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The relationship between the transportation export value and energy consumption of Thailand

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A B S T R A C T

This study was conducted to consider the relationship between the transportation export value (TR) and energy consumption of Thailand (EN) in the long run by a comparative analysis that relied on testing by the ARDL and NARDL models. The Granger causality of each item was also tested by quarterly time series data from Quarter 1 of 2011-Quarter 4 of 2021. The results revealed a long relationship from the EN to TR. However, only the reduction of the TR affected the EN. According to the results, the energy agencies of Thailand should maintain the balance of EN and sufficient energy imports to drive the TR for its stability.

1. Introduction

From the past until the present, transportation has been one of the necessary activities for the development and livelihood of humans because it facilitates goods as well as knowledge sharing. In particular, human transport for tourism generates economic advantages (Nonthapot & Ueasin, 2014). Even so, travel and transportation in the past was quite dangerous; thus, humans took a long time to travel to remote areas. Nevertheless, with the development of transportation, today humans can travel anywhere in a shorter time and with higher safety (Garrison, 2003) by modern vehicles, e.g., airplanes. A large number of goods can also be transported by ships, trains, and trucks. These vehicles require large amounts of energy to be driven for relocating humans and goods to their respective destinations.

In general, the relationship between transportation and energy consumption (EN) is usually described in the way that energy is a factor of production/manufacturing for transportation (Chukwu et al., 2015). Furthermore, only the direct effects caused by transportation on driving energy have been considered. However, the key characteristic of transportation is the human/goods relocation process to different areas for different purposes, e.g., human transport for tourism, which could cause the levels of need for EN in the target area because of the different styles of the tourism activities. This was similar to the study of Khanal et al. (2021) who found that an increase of tourists by 1% would increase the levels of need for EN by 0.062%. Thus, it may not be suitable to consider the relationship under the traditional concept. Hence, the description should be extended to the relationship between transportation and local EN, too.

In contrast, there have been a few studies that have described the influences of EN affecting transportation in that issue. Nonetheless, energy is indispensable for the use of machines for manufacturing. For this reason, the increase of EN could reflect local manufacturing that would finally lead to distribution by transportation.

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Thailand is one of the countries with prominence in tourism. In 2018, over 39.91 million foreign tourists traveled to Thailand (Thailand Economics Tourism and Sports Division, 2022). Moreover, exports are one of the key sectors in Thailand, and the country has an export market share of over 15% in the U.S. (U.S. International Trade administrator, 2021). Thus, Thailand could gain revenue from the transportation export value (TR) that would grow with tourism and exports.

According to the data from the International Trade Centre (2022), it was found that Thailand gained more revenue from the TR from 5,830 million USD up to 7,694 million USD between 2011-2018 before it slightly reduced to 7,196 million USD in 2019. However, the COVID-19 outbreak caused the export value of this sector to reduce to 3,334.948 million USD in 2020 due to the interruption of economic activities resulting from the implementation of preventive measures against the outbreak, particularly the control of entering-leaving the country. This affected the tourism industry of Thailand before the TR slightly increased to 4,321.570 million USD in 2021 after the relief of the control measures.

In addition, according to the data from the Thailand Energy Policy and Planning Office (2022), it was found that EN (from primary energy and final energy) kept increasing from 149,692 kilo tons of oil equivalent (KTOE) in 2011 to 184,199 KTOE in 2018 before it slightly reduced to 182,369 KTOE in 2019. The effects of COVID-19 caused the reduction of EN down to 171,087 KTOE in 2020, and even slightly less than 2020 down to 170,342 KTOE in 2021 due to the operational cessation of some businesses, e.g., aviation that usually requires large amounts of fuel for driving aircraft and some industrial plants (see Fig. 1).

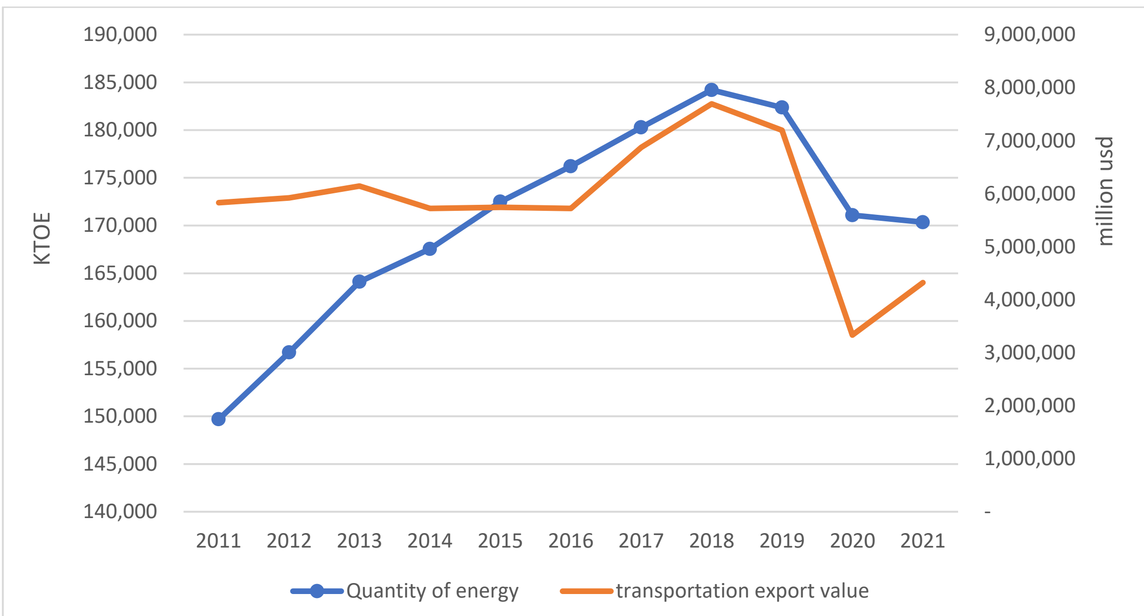

Fig. 1. Trend of the energy consumption and transportation export value of Thailand.

