization and GDP growth in Thailand at different frequencies and different periods is scarce in the literature. Based on the techniques utilized findings reveal; (i) Negative and insignificant link between CO_2 emissions and urbanization. (ii) GDP growth impact CO_2 emissions positively. (iii) The interconnection between CO_2 emissions and energy usage is positive. (iv) Gross capital formation impact CO_2 emissions positively. (v) Positive interconnection exists between financial development and CO_2 emissions in Thailand.

In recent times, several studies have been conducted on the interaction between CO_2 emissions and its determinants (financial development, energy usage, GDP growth, urbanization, and gross capital formation) using various techniques, countries and time-frame. The findings from those studies proves inconclusive due to dissimilar techniques, different nation(s) or group under investigation and the techniques employed. For example, Bukhari et al. (2014) examined the interconnection between CO_2 emissions and energy use, FDI inflows and domestic investment in Pakistan between 1974 and 2010. The authors used ARDL and VECM to explore this linkage. Findings from the study posit positive link between FDI inflows and CO_2 emissions while domestic investment cause detrimental impact on CO_2 emissions. Besides, Yazdi & Shakouri (2014) used the ECM and the Granger causality approach to investigate the validity of the EKC hypothesis in Iran between 1975 and 2011. Findings reveal support for the EKC hypothesis.

Furthermore, growth, energy use, and financial development impact CO_2 emissions positively. The study of Tariq et al. (2016) corroborate Yazdi & Shakouri (2014) who found positive linkage between CO_2 emissions. Also gross capital formation impact CO_2 emissions positively. Liu (2016) explored the determinants of environmental degradation in China between 1982 and 2014. The author use Input-output technique and finding revealed that GDP growth, gross capital formation and energy consumption cause harm to the environment. Using Turkey as a case study, Ozatac et al. (2017) used yearly data between 1960 and 2013 to analyze the interconnection between CO_2 emissions and selected indicators. Using ARDL and causality techniques, the investigators found support for the EKC hypothesis while one-way causality was found running found to CO_2 emissions and from urbanization to CO_2 emissions. Just as Ozatac et al. (2017), Haseeb et al. (2018) found support for the EKC hypothesis in BRICS. Also, urbanization, GDP growth and energy usage cause damage to the environment. In Nigeria, between 1981 and 2016, Mesagan & Nwachukwu (2018) examined the connection between CO_2 emissions and it determining indicators. Using the ARDL technique, finding found support for the EKC hypothesis.

In South-Korea, Koc & Bulus (2020) used yearly data between 1971 and 2017 to investigate the relationship between CO_2 emissions, energy usage, and growth. Utilizing the ARDL, the author found no support for the EKC hypothesis while energy usage and economic growth lead to environmental degradation. Adebayo et al. (2020) explored the factors influencing CO_2 emissions in MINT economies using data spanning from 1980 to 2018. The authors used pedronni cointegration, Westerlund Cointegration and, PMG in the analysis. The result of their study demonstrates an insignificant linkage between growth and CO_2 emissions, while energy use impacts CO_2 emissions positively. Though trade openness and CO_2 emissions interaction is negative, thus causing improvement in the environmental quality. In Malaysia, using ARDL and bound testing techniques, Etokakpan, et al. (2020) explored the interconnection among CO_2 emissions, GDP growth, globalization and gross capital formation. The study found that globalization, economic growth, urbanization and gross capital formation impact CO_2 emissions positively. The summaries of related studies used in this study are presented in Table 1.

It is evident from the studies examined that the association among energy use, financial development, gross capital formation, urbanization and CO_2 emissions has been extensively studied. Nevertheless, the usage of the wavelet coherence technique to examine the association and causality between CO_2 emissions and financial development, gross capital formation, urbanization and real growth is scarce in the context of Thailand. The main benefit of wavelet coherence is that this approach allows current research to explain correlation and causality at different period and scales. The defined deficiencies in literature could therefore be resolved in order to contribute to the ongoing research on Thailand. Thus, the study aim is to investigate influence of some macroeconomic variables on the CO_2 emissions in Thailand using a time and domain-frequency technique.

