

Renewable Energy and Population for Sustainable Development in the Southeast Asian Countries

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Renewable Energy and Population for Sustainable Development in the Southeast Asian Countries

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Abstract

Background

The energy – environment – growth nexus has been examined for the Southeast Asian countries mainly using time series data. Few studies have been conducted using panel data. The roles of renewable energy and population have largely been ignored in previous studies. As such, this study is conducted to investigate a dynamic causal link between renewable energy usage, population, carbon emissions, and economic growth. Unlike previous panel data studies for the ASEAN region, a relatively new and advanced panel vector autoregressive model and the Granger non-causality test for heterogeneous panels are utilized using a sample of seven ASEAN countries for almost three decades since 1990.

Results

Key findings from this paper are as follows. *First*, energy consumption does lead to CO₂ emissions - a 1 per cent increase in energy consumption will lead to an increase of about 0.34 per cent CO₂ emissions which is lower than previously reported. *Second*, renewable energy usage explains a substantial proportion of the change in economic growth and energy consumption. Renewable energy also responds to population. *Third*, a bidirectional Granger causality between renewable energy, carbon emissions and population.

Conclusions

We argue that moderating population growth and extending renewable energy usage are important to achieve sustainable economic development in the ASEAN region.

Keywords: Renewable energy, Population, Carbon emissions, Economic growth, Granger non-causality, Panel vector autoregressive (panel VAR) model

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1 Introduction

A growing concern on the interaction among carbon emissions, economic growth, and energy consumption in different parts of the world has been driven by the adverse effect of greenhouse gas (GHG) emissions and the climate change. Climate change poses a threat to individuals' well-being both in a country and at a regional level. This concern appears to be more prevalent and severe in the Association of Southeast Asian Nations (ASEAN) region. The region has recorded significant economic growth over the past decades and has also expected to maintain its growth rate level in many years to come. The result of economic growth exerts increasing pressure on the demand for energy, which currently relies heavily on fossil fuel. The energy demand in the ASEAN region is expected to grow as much as 2.3 times (or 230 per cent) over the long-term projection to 2040 (ACE, 2017). ASEAN members have to make great efforts to adapt to climate change.

Unlike fossil fuel, renewable energy releases lesser CO₂ emissions, thus mitigating the negative impact on the environment. Apart from not being depleted, renewable energy offers a wide range of merits as increased energy security, sustainable economic growth, and pollution reduction (Can Şener et al., 2018). The ASEAN members have realized that the adoption of renewable energy is associated with the reducing reliance on fossil fuels, thus ensuring targeted economic growth and achieving energy security, affordability and sustainability. Within the framework of ASEAN Economic Community (ACE), the members continue improving technological innovation, reducing the costs of renewable energy and setting a target that renewable energy will account for 23 per cent of total energy supply by 2025 (ACE, 2017). As such, proper policies and investment should be considered.

Most previous studies on the relationship between energy consumption, economic growth, and environmental quality have focused on a particular country in the ASEAN region, for example, for Cambodia (Ozturk and Al-Mulali, 2015), Indonesia (Shahbaz et al., 2013; Sugiawan and Managi, 2016), Malaysia (Ali et al., 2017a, 2017b; Ang, 2008; Begum et al., 2015; Saboori et al., 2016; Saboori and Sulaiman, 2013a; Sulaiman and Abdul-Rahim, 2017; Tang and Tan, 2014), Thailand (Kyophilavong et al., 2015), and Vietnam (Al-Mulali et al., 2015; Nguyen et al., 2019; Shahbaz et al., 2019; Tang et al., 2016). Earlier studies have also approached a number of ASEAN

countries (Chandran and Tang, 2013; Mahi et al., 2020; Munir et al., 2020; Saboori and Sulaiman, 2013b; To et al., 2019; A. T. Vo et al., 2019). However, the short timeframe may be the most concerned limitation for empirical studies using the time series data as data may be not sufficient in developing countries (Ouyang and Li, 2018).