Source: International Trade Centre (2022) and Thailand Energy Policy and Planning Office (2022).

When comparing the data between the TR of Thailand and EN (Fig. 1), it was found that the export value tended to be congruent with EN, particularly between 2016-2021. Both were even more clearly reduced in 2020 due to COVID-19.

Such congruence could be described that the factors of energy production could depend on transportation. Moreover, Thailand is one of the countries with a large number of tourists entering and departing the country. Thus, transportation could affect EN more in terms of the need for fuel. Simultaneously, EN from production/manufacturing activities could be the determiner of the TR.

Therefore, this study aimed to consider the relationship between the TR of Thailand (thousand USD) and EN (KTOE). The analysis methods of the autoregressive distribution lag (ARDL) and non-linear autoregressive distribution lag (NARDL) models were compared. The Granger causality of each item was also tested by quarterly time series data from Quarter 1 of 2011 - Quarter 4 of 2021, a total of 44 quarters.

2. Literature Review

The current situation of global EN is critical (Frey, 2018). As such, people must be aware of this situation and pay huge attention to it due to more EN to respond to their needs, EN by tourists, and transportation of all types of businesses. Furthermore, global EN has changed to more various forms caused by global warming and the effects of economic EN.

Thus, this could be seen from the speculation of the prices from pre-orders and hoarding oil. Additionally, wars in the world have affected the global economy directly in terms of higher prices in consumer goods, transportation, and the overall cost of living.

For the current situation of EN, higher energy was once required. Then, it was reduced in terms of tourism and TR. When the COVID-19 outbreak occurred, it was found that personal worries about the risk of COVID-19 infection caused people to change their behavior of living to reduce such risk, including travel behavior (Jaruwattananon, 2021) and the change of customer needs for logistics under varied economic situations due to the COVID-19 outbreak and possible emerging diseases in the future (Niyawanont, 2022). In addition, the Energy Policy and Planning Office (EPPO) has prepared to revise the energy policy to support the changes of the future in which the world would move forward to clean energy to respond to the need for EN that continues to increase with the economic growth rate, i.e., setting the energy framework to drive the energy plans in all aspects, particularly the clean energy policy to move forward to carbon neutrality (Energy Policy and Planning Office, 2021).

Transportation is also required for today and future living. It provides convenience and efficiency of the people and goods relocation. Additionally, using clean energy for transportation has rapidly increased, e.g., hybrid automobiles and other upcoming innovations. Thus, the study of Chai et al. (2016) and Davis and Boundy (2021) confirmed that the need for energy certainly influences the transportation sector. One of those influences includes TR.

3. Methodology

This study analyzed the relationship between the EN represented by total En, and TR, represented by the TR of Thailand. The estimated results between the ARDL and NARDL models were analyzed and compared. The Granger causality of those variables was also tested by time series data from Quarter 1 of 2011-Quarter 4 of 2021, a total of 44 quarters. The data in this study consisted of the following variables. EN was the total EN calculated by the sum of primary EN and final EN in KTOE. The data were collected from the EPPO. TR was the TR of Thailand calculated in thousand USD. The data were collected from the International Trade Centre. Co was the COVID-19 outbreak from Quarter 1 of 2011- Quarter 4 of 2021, a total of 44 quarters. This was the dummy variable. For the duration of the outbreak, Co was set as 1, but in case of other durations, Co was set as 0. Furthermore, the influences of change between EN and TR were separated in the positive and negative directions of EN and TR. The analysis process by NARDL was set as follows:

$$EN_t^+ = \Sigma_{i=1}^{t} \Delta EN_i \quad \text{when} \quad \Delta EN_i > 0 \tag{1}$$

$$EN_t^- = \Sigma_{i=1}^{t} \Delta EN_i \quad \text{when} \quad \Delta EN_i < 0 \tag{2}$$

$$TR_t^+ = \Sigma_{i=1}^{t} \Delta TR_i \quad \text{when} \quad \Delta TR_i > 0 \tag{3}$$

$$TR_t^- = \Sigma_{i=1}^{t} \Delta TR_i \quad \text{when} \quad \Delta TR_i < 0 \tag{4}$$

In general, time series data usually confront with spurious regression when used to find the correlation by linear regression due to non-stationary data. This caused a significant correlation of the independent variables, but with a low R^2. Thus, those data were tested for stationarity before use. Thus, the data of EN and TR were tested for stationarity or a unit root test by an Augmented Dickey-Fuller Test (ADF) of the Phillip-Perron Test (PP test), with the following models:

None $$\Delta z_t = \alpha z_{t-1} + \Sigma_{i=1}^{p} \beta \Delta z_{t-i} + \varepsilon_t \tag{5}$$

Intercept $$\Delta z_t = \delta + \alpha z_{t-1} + \Sigma_{i=1}^{p} \beta \Delta z_{t-i} + \varepsilon_t \tag{6}$$

Intercept and Trending $$\Delta z_t = \delta + \eta\theta + \alpha z_{t-1} + \Sigma_{i=1}^{p} \beta \Delta z_{t-i} + \varepsilon_t \tag{7}$$

When z was the tested variable, t referred to the duration, α was the coefficient of z, δ referred to the intercept, $\eta\theta$ was the trend, $\Sigma_{i=1}^{p} \beta \Delta x_{t-i}$ was the autoregressive process term, and ε_t was the error in the model.