Table 1. Summary of Recent studies

Investigator(s)	Period	Nation(s)	Variable(s)	Method(s)	Result(s)
Bukhari et al. (2014)	1974-2010	Pakistan	GDP, EN, GCF, FDI	ARDL, VECM	FDI→ CO_2 (+) GCF→ CO_2 (-)
Sadorsky (2014).	1971-2009	Developing Nations	URB, CO_2	Panel OLS	URB≠ CO_2
Yazdi & Shakouri (2014)	1975-2011	Iran	GDP, GDP^2, FD, URB,EN, CO_2	ECM, Granger causality approach	GDP^2 → CO_2 (-) GDP→ CO_2 (+) EN→ CO_2 (+) FD→ CO_2 (+) URB→ CO_2 (+)
Tariq et al. (2016)	1971-2011	Pakistan & India	GDP, ENE, POP, GCF, CO_2	OLS	GDP→ CO_2 (+) EN→ CO_2 (+) GCF→ CO_2 (+)
Liu (2016)	1982-2014	China	GDP, ENE, GCF, MAN, CO_2	Input-output technique	GDP→ CO_2 (+) EN→ CO_2 (+) GCF→ CO_2 (+)
Ozatac et al. (2017)	1960-2013	Turkey	ENE, TR, URB, FD, CO_2	ARDL, Causality.	GDP^2 → CO_2 (-) GDP→ CO_2 URB→ CO_2
Bekhet et al. (2017).	1980-2011	GCC countries	ENE, GDP, FD, CO_2	ARDL, VECM	FD→ CO_2 (-) EN→ CO_2 (+) GDP→ CO_2 (+)
Li et al. (2018)	1993-2013	US and China	HS, GCF, CO_2	Input-output analysis	HS→ CO_2 (+) GCF→ CO_2 (+)
Sarkodie (2018).	1971-2013	17 African Nations	EN, GDP, FPRO, BR GDP^2, CO_2	Westerlund, ECM, Panel OLS	GDP^2 ≠CO_2 EN→ CO_2 (+) GDP→ CO_2 (+) BR→ CO_2 (+) FPRO→ CO_2 (+)
Haseeb et al. (2018).	1995-2014	BRICS	EN, GDP,GDP^2, FD, URB, CO_2	CIPS, CADF Westerlund Cointegration, Dumitrescu-Hurlin Granger causality	GDP^2→ CO_2 (-) FD→ CO_2 (+) GDP→ CO_2 (+) URB→ CO_2 (+)
Mesagan & Nwachukwu (2018)	1981 to 2016	Nigeria	GDP, FD, GCF, TO, ,EN, CO_2	ARDL	GDP^2 → CO_2 (-) GDP→ CO_2 (+) EC→ CO_2 (+) FD→ CO_2 (+) URB≠ CO_2 GCF≠ CO_2
Bekun et al. (2020).	1971-2015	Nigeria	GDP, FDI, EN, CO_2	ARDL	GDP^2 → CO_2 (-) GDP→ CO_2 (+) EN→ CO_2 (+) FDI→ CO_2 (-)
Yasin, et al. (2020).	1996–2016	59 less-developed countries	GDP, GDP^2, FD, URB,EN, CO_2	EGLS, A-B GMM, GMM (O-D GMM)	GDP^2 → CO_2 (-) GDP→ CO_2 (+) EN→ CO_2 (+) FD→ CO_2 (+)
Dogan & Inglesi-Lotz (2020).	1980-2014	European countries	ENE, GDP, GDP^2,	Panel OLS, FMOLS, FE	GDP^2 ≠CO_2 GDP→ CO_2 (-)
Etokakpan, et al. (2020)	1980 to 2014	Malaysia	GDP, GDP, GCF, GL,EN, CO_2	Combined co-integration test, ARDL	GDP→ CO_2 (+) EN→ CO_2 (+) GCF→ CO_2 (+) GL→ CO_2 (+)
Pata & Aydin (2020).	1965–2016	Brazil, China, Canada, India, Norway and the US	ENE, HENE GDP, GDP^2, CO_2	Fourier bootstrap ARDL, Fourier TYGC	GDP^2 ≠CO_2 HENE→ GDP in Brazil HENE↔GDP in China
Koc & Bulus (2020)	1971-2017	South Korea	GDP, GDP^2, ENE, CO_2	ARDL,	GDP^2 ≠CO_2 GDP→ CO_2 (+) EN→ CO_2 (+) TO→ CO_2 (-) REN→ CO_2 (-)
Leal & Marques (2020).	1990–2014.	OECD) countries	GDP, GDP^2, TO, CO_2	FMOLS, DOLS, AMG, CDS	GDP^2 ≠CO_2 OP→ CO_2 (+) REN→ CO_2 (+)
Arango Miranda (2020)	1990-2016.	Mexico, US, Canada	GDP,GDP^2, TO, HDI, CO_2	OLS, VECM, Causality	For US and Mexico GDP^2 → CO_2 (-) For Canada GDP^2 ≠CO_2
Adebayo et al. (2020)	1980-2018	Mint Nations	GDP, TO, URB, EN, CO_2	Westerlund Coint, PMG, CDS, Panel Causality	GDP≠ CO_2 EN→ CO_2 (+) TO→ CO_2 (-) URB→ CO_2 (+)

Note: →: Unidirectional causality, ↔: bidirectional causality, GDP: real growth, TO: trade openness, EN: energy use/consumption, CO_2: Carbon emissions, FD: financial development, FDI: foreign direct investment, REN: renewable energy, GCF: gross capital formation, (-) and (+): negative and positive relationship.

MATERIAL AND METHODS

The investigator utilizes yearly time-series variables covering between 1971 and 2016. The dependent variable is carbon emission (CO_2) and the independent variables are; urbanization (URB), gross capital formation (GCF), energy consumption (EN), financial development (FD) and economic growth (GDPpc). The variables are sourced from the database of World Bank (2020). Table 2 illustrates the short description of the times-series variables.