Some studies have utilized panel econometrics techniques to examine the link between CO₂ emissions and economic growth, energy consumption and different factors in the ASEAN region. Using panel quantile regression, Zhu et al. (2016) evaluated the influence of foreign direct investment (FDI), economic growth, and energy consumption on CO₂ emissions for ASEAN-5 countries, namely Indonesia, Malaysia, the Philippines, Singapore and Thailand over the period of 1981-2011. To investigate the dynamic causal relationship between CO₂ emissions, economic growth, and energy consumption using the same sample of ASEAN-5 over the period of 1970-2016, Munir et al. (2020) took the cross-sectional dependence into account for the panel analysis, while Heidari et al. (2015) applied the panel smooth transition regression (PSTR) model and the panel quantile regression. In these panel data studies, we note that the roles of renewable energy and population to economic growth have largely been ignored.

It appears that the empirical research that incorporates renewable energy in energy consumption - economic growth - environmental quality nexus in the ASEAN region is an understudied topic. A few empirical studies have been found. Rahman and Velayutham (2020) investigated the different impact of renewable and non-renewable energy consumption on economic growth for a panel of five ASEAN countries. They showed the positive effect of energy consumption on economic growth, both renewable and non-renewable. Liu et al., (2017) explored the effect of per capita renewable energy consumption on CO₂ emissions for ASEAN-4 countries, namely Indonesia, Malaysia, the Philippines, and Thailand, using the time-series data analysis. They revealed that an increase in renewable energy consumption decreases the level of CO₂ emissions, supporting the view that the adoption of renewable energy appears to be a cure for environment degradation. Nathaniel and Khan (2020) considered the impact of renewable and non-renewable energy consumption on environmental degradation for a panel of ASEAN countries, in which economic growth, urbanization and trade are used as controlled variables. Nathaniel and Khan's (2020) adopted an ecological footprint as an environmental indicator. Like Munir et al.

(2020), they took the cross-sectional dependence into account. They documented that economic growth and non-renewable energy consumption were the main sources of environmental degradation in the long run. However, renewable energy consumption does not affect the level of environmental degradation in the long run, not only the whole panel of ASEAN countries but also for the individual country in the sample. As such, we consider that the above-mentioned analyses require more empirical studies exploring the role of renewable energy on the energy consumption-economic growth-environmental quality nexus in the ASEAN region using panel data.

Given the increasingly important role played by renewable energy in enhancing economic growth and lessening the amount of CO₂ emissions into the environment together with an increasing population of the ASEAN members, the main focus of this paper is to examine the dynamic causal link between population, renewable energy and economic growth in association with carbon emissions and energy consumption. Seven ASEAN members, the ASEAN-7, namely Indonesia, Malaysia, Myanmar, the Philippines, Singapore, Thailand and Vietnam, are utilized depending on the data availability over the 1990-2014 period.

Our study differs from other previous studies in two aspects. *First*, we focus on a sample of the ASEAN countries using panel data for providing new insights on a traditional relationship between energy consumption and economic growth. In this paper, renewable energy usage, which has recently gained attention and debate among scholars, is examined. The focus of ASEAN-7 makes our paper contribute significantly to the current empirical literature and to provide policy implications for ASEAN members and other emerging markets. A number of studies appear to confirm the important role of renewable energy in boosting economic growth, reducing the amount of carbon emissions and contributing to a higher demand for energy usage. Little attention has been paid to the ASEAN region (Liu et al., 2017; Nathaniel and Khan, 2020; Rahman and Velayutham, 2020). Understanding the causal relationship among population, renewable energy usage, and economic growth would help policymakers prepare proper strategies in the process towards the adoption and implementation of renewable energy and energy-intensive policies.

Second, a recently developed panel vector autoregressive (VAR) model is utilized in this paper. Unlike other empirical studies in the ASEAN region that reveals the long-run relationship among variable, we are interested in the short-run relationship among renewable energy usage,

energy consumption economic growth, population, and CO₂ emissions. Our paper is the first of its kind that employs an advanced econometrics approach for a sample of seven ASEAN countries. The panel VAR model is estimated using the system generalized method of moment (GMM) estimator rather than the ordinary least square (OLS) method. Therefore, the model yields a more efficient and robust estimator (Acheampong, 2018; Love and Zicchino, 2006). Also, the panel VAR framework can deal with the potential issue of endogeneity. The approach allows to treat all the concerned variables as endogenous, place them in a system of equations, and control the country fixed effects as well as the lagged interdependence. Finally, the panel VAR model has been increasingly attractive among scholars in the energy economic literature (i.e. Acheampong, 2018; Love and Zicchino, 2006).