For the stationarity test by the ADF, α was obtained by the estimation of Eqs. (1-3). The data were stationary when $\alpha < 0$, and were interpreted into an ADF t-statistic for testing the hypothesis as follows:

$$ADF = \frac{(\hat{\alpha})}{SE(\hat{\alpha})} \tag{8}$$

The ADF of each variable was compared with the McKinnon critical value to test the main hypothesis that $\alpha = 0$. If the ADF obtained by the estimation was higher than the McKinnon critical value at the significance level, the main hypothesis could not be rejected, thus implying non-stationary data at the level of the tested data. In contrast, if the ADF obtained by the estimation was lower than the McKinnon critical value at the significance level, the main hypothesis would be rejected, thus implying stationary data. However, despite the non-stationary data to estimate the correlation by regression, that correlation could be reliable in case of cointegration. The method of testing contained the conditions of the stationary data sequence as the determiner, e.g., conditions of data stationarity at the same level as the Engle-Granger test and Johanson test, or the conditions of the stationary data sequence lower than the second rank of the difference for the ARDL and NARDL tests. Thus, the data of the EN and TR were tested for data stationarity in terms of the data levels and the first rank of the difference to consider the data stationarity of the cointegration test conditions in the following step. From the results of the data stationarity test, it was found that EN and TR contained different stationarity levels, but were lower than the second rank of the difference of correlation. Thus, cointegration was tested by ARDL and NARDL.

The ARDL and NARDL models were used for testing the cointegration. The effects of the previous dependent variables (autoregressive process term) and the current, as well as previous, independent variables that affected the current dependent variables were combined in the models. The difference was that the ARDL model would consider the symmetric influences of the positive and negative independent variables on the dependent variables. In contrast, the NARDL model believed in the asymmetric influences of the positive and negative independent variables on the dependent variables. Thus, the influences of the positive and negative changes of the independent variables on the dependent variables would be separated. This study applied the ARDL and NARDL models as follows:

ARDL model:
$$y_t = a_0 + a_1 t + a_2 Co_t + \sum_{i=1}^{k} b_i y_{t-i} + \sum_{j=1}^{l} c_j x_{t-j,} + u_t \tag{9}$$

NARDL model:
$$y_t = a_0 + a_1 t + a_2 Co_t + \sum_{i=1}^{k} b_i y_{t-i} + \sum_{j=0}^{l} c_j^+ x_{t-j}^+ + \sum_{k=0}^{m} c_k^- x_{t-k}^- + v_t \tag{10}$$

According to Eq. (9) and Eq. (10), u_t and v_t were the errors of the models when y was the considered dependent variable. x was the independent variable. x^+ was the sum of the positive change of the independent variable. t_0 to l, x^- was the sum of the positive change of the independent variable. t_0 to $m, j,$ and k as the lag. a_0 was the intercept. $a_1 t$ was the trend. a_2 was the influence of COVID-19. b_i was the influence of the previous y affecting the current y. c_j was the influence of the independent variable during $t-k$ on y. c_j^- was the negative change of the independent variable during $t-k$ on y. c_j^+ was the positive change of the independent variable during $t-k$ on y. The lags of the variables in the models were set by the Akaike information criterion (AIC), which caused the smallest loss of data in the estimation.

The ARDL and NARDL models could be transformed into three different models for further consideration, i.e., the condition error correction form (CEC form) for the cointegration bound test and estimation of the error correction term, post regression derivation of long-run dynamics for the finding the long-run relationship, and the model of the error correction mechanism to confirm the cointegration and speed of adaptation to the equilibrium in the long run. For the cointegration test process based on the concept of the bound test, it was considered by the CEC form of the ARDL and NARDL models, which were modified from the models of Eq. (9) and Eq. (10). Pesaran et al. (2001) differentiated the CECM into five cases as follows.

Case 1: The model with neither the intercept nor trend.
Case 2: The model with a restricted intercept but without a trend.
Case 3: The model with neither a restricted intercept nor trend.
Case 4: The model without a restricted intercept but with a restricted trend.
Case 5: The model with neither a restricted intercept nor restricted trend.

According to the primary estimation to find suitable models based on the consideration of normality, heteroskedasticity, and autocorrelation, the results of the model stability test by a cumulative sum (CUSUM) and CUSUM square found that the suitable model to study the influences of EN on TR was Case 1 for the ARDL model, and Case 2 for the NARDL model. Simultaneously, the suitable model to consider the influences of TR on EN was Case 4 that was analyzed by the NARDL model. However, using the ARDL model for the analysis revealed the problems of heteroskedasticity and autocorrelation in the models of all cases. Nonetheless, this study presented the results from Case 4, which contained a similar structure to the consideration in the form of the NARDL model. The analysis results in this part were not confirmed. As a result, the CEC form of the ARDL and NARDL models used in this study contained the following characteristics:

The CEC form of the ARDL model: Case 1: The model with neither an intercept nor trend (None).

$$\Delta TR_t = a_2 Co_t + b_0 TR_{t-1} + b_1 EN_{t-1} + c_1 \Delta \mathrm{EN_t} + \Sigma_{i=1}^{j-1} d_i \Delta TR_{t-j} + \Sigma_{l=1}^{q-1} e_l \Delta EN_{t-l_j} + \epsilon_t \tag{11}$$

The error term could be calculated by

$$EC_t = TR_t - \frac{b_1}{b_0} EN_t \tag{12}$$

The properties of the cointegration bound test or long-run relationship was considered by the F-statistic based on the following hypothesis test:

$H_0: b_0 = b_1 = 0$ Non-cointegratio

$H_1: b_0 \neq b_1 \neq 0$ Cointegration

The CEC form of the NARDL model: Case 2: The model with the restricted intercept and trend.

$$\Delta TR_t = a_0 + a_2 Co_t + b_0 TR_{t-1} + b_1 EN_{t-1}^{+} + b_2 EN_{t-1}^{-} + c_1 \Delta \mathrm{EN}_{\mathrm{j,t}}^{+} + c_2 \Delta \mathrm{EN}_{\mathrm{j,t}}^{-} + \Sigma_{i=1}^{j-1} d_i \Delta TR_{t-j} + \Sigma_{l^{+}=1}^{q^{+}-1} e_{l^{+}}^{+} \Delta EN_{t-l}^{+} + \Sigma_{l^{-}=1}^{q^{-}-1} e_{l^{-}}^{-} \Delta EN_{t-l}^{-} + \epsilon_t \tag{13}$$