Table 2. Descriptive Statistics

Code	CO_2	GDPpc	EN	FD	GCF	URB
Mean	2.092299	2101.805	958.0470	79.85194	28.92191	3.245132
Median	2.004141	1869.546	858.5890	88.30704	27.10843	2.828098
Maximum	4.214834	6168.263	1991.594	166.5037	42.86269	5.495581
Minimum	0.507018	194.2667	360.5937	20.53673	20.07150	1.479932
Std. Dev.	1.262428	1716.912	522.8641	37.91546	6.410287	1.283127
Skewness	0.169719	0.960379	0.465025	0.218638	0.968793	0.250034
Kurtosis	1.472573	2.948206	1.850770	2.330225	2.984582	1.729517
Jarque-Bera	4.488458	6.768661	4.007159	1.172984	6.883207	3.417694
Probability	0.106009	0.033900	0.134852	0.556275	0.032013	0.181074
Observations	44	44	44	44	44	44

Dataset utilized in this study was gathered from the World Bank database stretching between 1980 and 2016. The CO_2 emissions (CO_2), which is the dependent variable is measured in metric tons per capita, gross capital formation is measured as gross capital formation % of GDP. Furthermore, energy usage is calculated as kt of oil equivalent per capita, economic growth is calculated as GDP per capita constant 2010 US$, urbanization is measured as urban growth rate and financial development is measured as domestic credit to private % of GDP. The research also explores the effect of financial development, real growth, urbanization, energy use and gross capital formation on Thailand's CO_2 emissions by using ARDL techniques and a new technique called wavelet coherence. The wavelet coherence is recognized in econo-physics and it's used in this study to fill the void in the past studies. The integration order of the time-series was ascertained by utilizing the ADF, PP, ZA, and LM unit-root tests. As yet another step in this study, the investigator measured long-run co-integration between CO_2 and its regressors in Thailand using the ARDL bound test. The benefit the ARDL methods have is the capability to examine both short and long-run interconnection together when series are I(0) or I(1) or both I(0) and I(1), respectively, though it will not work for I(2) series. The next equations depict the economic functions, economic model and econometric model.

$$CO_2 = f\left(EN, GDPpc, FD, GCF, URB\right) \quad (1)$$

$$CO_2 = \vartheta_0 + \vartheta_1 EN_t + \vartheta_2 GDPpc_t + \vartheta_3 FD_t + \vartheta_4 GCF_t + \vartheta_5 URB_t \quad (2)$$

$$CO_2 = \vartheta_0 + \vartheta_1 EN_t + \vartheta_2 GDPpc_t + \vartheta_3 FD_t + \vartheta_4 GCF_t + \vartheta_5 URB_t + \varepsilon_t \quad (3)$$

Before the ARDL is constructed in equation 4, natural logarithm of variables was taken t reduce skewness and deviation. Thus, the ARDL framework was constructed below in equation 4 as follows;

$$\begin{aligned} \Delta CO_{2t} = {} & \vartheta_0 + \sum_{i=1}^{t}\vartheta_1 \Delta CO_{2t-i} + \sum_{i=1}^{t}\vartheta_2 \Delta EN_{t-i} + \sum_{i=1}^{t}\vartheta_3 GDPpc_{t-i} + \sum_{i=1}^{t}\vartheta_4 \Delta FD_{t-i} + \sum_{i=1}^{t}\vartheta_4 \Delta GCF_{t-i} \\ & + \sum_{i=1}^{t}\vartheta_4 \Delta URB_{t-i} + \beta_1 CO_{2t-1} + \beta_2 EN_{t-1} + \beta_3 GDPpc_{t-1} + \beta_4 FD_{t-1} + \beta_5 GCF_{t-1} + \beta_6 URB_{t-1} + \varepsilon_t \end{aligned} \quad (4)$$

where in the first difference is depicted by Δ. The variables coefficients in the long-run are illustrated by $\vartheta_1 \ldots\ldots 6$. After long-run connections have been determined, short-run interconnections have been calculated using the Error Correction Model (ECM) developed by Engle & Granger (1987) to analyze short-run coefficients and the Error Correction Term (ECT). This is achieved by adding the ECM in the ARDL framework for model 1 and 2 respectively;

$$\Delta CO_{2t} = \vartheta_0 + \sum_{i=1}^{t}\vartheta_1 \Delta CO_{2t-i} + \sum_{i=1}^{t}\vartheta_2 \Delta EN_{t-i} + \sum_{i=1}^{t}\vartheta_3 GDPpc_{t-i} + \sum_{i=1}^{t}\vartheta_4 \Delta FD_{t-i} + \sum_{i=1}^{t}\vartheta_4 \Delta GCF_{t-i} + \sum_{i=1}^{t}\vartheta_4 \Delta URB_{t-i} + \beta_1 CO_{2t-1} + \beta_2 EN_{t-1} + \beta_3 GDPpc_{t-1} + \beta_4 FD_{t-1} + \beta_5 GCF_{t-1} + \beta_6 URB_{t-1} + \pi ECT_{t-i} + \varepsilon_{t-1} \quad (5)$$

where the speed of adjustment is depicted by π, the first lag of the error term is illustrated by ECT_{t-1}, which signifies the error correction term.