The paper is organized as follows. Following this Introduction, section 2 discusses relevant theories and empirical studies related to the above variables. The methodology is presented in section 3, while section 4 presents data descriptions and empirical results. Our concluding remarks are in section 5.

2 Literature review

The topic of causal links between CO₂ emissions, economic growth, and energy consumption has been widely discussed in energy economics. Various directional causalities have been extensively investigated for the developed world. For example, Tzeremes (2018) verified the time-varying causalities between CO₂ emissions, energy consumption, and economic growth of 50 U.S. states from 1960 to 2010 using a time-varying VAR approach. Kalaitzidakis et al. (2018) found that CO₂ emissions contributed positively and significantly to economic growth for a sample of 18 OECD nations from 1981 to 1998, using a semiparametric smooth coefficient model.

Ang (2008) investigated the relationship between economic growth, CO₂ emissions, and energy use for Malaysia over the period 1971-1999 using causality tests on the ground of the Error-Correction Model (ECM) framework. The paper found unidirectional causality running from economic growth to energy consumption. The results were robust for both long- and short-run tests. Fatai et al. (2004) found a bidirectional Granger causality between energy consumption and economic growth for the Philippines and Thailand. Similar bidirectional causality was found by

Lim et al. (2014) for the Philippines over the period 1965-2012 using the ECM-based Granger causality test. Using a similar approach, Hwang and Yoo (2014) found a Granger causality running from economic growth to energy consumption, without feedback effects for Indonesia over the period 1965-2006.

Also, the causal link between CO₂ emissions and energy consumption has gained great attention from scholars. Hwang and Yoo (2014) revealed a bidirectional causality between CO₂ emissions and energy consumption for the case of Indonesia. Saboori and Sulaiman (2013b) employed VECM to detect the causal link between CO₂ emissions and energy consumption for ASEAN-5 countries over the period 1971-2009. Long-run causality from energy consumption to CO₂ emissions is found in Malaysia, the Philippines, Singapore and Thailand while short-run causality is observed in Indonesia, Malaysia, the Philippines and Singapore. Moreover, the study found that estimated elasticities, in the long run, were larger than the short run, implying that the effect of energy consumption on CO₂ emissions increases over time in the surveyed countries.

Shahzad et al. (2017) found evidence of an inverted U-shaped relationship between energy consumption and CO₂ emissions in Pakistan from 1971 to 2011, using an ARDL bound tests framework. The threshold effect of energy consumption where the impact of energy consumption on CO₂ emissions is positive below a certain threshold and becomes negative when energy use passes a turning point. The authors claimed that when energy consumption was below the threshold, the economy was expanding, thus consuming more energy, and producing more CO₂ emissions (scale effect). Moreover, economic development attracts more polluting industries (composition effect). When the economic development and energy consumption are above the threshold, more efficient technologies are applied, leading to less pollution (technology effect).

The sources of energy consumption play a significant role in the relationship between energy consumption and environmental degradation. Al-Mulali et al. (2015) found a significantly positive relationship between fossil fuel energy consumption and CO₂ emissions for Vietnam. The authors showed that renewable energy consumption and CO₂ emissions are negatively correlated. However, the link was insignificant. In contrast, Raza and Shah (2018) found evidence of a significantly negative link between CO₂ emissions and renewable energy for the G7 countries (including Canada, France, Germany, Italy, Japan, U.K., and the U.S.). Nguyen and Kakinaka

(2019) found that the relationship between renewable energy consumption and CO₂ emissions was dependent on the development stages of investigated countries, for 107 countries from 1990 to 2013. Their paper uses mean group estimators. Renewable energy consumption was positively correlated with CO₂ emissions and negatively correlated with economic growth for low-income countries. However, the outcomes were reversed for high-income countries. Solarin et al. (2017) found evidence for the negative impact of hydroelectricity on CO₂ emissions in China and India from 1965 to 2013, utilizing the ARDL bound testing approach. Recent literature on the nexus of carbon emissions, economic growth, energy consumption (in general) has also been considered from both market integration and (price) convergence perspectives. For instance, Nyangon et al. (2017) applied the Phillips–Sul convergence test to investigate energy market integration, price convergence, and supply-demand imbalance. Findings from this study enhance the understanding of the effects of increased U.S. shale energy consumption on solar energy consumption, carbon emissions and economic growth.