The errror term could be calculated by

$$EC_t = TR_t - \left(\frac{b_1}{b_0} EN_t^{+} + \frac{b_2}{b_0} EN_t^{-}\right) - \frac{a_0}{b_0} \tag{14}$$

The properties of the cointegration bound test or long-run relationship was considered by the F-statistic based on the following hypothesis test:

$H_0: b_0 = b_1 = b_2 = 0$ Non-cointegration

$H_1: b_0 \neq b_1 \neq b_2 \neq 0$ Cointegration

The CEC form of the ARDL model: Case 4: The model with the restricted intercept and restricted trend.

$$\Delta EN_t = a_0 + a_1 t + a_2 Co + b_0 EN_{t-1} + b_1 TR_{t-1} + c_1 \Delta \mathrm{TR_t} + \Sigma_{i=1}^{j-1} d_0 \Delta EN_{t-j} + \Sigma_{l=1}^{q-1} e \Delta TR_{t-l_j} + \epsilon_t \tag{15}$$

The error term could be calculated by

$$EC_t = EN_t - \frac{b_1}{b_0} TR_t - \frac{b_1}{b_0} t \tag{16}$$

The properties of the cointegration bound test or long-run relationship was considered by the F-statistic based on the following hypothesis test:

$H_0: b_0 = b_1 = a_1 = 0$ Non-cointegration

$H_1: b_0 \neq b_1 \neq a_1 \neq 0$ Cointegration

The CEC form of the NARDL model: Case 4: The model with the restricted intercept and restricted trend.

$$\Delta EN_t = a_0 + a_1 t + a_2 Co + b_0 EN_{t-1} + b_1 TR_{t-1}^{+} + b_2 TR_{t-1}^{-} + c_1 \Delta \mathrm{TR}_{\mathrm{j,t}}^{+} + c_2 \Delta \mathrm{TR}_{\mathrm{j,t}}^{-} + \Sigma_{i=1}^{j-1} d_0 \Delta EN_{t-j} + \Sigma_{l^{+}=1}^{q^{+}-1} e_l^{+} \Delta TR_{t-l}^{+} + \Sigma_{l^{-}=1}^{q^{-}-1} e_l^{-} \Delta TR_{t-l}^{-} + \epsilon_t \tag{17}$$

The error term could be calculated by

$$EC_t = EN_t - \left(\frac{b_1}{b_0} TR_t^{+} + \frac{b_2}{b_0} TR_t^{-}\right) - \frac{a_1}{b_0} t \tag{18}$$

The properties of the cointegration bound test or long-run relationship was considered by the F-statistic based on the following hypothesis test:

$H_0: b_0 = b_1 = b_2 = a_1 = 0$ Non-cointegration

$H_1: b_0 \neq b_1 \neq b_2 \neq a_1 \neq 0$ Cointegration

In case the relationship contained cointegration, long-run influences between the dependent and independent variables could be calculated from the model as the post regression derivation of the long-run dynamics as follows:

The ARDL model

$$y_t = a_0 + a_1 t + a_2 Co + \Sigma_{i=1}^{p} b_i y_{t-i} + c_1 x_t + \Sigma_{l=1}^{q-1} \mathrm{d_l} \Delta x_{t-l} + \epsilon_t \tag{19}$$

Conditions

$$\alpha_1 = \frac{a_1}{1 - \Sigma_{i=1}^{p} b_i} \tag{20}$$

$$\beta_1 = \frac{c_1}{1 - \Sigma_{i=1}^{p} b_i} \tag{21}$$

where α_1 was the influence of the trend, and β_1 was the influence of the independent variable on the variable that was being considered.

The NARDL model

$$y_t = a_0 + a_1 t + a_2 Co + \Sigma_{i=1}^{p} b_i y_{t-i} + c_1^+ x_t^+ + c_1^- x_t^- + \Sigma_{l^+=1}^{q^+-1} \mathrm{d}_{\mathrm{l}^+}^+ \Delta x_{t-l^+} + \Sigma_{l^-=1}^{q^--1} \mathrm{d}_{\mathrm{l}^-}^- \Delta x_{t-l^-}^- + \epsilon_t \tag{22}$$

Conditions

$$\alpha_1 = \frac{a_1}{1 - \Sigma_{i=1}^{p} b_i} \tag{23}$$

$$\beta_1^+ = \frac{c_1^+}{1-\Sigma_{i=1}^{p} b_i} \tag{24}$$

and $$\beta_1^- = \frac{c_1^-}{1-\Sigma_{i=1}^{p} b_i} \tag{25}$$

where α_1 was the influence of the trend, β_1^+ was the influence of the positive change of the independent variable on the variable that was being considered, and β_1^- was the influence of the negative change of the independent variable on the variable that was being considered. In addition, the estimated results of the CEC form in the ARDL and NARDL models could take the error term obtained by the estimation to create the error correction mechanism (ECM) as follows:

The ECM model from the ARDL model

$$\Delta y_t = \alpha_1 Co_t + \alpha_2 EC_{t-1} + \Sigma_{i=1}^{n-1} \beta_1 \Delta y_i + \Sigma_{i=0}^{n-1} \beta_2 \Delta x_i + u_t \tag{26}$$

The ECM model from the NARDL model

$$\Delta y_t = \alpha_1 Co_t + \alpha_2 EC_{t-1} + \Sigma_{i=1}^{n-1} \beta_1 \Delta y_i + \Sigma_{i=0}^{n-1} \beta_2^+ \Delta x_i^+ + \Sigma_{i=0}^{n-1} \beta_2^- \Delta x_i^- + u_t \tag{27}$$