In addition, the research utilized a wavelet coherence method to obtain simultaneous association and causality between the time-series indicators used in this analysis. As a preliminary test, the investigator evaluated the integration order of the time-series using the ADF and PP root tests. Furthermore, the ZA and LM unit-root tests were deployed to check the structural break(s) in the series. With regard to the main aim of the research, the investigator explored the time-frequency dependence between CO_2 emissions and their determinants in Thailand using the R-program 's wavelet coherence technique, a statistical software package. The techniques were initially created by Goupillaud et al. (1984). It is well-known- and widely agreed that time-series economic metrics are likely to be non-stationary at their level. In addition, "the primary issue with the standalone frequency-domain method, more precisely known as the Fourier Transformation, is that by concentrating exclusively on the frequency domain, information from the time domain is entirely excluded" (Pal & Mitra, 2017). Additionally, structural break(s) in the time-series makes the predicted outcomes of conventional causality tests with defined parameters to be distorted. To circumvent these complications, we utilized Granger's wavelet-based causality test. The present paper uses a wavelet ϖ method, which is a part of the Morlet wavelet family. The ϖ is portrayed by Eq.6 below:

$$\varpi(t) = \pi^{-\frac{1}{4}} e^{-i\varpi t} e^{-\frac{1}{2}t^2} \quad (6)$$

where, w denotes the frequency utilized on the constrained time series; i portray p (t), n = 0, 1, 2, 3…….N-1; and $\sqrt{-1}$. As stated by Kalmaz & Kirikkaleli (2019) and Pal & Mitra (2019), there is a conversion by the Time into the time-frequency domain, which connects to adjustment in wavelet. ϖ is changed; hence, it advanced into $\varpi_{k,f}$. Eq.7 illustrates this explanation;

$$\varpi_{k,f}(t) = \frac{1}{\sqrt{h}}\varpi\left(\frac{t-k}{f}\right), \quad k, f \in \mathbb{R}, f \neq 0 \quad (7)$$

p(t), which is the time-series data is incorporated. Therefore, Eq.8 illustrates the continuous wavelet function:

$$\varpi_p(k, f) = \int_{-\infty}^{\infty} p(t)\frac{1}{\sqrt{f}}\varpi\left(\overline{\frac{t-k}{f}}\right)dt, \quad (8)$$

As stated by Adebayo (2020) and Kirikkaleli (2020) when the coefficient ψ is added to the equation, the Eq.9 and Eq.10 are regenerated.

$$p(t) = \frac{1}{C_\varpi}\int_0^{\infty}\left[\int_{-\infty}^{\infty}\left|\varpi_p(a, b)\right|^2 da\right]\frac{db}{b^2} \quad (9)$$

In order to capture the vulnerability of energy usage, CO_2 emission, gross capital formation, financial development and GDP growth, the wavelet power spectrum (WPS), which is represented in Eq.10 is employed.

$$WPS_p(k, f)\left|W_p(k, f)\right|^2 \quad (10)$$

The cross-wavelet transform (CWT) technique transformed the time-series variable in the Eq.10 into Eq.11.

$$W_{pq}(k,f) = W_p(k,f)\overline{W_q(k,f)} \quad (11)$$

where: $W_p(k,f)$ and $W_q(k,f)$ represent the two time-series variables, The squared wavelet coherence is demonstrated in Eq 12:

$$R^2(k,f) = \frac{\left|S\left(f^{-1}W_{pq}(k,f)\right)\right|^2}{S\left(f^{-1}\left|W_p(k,f)\right|^2\right)S\left(f^{-1}\left|W_q(k,f)\right|^2\right)} \quad (12)$$

If the $R^2(k,f)$ nears 1, shows either that the time-series indicators are connected, or there is a causal relationship between the time series variables at a specific frequency, surrounded by a black line and colored in red color. Also, whenever $R^2(k,f)$ nears 0, it demonstrates that no evidence of correlation or causality between the two tie series variables. Although, $R^2(k,f)$ Does not offer any comprehensive information on the symbol of the interaction. Thus, "Torrence and Compo (1998) asserted a system for detecting distinctions in wavelet coherence utilizing deferral signs in the wavering of two-time series" (Pal & Mitra, 2017). The equation for the wavelet coherence difference process established is depicted in the Eq.13:

$$\phi_{pq}(k,f) = \tan^{-1}\left(\frac{L\left\{S\left(f^{-1}W_{pj}(k,f)\right)\right\}}{O\left\{S\left(f^{-1}W_{pj}(k,f)\right)\right\}}\right) \quad (13)$$

An imaginary operator and a real part operator are symbolized by L and O separately.

RESULTS AND DISCUSSION

As previously mentioned, the research seeks to investigate the relationship and causality between CO_2 emissions, GDP growth, financial development, energy use and gross capital formation and urbanization in Thailand. The novelty of the research comes from the fact that no earlier studies in Thailand have investigated such interconnections by applying the wavelet coherence technique. To remedy this vacuum in the previous study and to fix the problem "What is the relationship and causal linkage between CO_2 emissions and its determinants in Thailand? The order of integration of the indicators utilized in this study is tested by the ADF, PP, ZA and LM unit-root tests. The outcome of these unit root checks indicates that all metrics used are implemented in a mixed order as indicated in Table 3.