3 Model and methodology

3.1 Model specification

Our main objective is to analyze the causal link among renewable energy usage, population, the carbon emissions, energy consumption and economic growth. The choice of these variables is based on the Stochastic Impacts by Regression on population, affluence, and technology (STIRPAT) model, developed by Dietz and Rosa (1997) and recently applied by (Begum et al., 2015; Dong et al., 2018), population and economic activity are two main elements of CO₂ emissions. The energy-economic literature has been intensively investigated on the link between economic growth, energy consumption and environmental quality (see Tiba and Omri, 2017) for a review). Given an increasingly important role of renewable energy usage placed in contemporary energy literature (Edenhofer et al., 2013; Sadorsky, 2009; Salim and Rafiq, 2012), we add the variable of renewable energy in our analysis. The model specification is expressed as follows:

$$\ln co2pc_{i,t} = f(\ln gdppc_{i,t}, \ln pop_{i,t}, \ln recpc_{i,t}, \ln ecpc_{i,t}) \quad (1)$$

where i and t represent the number of countries and the time period, respectively. $co2pc_{it}$ is the amount of CO₂ emissions, and $gdppc_{i,t}$ is the real gross domestic product (GDP). $recpc_{i,t}$ is

the amount of renewable energy usage. $ecpc_{i,t}$ is energy consumption. $pop_{i,t}$ is the population size of each country i over the period of time t . Finally, ε_{it} is the error term, and “ln” denotes the nature of the logarithm. The given variables are in forms of logarithm so that we can interpret the estimated coefficients in terms of the elasticity, which show how many per cent of the amount of CO₂ change over a 1 per cent change in the independent variables. Table 1 shows descriptive statistics for the variables in this study.

Table 1. Data description

Variable	Obs.	Mean	Std. Dev.	Min	Max
lnco2pc	174	0.51	1.31	-2.29	2.89
lngdppc	174	7.97	1.38	5.26	10.86
lnpop	174	17.63	1.17	14.93	19.36
lnrecpc	174	5.07	0.84	2.00	6.16
lnecpc	174	6.83	0.97	5.54	8.91

Notes: **co2pc**: per capita CO2 emissions; **gdppc**: per capita real GDP; **pop**: population; **recpc**: per capita renewable energy consumption; **ecpc**: per capita energy consumption. “ln” represents the variables in terms of the logarithm.

3.2 Methodology

The panel VAR model is employed for the analysis on the dynamic causal link as it supplements sufficient information about the relationship among the variables of interest. The panel VAR technique has been employed in analyzing dynamic effects among variables in various areas of research (Ouyang and Li, 2018). The panel VAR framework treats all variables to be endogenous and controls the heterogeneity in the panel (Love and Zicchino, 2006; D. H. Vo et al., 2019). The panel VAR framework can be expressed as follows:

$$Y_{i,t} = A_0 + \sum_{s=1}^m A_s Y_{i,t-s} + c_i + d_{c,t} + \varepsilon_{i,t} \quad (2)$$

where i represents the number of cross-sectional countries and s is the lagged length, determined by the serial correlation test of the dependent variable. All the countries i at time t are

assumed to have the same structure in the model. Using a fixed-effects model will correlate with regressors owing to the lagged dependent variable and will generate bias estimation coefficients. Thus, we employ the panel VAR on the ground of the generalized method of moments (GMM) estimators by Arellano and Bond (1991) with lags of regressors as proposed by previous studies (Acheampong, 2018; Love and Zicchino, 2006; Ouyang and Li, 2018; D. H. Vo et al., 2019).