α_2 was the speed of adaptation to the long-run equilibrium. If the estimated α_2 was significantly negative, the cointegration between the independent and dependent variables would be confirmed. After considering the long-run relationship by the ARDL and NARDL models, The NARDL model would add symmetry between the positive and negative influences of the independent variables on the dependent ones by the long-run asymmetric test and short-run asymmetric test. The estimated results of the CEC form in the NARDL model were tested by the F-statistic. The hypothesis for the test was as follows:

Long-run asymmetric test

H_0: $\frac{b_1}{b_0} = \frac{b_2}{b_0}$ Long-run symmetric

H_0: $\frac{b_1}{b_0} \neq \frac{b_2}{b_0}$ Long-run asymmetric

If the main hypothesis could not be rejected, it could be said that the change of the independent variables in the positive and negative directions would result in no difference of the long-run change in the independent variables. After considering the long-run relationship test between EN and TR as per the suggested method, the estimated results of the CEC form from those models could be applied to test the causality between the variables. However, without the lag of the independent variables to be considered, the vector autoregressive model could be applied to set the lag by the AIC to consider this characteristic. This study used the vector autoregressive model for testing with the following characteristic:

$$y_t = a_0 + \Sigma_{i=1}^{p} b_i y_{t-i} + \Sigma_{j=1}^{q} c_i x_{t-j} + e_t \tag{28}$$

According to the estimated results, the Granger causality could be considered based on the following hypotheses:

$H_0: c_1 = c_2 = \ldots = c_j = 0$ x was not the Granger causality of y.
$H_1: c_1 \neq c_2 \neq \ldots \neq c_j \neq 0$ x was the Granger causality of y.

4. Results

According to the stationarity test by the ADF test and PP test, it was found that EN had stationarity at Level I (1) for both methods. In contrast, TR contained stationarity at the data level for the models with the intercept and trend in the stationarity test by the ADF test. However, it was stationary at Level I (1) for the models with neither the intercept and trend and by the PP test (Tables 1 and 2).

Table 1
Stationarity test by the Augmented Dickey-Fuller test.

Variables	Level			First Difference		
	None	Intercept	Intercept and Trend	None	Intercept	Intercept and Trend
EN	0.6705	-2.4099	-2.2693	-8.806***	-8.7994***	-9.1287***
TR	-0.6445	-4.039***	-4.4369***	-7.1696***	-7.0754***	-6.9998***

Notes: *** Significance level of 99%. ** Significance level of 95 %. * Significance level of 90 %.
Source: Author's estimation.

Table 2
Stationarity test by the Phillip-Perron test.

Variables	Level			First Difference		
	None	Intercept	Intercept and Trend	None	Intercept	Intercept and Trend
EN	0.9155	-2.3544	-2.0632	-9.0374***	-9.0106***	-21.5017***
TR	-0.5815	-2.3893	-2.3692	-7.2208***	-7.1225***	-7.0632***

Notes: *** Significance level of 99%. ** Significance level of 95 %. * Significance level of 90 %.
Source: Author's estimation.

If these data were brought for the analysis regression equation, the estimated results would contain errors. Furthermore, due to the stationarity at the different levels, cointegration could not be calculated by the Engle-Granger test and Johansen test but by the ARDL model instead. This removed the conditions of stationarity at the different levels. However, those data would need to contain stationarity lower than I (2). Nevertheless, the correlation might be influenced differently by the positive and negative changes. Thus, cointegration should be tested to find the long-run relationship. The NARDL model should also be used for separating the positive and negative influences on the dependent variables.

Table 3
ARDL and NARDL regression models

Model	Independent Variable	Coefficient	t-statistic	lag	AIC	LM test	Breusch-Pagan test	Jarque-Bera
ARDL TR → EN (Case 4)	EN_{t-1}	0.1231	0.7608	(4,2)	16.7634	9.5054***	3.3648***	2.9157
	EN_{t-2}	0.1386	0.7466					
	EN_{t-3}	0.1775	1.0753					
	EN_{t-4}	0.3738	2.246**					
	TR	0.0024	2.4795**					
	TR_{t-1}	-0.0008	-0.7539					
	TR_{t-2}	-0.0016	-1.8215*					
	Co	-1405.447	-1.1003					
	C	8579.289	0.9952					
	$TREND$	3.8748	0.0591					
ARDL EN → TR (Case 1)	TR_{t-1}	0.5463	3.7922***	(3,1)	26.9915	0.5744	1.6799	1.9829
	TR_{t-2}	0.2061	1.3538					
	TR_{t-3}	-0.3677	-2.9946***					
	EN	62.8302	3.1236***					
	EN_{t-1}	-40.3424	-1.8797*					
	Co	-337522.7	-3.5542***					
NARDL Tr → EN (Case 4)	EN_{t-1}	0.1845	1.2983	(1,0,0)	16.7828	0.0676	1.9265	5.2413*
	TR^{+}	-0.0023	-1.462					
	TR^{-}	0.0026	2.2226**					
	Co	-2496.322	-2.0567**					
	C	31703.15	5.8509***					
	$TREND$	527.273	3.1181***					
NARDL EN → Tr (Case 2)	TR_{t-1}	0.6035	3.8704***	(4,0,4)	26.6919	1.2659	0.4560	0.7309
	TR_{t-2}	0.3049	1.5488					
	TR_{t-3}	-0.537	-2.9786***					
	TR_{t-4}	0.3735	2.1696**					
	$EN\wedge +$	-45.5	-1.7912*					
	$EN\wedge -$	94.0415	2.6582**					
	EN_{t-1}^{-}	-121.5873	-2.9959***					
	EN_{t-2}^{-}	-54.6509	-1.0426					
	EN_{t-3}^{-}	76.7821	1.654					
	EN_{t-4}^{-}	-114.3107	-2.5263**					
	$LOCK$	-665233.2	-4.2791***					
	C	507598.2	3.0136***					

Notes: *** Significance level of 99%. ** Significance level of 95 %. * Significance level of 90 %.
Source: Author's estimation.