Table 3. Unit Root Tests

Tests		CO_2	EN	GDP	FD	GCF	URB
Panel T: At Level							
ADF	K&T	-2.529	-1.704	-1.606	-2.175	-2.223	-1.959
PP	K&T	-2.205	-1.705	-1.123	-1.414	-2.300	-1.709
ZA	K&T	-3.204 [1988]	-3.72 [1983]	-5.472^{V} [1997]	-4.249 [1992]	-5.745^{V} [1998]	-4.224 [2000]
LM	K&T	-5.775 [1984] {1993}	-7.254^{T} [1981] {1992}	-5.411 [1985] {2005}	-6.166^{T} [1991] {2008}	-6.752^{T} [1996] {2008}	-6.290^{T} [1994] {2009}
Panel B: First Difference							
ADF	K&T	-4.524^{V}	-6.059^{V}	-4.340^{V}	-3.249^{M}	-6.188^{V}	-4.715^{V}
PP	K&T	-4.492^{V}	-6.053^{V}	-4.366^{V}	-3.397^{M}	-6.193^{V}	-4.732^{V}
ZA	K&T	-5.556^{V} [1997]	-5.172^{V} [1994]	-4.864^{T} [2003]	-5.510T [1998]	-6.612^{V} [2000]	-5.871^{V} [2000]
LM	K&T	-6.819^{T} [1986] {1984}	-5.721^{V} [1981] {1996}	-6.247^{T} [1993] {2007}	-7.364V [1995] {2008}	-6.058^{M} [1995] {2003}	-6.626^{T} [1999] {2009}

Note : $^{V, T}$ and ^{M} denote 1%, 5% and 10% level of significance correspondingly. ADF = augmented dickey-fuller, PP = Philip-Perron, ZA = zivot andrew, LM = lagrange multiplier. CO2 = carbon emissions, URB = urbanization, GCF = gross capital formation, EN = energy consumption, FD = financial development, GDPpc = economic growth.

Source: Author's Collation with EViews-11

Since the time series variables are stationary at a mixed level, the ARDL bounds test proposed by Pesaran et al. (2001) was utilized to examine the cointegration. Table 4 illustrates the cointegration outcomes. There is evidence of cointegration since the F-statistic (10.91) is greater than the lower bound and upper bound critical value. Based on this result, the null hypothesis is dismissed at a 1 % significance level. The result of this discovering sets the stage for the exploring the long and short-run ARDL estimations. In addition, several diagnostic tests were conducted on model. Based on the tests carried out, the model is good. In addition, multicollinearity test was carried out. Findings from this test revealed that there is no severe multicollinearity in the model since the VIF values are less than 10 (see Table 3). Furthermore, the outcomes of CUSUM and CUSUMsq in Figures 1a and 1b indicate that the model is stable at a 5 % level of significance.

Table 4. ARDL Cointegration Result

Model	**(3, 4, 4, 0, 1, 4)**	
F-Stats	10.91*	
Cointegration	Yes	
Significant Level	L-B I(0)	U-B I(1)
10%	2.26	3.35
5%	2.62	3.79
1%	3.41	4.68
Diagnostic Tests		
χ^2 Heteroscedasticity	0.68(0.79)	
χ^2 Ramsey	0.74(0.39)	
χ^2 Normality	0.20(0.90)	
χ^2 LM	0.83(0.45)	
Multicollinearity Test		
GDPpc	4.713	
EN	5.632	
FD	6.483	
GCF	3.873	
URB	5.284	

Note: 1% significance level is depicted by *. L-B & U-B illustrates the lower and upper bound correspondingly.
Source: Investigators Collation with EViews-11