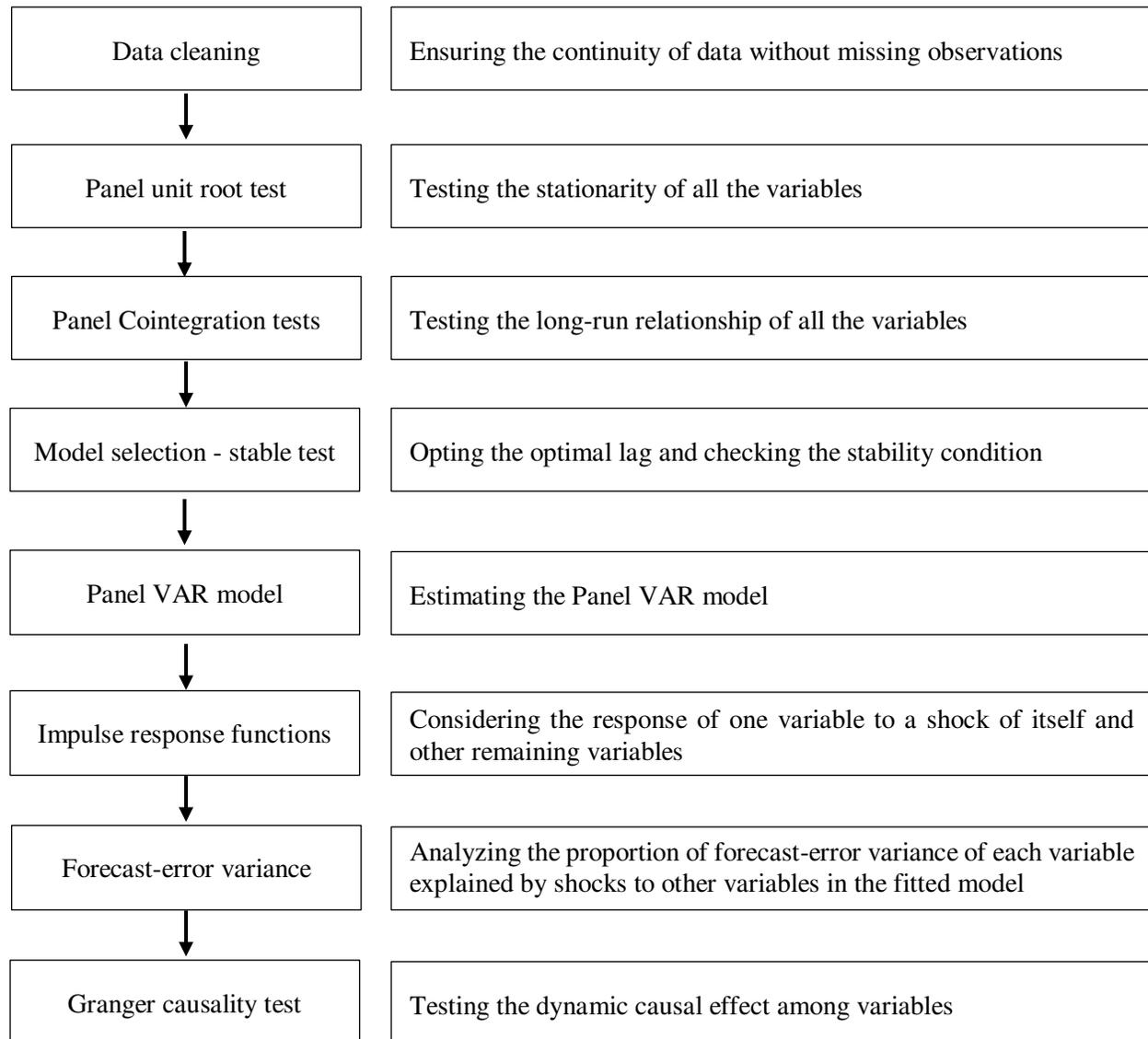
In this study, $Y_{i,t}$ consists of a set of five variables of concern, expressed a (1 x k) vector of endogenous variables.

$$Y_{i,t} = (\text{dlnc}o2pc, \text{dlngdppc}, \text{dlnpop}, \text{dlnrecpc}, \text{dlnecpc}) \quad (3)$$

A_s is the coefficient vector to be estimated. $\varepsilon_{i,t}$ denotes idiosyncratic errors, with $E(\varepsilon_{i,t}) = 0$, $E(\varepsilon'_{i,t} \varepsilon_{i,t}) = \Sigma$, and $E(\varepsilon'_{i,t} \varepsilon_{i,s}) = 0$ for $t > s$. $d_{c,t}$ is a country-specific time dummy to control the year effects, and c_i is to consider the fixed effects of the country in the equation (2).

The whole process of data analysis, which includes eight major steps, is depicted in the flowchart in Figure 1.

Figure 1. The procedure of data analysis



4 Results

To confirm whether the variables are stationary, we use the panel unit root test by Choi (2001). This panel-based test is a modified form from a standard Dickey-Fuller unit root test by Dickey and Fuller (1979) and includes four types of statistics, namely inverse chi-square, inverse normal, inverse logit and modified inverse chi-square. The results of these statistics are shown in Table 2. All four test statistics reject the null hypothesis of containing the unit root at the first difference rather than at the level, indicating all variables are integrated I(1).