As shown in Table 3 and the analysis results of the model stability by the CUSUM and CUSUM square (Nonthapot & Srichaiyo, 2017) which is presented from Figs. 2-5, this displayed the estimated results of the primary relationship between EN and TR by the ARDL and NARDL models. It was also found that the model displaying the relationship from the TR to EN had the problems of heteroskedasticity and autocorrelation, which could cause errors of interpretation. Thus, this study would not conclude the analysis of this model. Simultaneously, no problems were significantly found from the estimated results by other models (p<0.05).

Table 4
ARDL and NARDL conditional error correction form results

Model	Independent Variable	Coefficient	t-statistic	Bound Test (F-statistic)
ARDL TR → EN (Case 4)	C	8579.289	0.9952	2.3577
	$@TREND$	3.8748	0.0591	
	EN_{t-1}	-0.1869	-0.7835	
	TR_{t-1}	0	-0.0027	
	ΔEN_{t-1}	-0.6899	-2.7508**	
	ΔEN_{t-2}	-0.5513	-2.9316***	
	ΔEN_{t-3}	-0.3738	-2.246**	
	ΔTR	0.0024	2.4795**	
	ΔTR_{t-1}	0.0016	1.8215*	
	Co	-1405.45	-1.1003	
ARDL EN → TR (Case 1)	TR_{t-1}	-0.6153	-4.8781***	11.9493***
	EN_{t-1}	22.4878	4.7817***	
	ΔTR_{t-1}	0.1616	1.2774	
	ΔTR_{t-2}	0.3677	2.9946***	
	ΔEN	62.8302	3.1236***	
	Co	-337522.7	-3.5542***	
NARDL Tr → EN (Case 4)	C	31703.15	5.8509***	8.6361***
	$TREND$	527.273	3.1181***	
	EN_{t-1}	-0.8155	-5.7396***	
	TR^{+}	-0.0023	-1.462	
	TR^{-}	0.0026	2.2226**	
	Co	-2496.322	-2.0567**	
NARDL EN → Tr (Case 2)	C	507598.2	3.0136***	9.5591***
	TR_{t-1}	-0.2551	-1.7168*	
	EN^{+}	-45.5	-1.7912*	
	EN^{-}	-119.7253	-2.6809**	
	ΔTR_{t-1}	-0.1414	-0.7488	
	ΔTR_{t-2}	0.1634	0.8988	
	ΔTR_{t-3}	-0.3735	-2.1696**	
	ΔEN^{-}	94.0415	2.6582**	
	ΔEN^{-}_{t-1}	92.1795	1.5702	
	ΔEN^{-}_{t-2}	37.5286	0.6592	
	ΔEN^{-}_{t-3}	114.3107	2.5263**	
	Co	-665233.2	-4.2791***	

Notes: *** Significance level of 99%. ** Significance level of 95 %. * Significance level of 90 %.
Source: Author's estimation.

When considering the condition error correction in Table 4, it was found that apart from the ARDL model that considered the influences from the TR to EN with the detected problems as reported, all analyzed relationships had cointegration, or the independent and dependent variables had a long-run relationship.