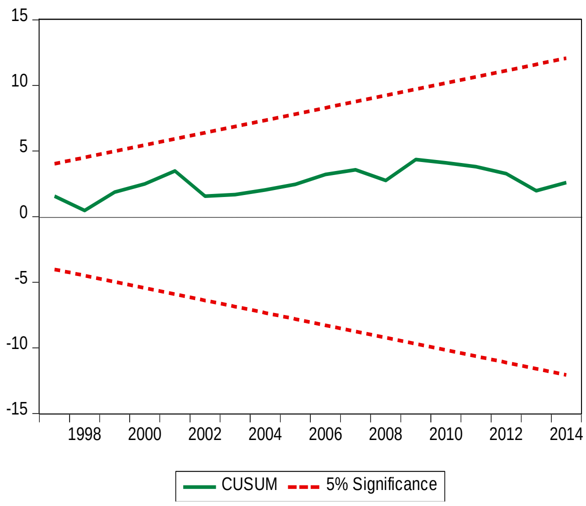

Fig. 1a. CUSUM

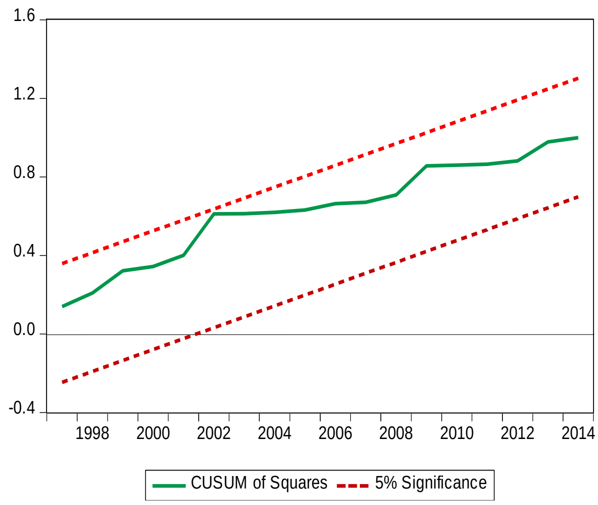

Fig. 1b. CUSUMSq

After the cointegration between CO_2 and financial development, growth, energy usage and gross capital formation was established, the study investigates the short and long-run interconnection between CO_2 emissions and its determining factors. The output of the short and long run interconnection is depicted in Table 5. Findings from the ARDL long-run estimation revealed; (i) Positive interrelationship between CO_2 emissions and GDP growth. It implies that keeping other indicators constant, 1% increase in GDP growth will trigger CO_2 emissions to increase by 0.305%. The finding agrees with prior studies (Yazdi & Shakouri 2014; Tariq et al. 2016; Kirikali & Demet, 2020). (ii) Negative and insignificant interconnection exist between CO_2 emissions and urbanization. The outcome complies with the studies of Mesagan & Nwachukwu (2018) and Sadorsky (2014). (iii) Financial development impact CO_2 emissions positively. It signifies that 0.243% increase in CO_2 emissions is due to 1% increase in financial development when other variables are held constant. Prior studies (Yazdi & Shakouri 2014; Bekhet et al. 2017; Haseeb et al. 2018) agree with this result. (iv) Gross capital formation impact CO_2 emissions positively. It demonstrates that 1% increase in gross capital formation will cause CO_2 emissions to rise by 0.09% keeping other indicators constant. The outcome corroborates with the findings of Tariq et al. (2016) Liu (2016) Li et al. (2018) and Etokakpan, et al. (2020). (v) Energy consumption impact CO_2 emissions positively. This portray that keeping 0.306% increase in CO_2 emissions is due to 1% rise in energy use. The finding corroborates with the study of Yazdi & Shakouri (2014), Tariq et al. (2016) Etokakpan, et al. (2020) and Adebayo et al. (2020). In the short run, GDP growth, financial development and energy use significantly impact CO_2 emissions. As expected, the ECM's coefficient (-0.57) is negative and statistically significant. It implies that previous periods correction can be corrected by the subsequent periods.

Table 5. ARDL Long and Short run Results

Long-Run Result			
Dep-Var	Regressors	Coefficient	T-stats
	GDPpc	0.305	3.600^V
	EN	0.306	2.163^T
CO_2	FD	0.243	2.510^T
	GCF	0.091	1.980^M
	URB	-0.0216	-0.499
Short-Run Result			
Dep-Var	Regressors	Coefficient	T-statistics
	ECM(-)	-0.572	-8.838^V
	ΔGDPpc	0.305	4.728^V
CO_2	ΔEN	0.306	3.123^V
	ΔFD	0.245	4.154^V
	ΔGCF	0.018	0.387
	ΔURB	0.210	1.102
R^2		0.99	
Adj R^2		0.99	

Note $^{V, T}$ and ^{M} denote 1%, 5% and 10% level of significance correspondingly

The research also verifies the robustness of the long-run ARDL estimation by implementing FMOLS, DOLS and CCR. Table) (illustrates that the FMOLS, DOLS and CCR results. The FMOLS, DOLS and CCR. The findings validate the long-run ARDL estimation.

Figures 1, 2, 3, 4 and 5 demonstrate the wavelet coherence between CO_2 emissions and GDP growth, CO_2 and energy consumption, CO_2 and financial development, CO_2 and gross capital formation and CO_2 and urbanization in Thailand. The y-axis and the x-axis represent frequency and time, respectively. Furthermore, in Figures 2, 3, 4, 5 and 6, the white cone-shaped line shows the impact area. On the right side of the figure, the color scale describes the strength of the correlation. The red color implies high correlations between time-series indicators, whereas the thick black shape in Figures 2,3, 4, 5 and 6 shows 5% level of significance. The arrows in the wavelet coherence portray the lead/Lag interconnection between CO_2 emissions and energy usage and real growth in Thailand. Table 6 illustrates the interpretation of the wavelet power spectrum as suggested by Pal & Mitra (2017) and Kalmaz & Kirikkaleli (2019).

Table 6. Long-Run Robustness Check

		FMOLS		DOLS		CCR	
Dependent-Var	**Regressors**	**Coefficient**	**T-stats**	**Coefficient**	**T-stats**	**Coefficient**	**T-stats**
	GDPpc	0.311	7.090^{V}	0.305	5.087^{V}	0.236	2.175^{T}
	EN	0.292	3.058^{V}	0.306	3.058^{V}	0.914	2.324^{T}
CO_2	FD	0.256	5.495^{V}	0.245	3.548^{V}	0.423	2.886^{T}
	GCF	0.059	2.026^{T}	0.091	2.798^{T}	0.257	2.275^{T}
	URB	-0.006	-1.487	-0.021	0.523	-0.060	1.381
R^2		0.99		0.99		0.99	
Adj R^2		0.99		0.99		0.99	

Note $^{V, T}$ and ^{M} denote 1%, 5% and 10% level of significance correspondingly

Table 7. Wavelet coherence Interpretation

Direction of Arrows	Interpretation
Right	A positive correlation between the two variable
Left	A negative correlation between the two variable
Right-Up	The second variable causes the first variable.
Right-Down	The first variable cause the second variable
Left-Up	The second variable causes the first variable
Left-Down	The first variable cause the second variable
Short-Term	0-4
Medium-Term	4-8
Long-term	8-32
Low-Frequency	0-2
Medium-Frequency	2-6
High-Frequency	6-1