Table 2. Unit-root tests based on (Choi, 2001)

	Inverse chi-squared	Inverse normal	Inverse logit t	Modified inverse chi-squared
	P	Z	L*	Pm
<i>The level</i>				
Inco2pc	10.46	0.28	0.31	-0.70
lngdppc	3.99	3.23	3.44	-1.89
lnpop	3.67	1.91	1.83	-1.95
lnrecpc	16.56	0.19	0.39	0.48
lnecpc	21.23*	-0.78	-0.83	1.36*
<i>The first difference</i>				
dlnco2pc	25.42**	-2.41***	-2.30**	2.16**
dlngdppc	25.39**	-2.23**	-2.19**	2.15**
dlnpop	70.30***	-1.56*	-5.31***	10.64***
dlnrecpc	42.91***	-4.05***	-4.31***	5.46***
dlnecpc	32.37***	-2.83***	-2.92***	3.47***

Notes: *** denotes the rejection of containing unit roots at a significance level of 1%. The test includes an intercept. One lag is included for lnpop and three lags for other remaining variables

To trace the existence of a long-run relationship, two widely-used cointegration tests for panel data are employed. Pedroni (2001, 1999) proposed critical inference and asymptotic properties for the residual-based test in dynamic panels and Westerlund (2007) suggested the error-correction-based cointegration tests for panel data.¹ The results of these panel cointegration tests are presented in Table 3. We conclude no cointegrating relationship is found among the selected variables as both tests fail to reject the null hypothesis of no cointegration.

¹ The panel cointegration tests by Pedroni (2001, 1999) and Westerlund (2007) are performed by the command `xtpedroni` and `xtwest` in Stata 15, respectively.

Table 3. Results of cointegration tests

The error-correction-based cointegration tests by (Westerlund, 2007)				
Statistics	Gt	Ga	Pt	Pa
Value	-2.82	-3.40	-5.06	-1.18
Z-value	1.04	3.30	0.58	2.83
P-value	0.15	1.00	0.72	1.00
The residual-based cointegration test by (Pedroni, 2001, 1999)				
Statistics	v	rho	t	ADF
Panel statistics	-0.66	0.09	-1.99	-1.53
Group statistics		1.12	-1.61	-1.08

Notes: In the error-correction-based cointegration tests by (Westerlund, 2007), *Gt* and *Ga* are the group-mean tests while *Pt* and *Pa* are the panel tests.

As all variables are $I(1)$ without cointegration, we use the first different data for the panel VAR framework. The procedure begins with the selection of optimal lag length. In Table 4, the first-order panel VAR is the preferred model as three criteria, namely MBIC, MAIC and MQIC, have the smallest value. We use one lag in the panel VAR model. After the panel VAR is fitted and stable, the moduli of the companion matrix based on the estimated parameters are calculated.

Table 4. The results of the optimal lag selection

lag	CD	J	J-pvalue	MBIC	MAIC	MHQIC
1	0.82	83.87	0.23	-282.34*	-66.13*	-153.99*
2	0.95	63.68	0.09	-180.46	-36.32	-94.89
3	0.79	28.77	0.27	-93.30	-21.23	-50.52

Notes: J and J-pvalue denote Hansen's J statistics and the corresponding p-value for testing over-identifying restrictions. CD: coefficient of determination, MBIC: moment model selection criteria (MMSC)-Bayesian information criterion (BIC), MAIC: MMSC-Akaike information criterion (AIC), MQIC: MMSC-Hannan and Quinn information criterion (HQIC).

Figure 2 depicts the eigenvalue stability condition by plotting all the real and imaginary eigenvalue in the companion matrix. The stability condition satisfies because the roots of the companion matrix are all inside the unit circle on the application of the panel VAR model (Abrigo and Love, 2016; Acheampong, 2018; Ouyang and Li, 2018).