CUSUM and CUSUM square test

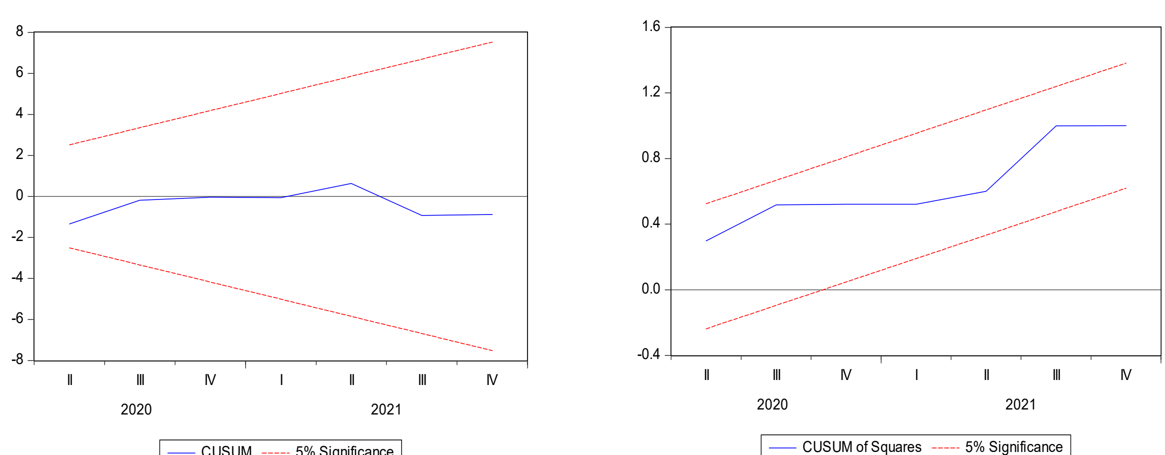

Fig. 2. CUSUM and CUSUM square test of Tr → EN in the ARDL model

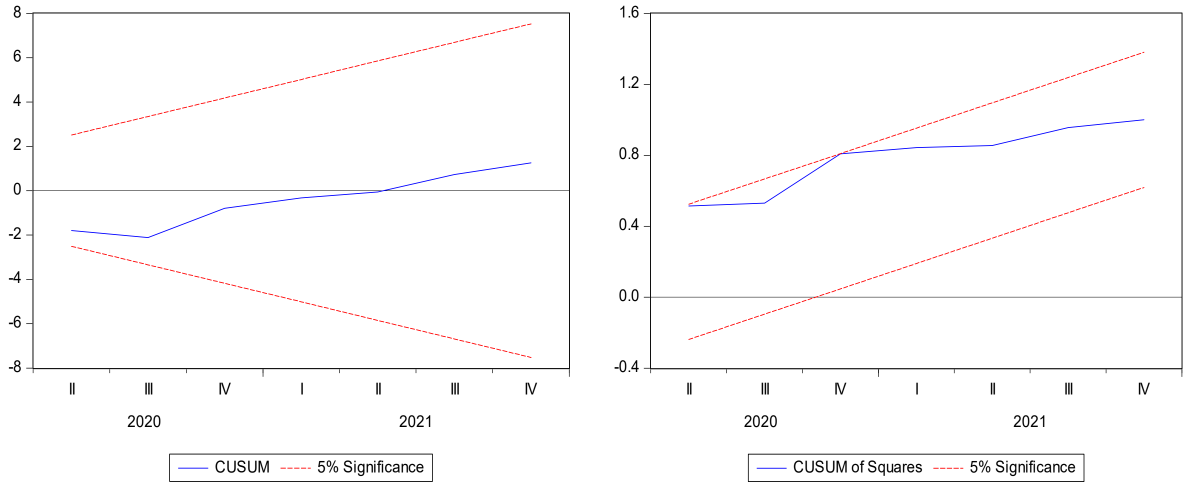

Fig. 3. CUSUM and CUSUM square test of EN → Tr in ARDL model.

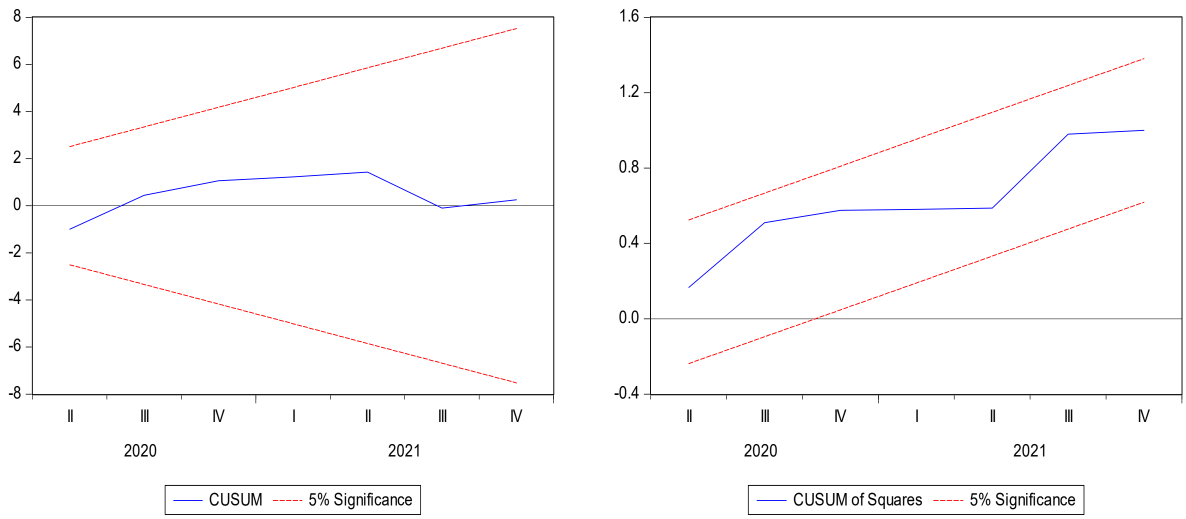

Fig. 4. CUSUM and CUSUM square test of Tr → EN in the NARDL model.

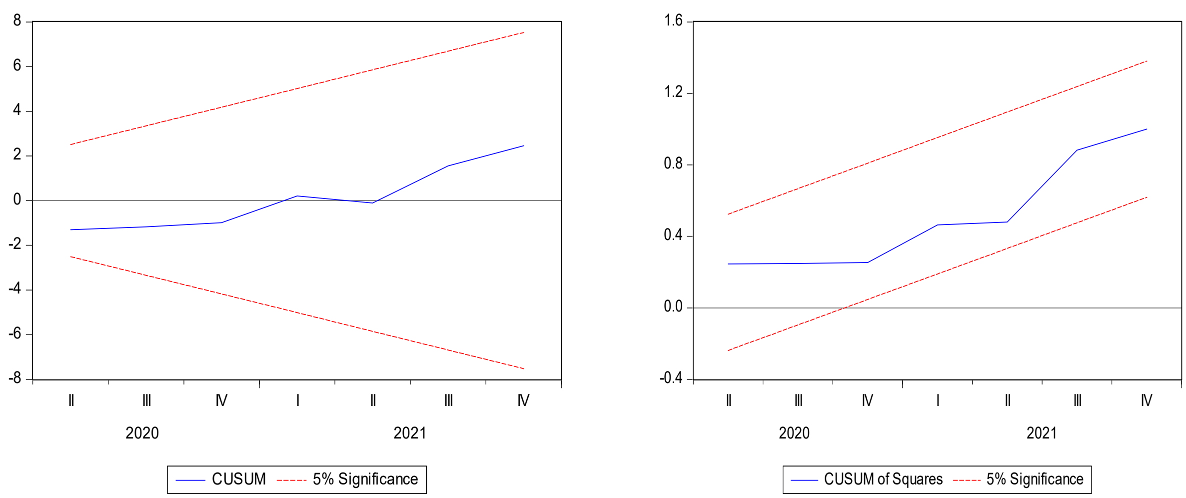

Fig. 5. CUSUM and CUSUM square test of EN → Tr in NARDL model.