Source: Investigator's Compilation

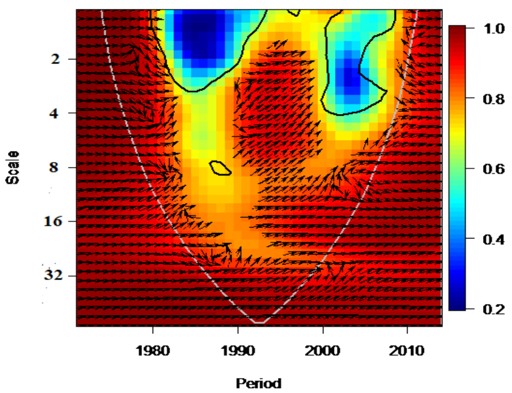

Fig. 2. Wavelet Coherence CO_2 & GDPpc

Source: Authors Collation with R-Software

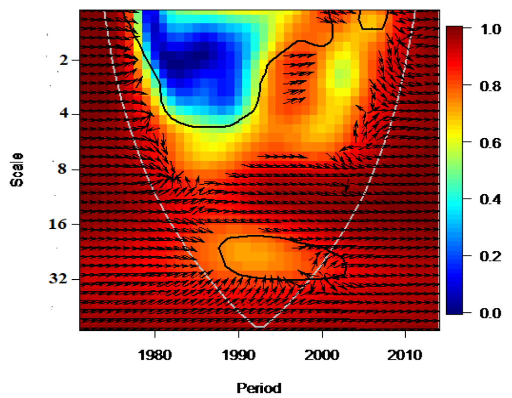

Fig. 3. Wavelet Coherence CO_2 & EN

Source: Authors Collation with R-Software

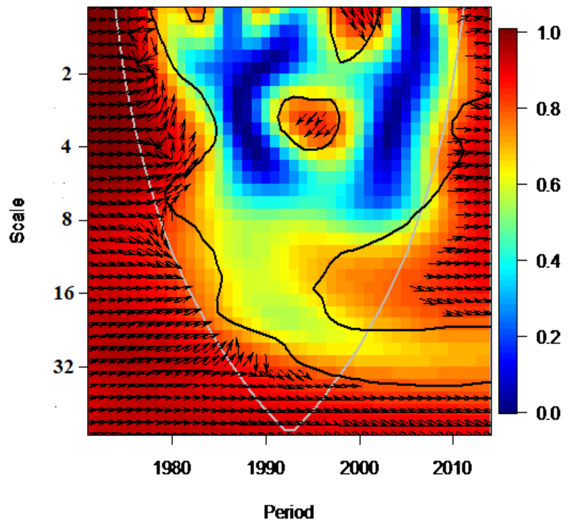

Fig. 4. Wavelet Coherence CO_2 & FD

Source: Authors Collation with R-Software

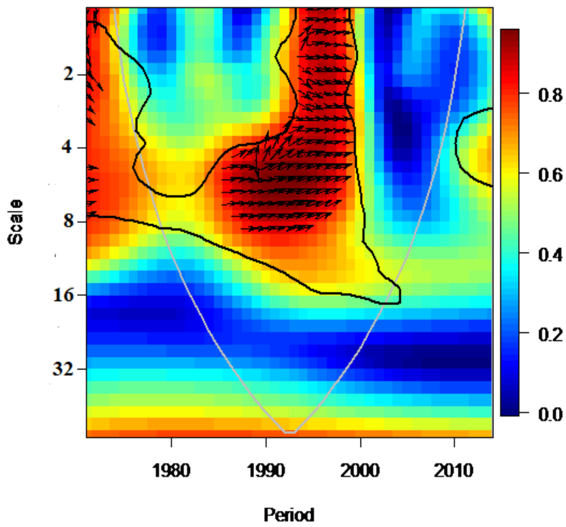

Fig. 5. Wavelet Coherence CO_2 & GCF

Source: Authors Collation with R-Software

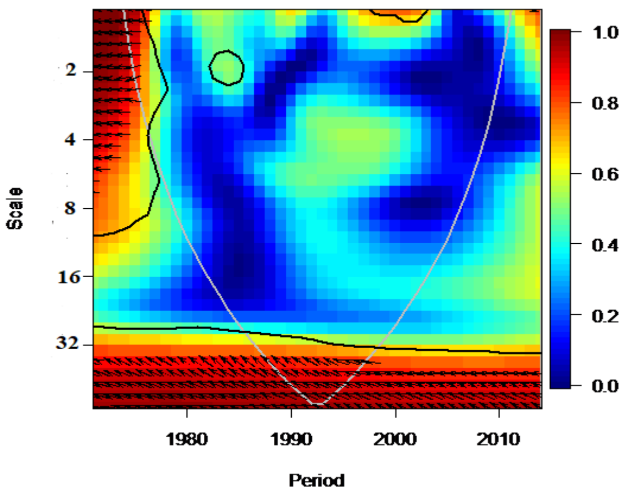

Fig. 6. Wavelet Coherence CO_2 & URB

Source: Authors Collation with R-Software

Figures 2, 3, 4, 5 and 6 exemplify the wavelet coherence between CO_2 and its determinants in Thailand between 1971 and 2014. This method explores at the same time the correlation and causality between CO_2 and the other indicators. As Kirikkaleli (2020) mentioned, this approach is extracted from mathematics by combining time and frequency domain information methods in order to acquire entirely undiscovered data. This research therefore enables short-term, medium-term and long-term associations and causalities to be investigated regarding CO_2 emissions and its determining factors in Thailand. No relationship between the two time-series is defined in Figures 2, 3, 4, 5 and 6 as cold (blue) color, whilst evidence of connection is represented by warmer (red) color. In Figure 2, at different scales (different frequencies), between 1975 and 2010, the arrows face the right-hand side, which depicts a positive correlation between CO_2 and energy usage. Furthermore, the right-up arrows illustrate that there is proof of one-way causality running from GDP growth to CO_2 emissions in Thailand. This indicates that GDP growth is an essential predictor of CO_2 emissions in Thailand. In Figure 5, at different scales (different frequencies), between 1975 and 2010, the arrows face the right-hand side, which depicts a positive correlation between CO_2 and energy usage. Furthermore, the right-down arrows illustrate that there is proof of unidirectional causality running from CO_2 to energy usage. This indicates that CO_2 emissions is an essential predictor of energy usage in Thailand. Furthermore, in Figure 4 between 1973 and 1995, at different scales (different frequencies), the right arrows mirror evidence of positive relationship between financial development and CO_2 emissions. However, rightward down and up arrows during this period indicate evidence of bidirectional causality between CO_2 emissions and financial development. It demonstrates that both financial development and CO_2 emissions can predict each other. In Figure 5, between 1988 and 2000, there is evidence of rightward arrows at short and medium term (low and medium frequencies) which indicates positive correlation between CO_2 emissions and gross capital formation. No sign of correlation between 2001 and 2014. Furthermore, the rightward and up arrows shows that financial development cause CO_2 emissions. The result denotes that gross capital formation is a good predictor of CO_2 emissions in Thailand. In figure 5, at long-term (low frequency) between 1989 and 2000, there is leftward arrows, indicating negative correlation between CO_2 emissions and urbanization.

CONCLUSION

By investigating the long-run and short-run causal effects of financial development, economic growth, urbanization, energy consumption, gross capital formation on CO_2 emissions in Thailand by employing the wavelet coherence technique, new evidence to the empirical literature in regards to CO_2 emissions is issued by this research. To the investigators understanding, no prior researches have firmly explored the long-run and short run interaction and causal effects of financial development, economic growth, urbanization, energy consumption, gross capital formation on CO_2 emissions in Thailand by employing the wavelet coherence technique. To obtain this information, we used newly developed econometric