Figure 2. Roots of the companion matrix

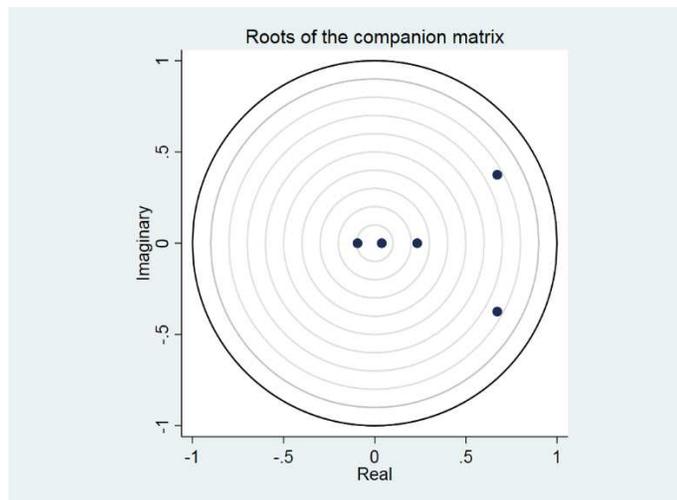


Table 5 presents the estimated results from the panel VAR analysis on the dynamic causal relationship among CO₂ emissions, economic growth, population size, renewable energy consumption, and energy consumption. *First*, for the result of CO₂ emissions in the first column, the results indicate that CO₂ emissions are negatively related to economic growth. *Second*, for the economic growth equation, the results report a positive link between economic growth and environmental degradation. Moreover, economic growth is found to be negatively related to energy consumption and population growth. It is observed from Table 5 that the usage of renewable energy has no effect on economic growth in the ASEAN region. Our result supports the claim by (Bekhet and Othman, 2018) that although renewable energy is increasingly adopted in the region, its role in promoting economic growth and supplementing energy consumption appears to be negligible as renewable energy has still accounted for a small proportion of the total energy consumption.

Table 5. Estimated results from the panel VAR.

	<i>Dependent variable</i>				
	dlnco2pc	dlngdppc	dlnpop	dlnrec	dlnec
<i>Independent variables</i>					
dlnco2pc(-1)	0.157*** [0.048]	0.021*** [0.007]	-0.014*** [0.001]	0.011 [0.012]	0.081*** [0.017]
dlngdppc(-1)	-1.019*** [0.190]	0.511*** [0.050]	0.104*** [0.011]	-0.087 [0.117]	-0.257*** [0.093]
dlnpop(-1)	-1.453 [1.035]	-1.721*** [0.258]	0.774*** [0.041]	-3.747*** [0.469]	-3.575*** [0.585]
dlnec(-1)	0.340*** [0.079]	-0.068*** [0.019]	0.000 [0.003]	-0.302*** [0.054]	0.042 [0.043]
dlnrec(-1)	-0.094*** [0.035]	0.005 [0.009]	-0.006*** [0.002]	0.037 [0.037]	-0.035 [0.031]

Notes: *** denotes the coefficients are at the significance level of 1%. The robust error terms are in square brackets.

co2pc: per capita CO₂ emissions; **gdppc**: per capita real GDP; **pop**: population; **recpc**: per capita renewable energy consumption; **ecpc**: per capita energy consumption. “ln” represents the variables in terms of the logarithm.

Third, our results show that population growth is positively related to economic growth, but negatively associated with CO₂ emissions and renewable energy. This supports for the Stochastic Impacts by Regression on population, affluence, and technology (STIRPAT) model that suggests population growth as an indispensable determinant of the economic activity and environment level. *Fourth*, for energy consumption, the results show that environment degradation positively causes energy consumption.