According to the estimation of the long-run relationship, it was found that EN was a factor that significantly affected the change of the TR estimated by the ARDL model. The change of EN 1 KTOE would change TR 36,549.2 USD in the same direction. This was different from the analysis results by the NARDL model, which found that both the positive and negative changes of EN did not significantly change the TR. However, the influences of the positive and negative effects of changing the EN on the TR were significantly different, thus implying the asymmetric influences of change in both directions. Additionally, according to the estimated results of the long-run relationship from the TR to the EN by the NARDL model, it was found that only the positive change of the TR did not affect EN. Nonetheless, the negative effects and trend were the factors significantly influencing EN. The negative change of the TR 1 thousand USD affected the change of EN by 0.0032 KTOE in the same direction. It was also found that the influences of the positive and negative effects of changing the TR on EN were significantly different, thus implying the asymmetric influences of change in both directions.

Table 5
Long-run relationship.

Model	Dependent Variable	Independent Variable	Coefficient	t-statistic	Long-run Asymmetric Test (F-statistic)
ARDL	TR	EN	36.5492	33.2648***	
NARDL	EN	TR^{+}	-0.0028	-1.5224	-2.1894**
		TR^{-}	0.0032	2.2563**	
		$Trend$	646.5448	3.6193***	
	TR	EN^{+}	-178.36	-0.9386	3.5391***
		EN^{-}	-469.324	-1.1287	
		C	1989790	2.915***	

Notes: *** Significance level of 99%. ** Significance level of 95 %. * Significance level of 90 %.
Source: Author's estimation.

For the estimated results by the ECM in Table 6, it was found that EC obtained by the estimation in each model was significantly negative. This helped confirm the long-run relationship in each pair. In case of other factors that disturbed this long-run relationship, they would finally adapt to the equilibrium.

Table 6
ARDL and NARDL error correction regression results

Model	Dependent Variable	Independent Variable	Coefficient	t-statistic
ARDL	ΔTR	ΔTR_{t-1}	0.1616	1.2972
		ΔTR_{t-2}	0.3677	3.0388***
		ΔEN	62.8302	3.2037***
		Co	-337522.7	-3.8832***
		EC_{t-1}	-0.6153	-4.958***
NARDL	ΔEN	C	32230.43	6.153***
		Co	-2496.322	-4.9977***
		EC_{t-1}	-0.8155	-6.1111***
	ΔTR	ΔTR_{t-1}	-0.1414	-1.1092
		ΔTR_{t-2}	0.1634	1.2392
		ΔTR_{t-3}	-0.3735	-2.4253**
		ΔEN^{-}	94.0415	3.2738***
		ΔEN^{-}_{t-1}	92.1795	2.2776**
		ΔEN^{-}_{t-2}	37.5286	0.9531
		ΔEN^{-}_{t-3}	114.3107	3.0709***
		Co	-665233.2	-5.2849***
		EC_{t-1}	-0.2551	-6.518***

Notes: *** Significance level of 99%. ** Significance level of 95 %. * Significance level of 90 %.
Source: Author's estimation.

From the results of the tested Granger causality, it was found that in the case of no separation for the influences of the independent variables in accordance with the positive and negative changes, only unidirectional relationship from EN to TR was found. However, when separating the influences of the independent variables in accordance with the positive and negative changes, it was found that the setting from the TR to EN would contain only a negative change of the TR that affected the EN, which was from the EN to the TR that found both the positive and negative changes of EN on the TR.

Table 7
Granger causality test.

Model			Lag	Granger Causality (F-statistic)	Direction
ARDL	$TR \rightarrow EN$		2	-0.0027	Unidirection
	$EN \rightarrow TR$		2	19.6134***	
NARDL	$TR \rightarrow EN$	$TR^{+} \rightarrow EN$	2	-1.462	
		$TR^{-} \rightarrow EN$	2	2.2226**	
	$EN \rightarrow TR$	$EN^{+} \rightarrow TR$	2	-2.7532**	
		$EN^{-} \rightarrow TR$	2	6.2955***	

Notes: *** Significance level of 99%. ** Significance level of 95 %. * Significance level of 90 %.
Source: Author's estimation.

5. Discussion and Conclusions

From the results of this study, several interesting issues were found, i.e., the long-run relationship from EN to the TR, and unidirectional relationship from EN to the TR. This conformed to the study of Chai et al. (2016) and Davis and Boundy (2021). Only a lower TR generated long-run effects on EN along with different conclusions of the relationship between the EN and TR during the separation of considering the effects due to the increase and reduction of the independent variables and effects without the separation of change. For the descriptions of the long-run relationship from the EN to the TR, we might have to return to the characteristics of transportation and energy. The need for transportation has basically arisen from the derived needs for other things among humans. Simultaneously, energy is also indispensable to implement daily activities, including manufacturing, tourism, transportation, and the consumption of the local inhabitants. This would imply that energy consumption is a reflection of local activities. In case energy is used for manufacturing exports, transportation to partner countries would certainly be required. Furthermore, if it were used in tourism activities or tourism public relations, indirect effects of using energy could also generate value added for the TR through the number of tourists traveling to the country.

Next, for the unidirectional long-run relationship from EN to the TR, when the influences of the changing directions were not separated (observed from the results of the tested Granger causality), this part/issue would not conform to the research hypothesis. That was because EN was used as the factor that drove transportation. In fact, transportation should determine EN. However, if separating the consideration of the influences of the changing directions for the TR, it was found that this value was still the factor that determined EN, but only in the results of the lower TR. Thus, this effect might not appear when considering the influences of the total TR on EN. With reference to the previous issue, only the TR generated long-run EN. This issue appeared from the estimation of the long-run relationship and the results of the tested Granger causality, which did not find any influences of the TR on EN in Thailand. This relationship might have arisen from the reason that international transportation service providers could buy domestically and import energy to drive vehicles for the international transportation of humans and food. Thus, higher international transportation of Thailand generated the TR. Thus, it might not need to use all the sources of energy from Thailand. Still, the lower TR might be due to the transportation service providers themselves, which finally resulted in their lower EN for transportation, both imported and national energy. This effect appeared as per the analysis results. According to all issues as aforementioned, the involved energy agencies in Thailand should maintain the balance between EN and energy imports to be sufficient for driving a sustainable TR.

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