techniques, such as; ARDL, FMOLS, DOLS, CCR and wavelet coherence techniques. The novelty of the wavelet coherence technique is that it can capture correlation and causality between time-series variables simultaneously at different periods and frequencies. The study utilized yearly data stretching between 1971 and 2016 to capture these dynamics. The ARDL bounds testing method to cointegration is utilized to explore the long-term interconnection between variables and ECM method is utilized to check the the short-run dynamics. Findings from the study revealed; (i) Positive interrelationship between CO_2 emissions and GDP growth. (ii) Negative and insignificant interconnection exist between CO_2 emissions and urbanization. (iii) Financial development impact CO_2 emissions positively. (iv) Gross capital formation impact CO_2 emissions positively. (v) Energy consumption impact CO_2 emissions positively. (vi) Findings from the wavelet coherence technique provide a supportive evidence for the ARDL, FMOLS, DOLS and CCR techniques. Recommendations are put forward as follows; firstly, the government of Thailand should be careful when formulating policies that trigger growth, which will have a detrimental impact on the environment. In this respect, the government will aid markets by developing a solid policy structure that provides long-term demand for the mitigation of greenhouse gas pollution and actively encourages the implementation of emerging technology that contribute to a less carbon-intensive economy. Secondly, in the developing nation in question, and perhaps in several other developing markets in which the structural transformation of the financial sector is at an initial point, financial development may not, however, tend to mitigate pollution. The government of Thailand must therefore take a more involved part in effective mitigation. In addition, the Government of Thailand should implement detailed and practical mitigation plans that integrate economic opportunities with regulatory mitigation steps.

Third, the research and development (R&D) on green technology to improve gross capital formation and reduce CO_2 emissions must be stepped up by specifically tracking gross capital formation and introducing modern technologies. As a consequence, the decrease of CO_2 pollution would have to come from a rise in energy efficiency and a stronger commitment to transition from fossil fuels to renewables. The regulation of CO_2 emissions by either taxation or limits and the market scheme will therefore aim to mitigate the use of fossil fuels. While the current research examines strong analytical results in the case of Thailand, one of the key restriction of this analysis is the data availability that inhibits the efficiency of the econometric models used because the time-series data accessible only encompasses period between 1971 and 2016. In turn, a CO_2 emission is seen as a proxy for environmental degradation, which is not just a consideration in the deterioration in the quality of the environmental. Additional research in the context of Thailand should be taken into account by adding other environmental degradation proxies. Also, such studies should be performed in various nations since one of the global issues is environmental degradation.

In conclusion, the limitation of this study lies in the use of domestic credit to private as a % of GDP, which has been criticized by Svirydzenka (2016) that it does not take into consideration the complexity of multidimensional nature of financial development. Thus, the future study should utilize the newly computed financial index (Svirydzenka, 2016) which incorporates the financial institutions and markets on terms of their depth, access, and efficiency. Nevertheless, this study provides significant contributions to the literature on environmental degradation which would serve as guide for policymakers in Thailand.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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