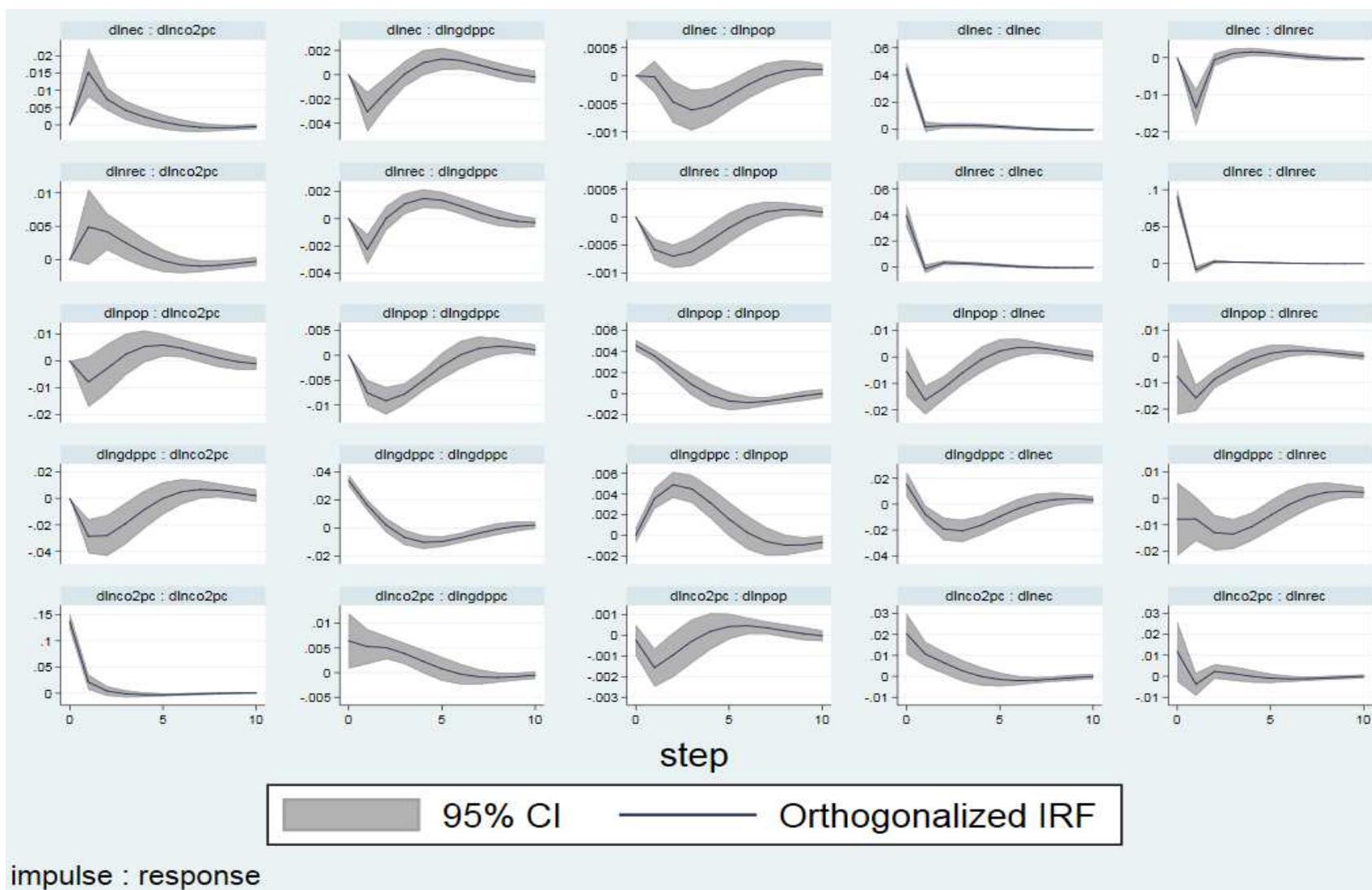
Figure 3 illustrates a response of a shock of (the growth of) energy consumption, renewable energy usage, population size, economic growth, and CO₂ emissions to the shock of itself and to other remaining variables. Notably, the response of the growth of energy consumption to a shock in the growth of renewable energy is positive at year 0 (step = 0) then it dies out completely in the next year. In contrast, it initially has a positive response to a shock in economic growth, then turns to negative in year 2 before dying out in year 5.

In the second column of Figure 3, economic growth is found to have the same responsive pattern to a shock of energy consumption and renewable energy usage, initially decreasing in year 1 and then increasing considerably in next two years before turning to zero at year 6. Economic growth reacts negatively to a shock of population growth and to respond positively to its own shock and a shock of CO₂ emissions. The IRFs results further support the findings from the panel VAR model in Table 5.

The response of population growth is presented in the third column of Figure 3. The responsive patterns of population growth to a shock of energy consumption, renewable energy usage, and CO₂ emissions are almost similar, depicting that the response initially decreases in the first two years and then die out after year 5. On the contrary, population growth has a statistically positive response to a shock of economic growth in the first two years before the response reduces gradually and dies out completely since the seventh year.

Next, as shown in the last two columns of Figure 3, both energy consumption and renewable energy usage seem to react the same to a shock of economic growth, CO₂ emissions and population. The implication is that both variables are strongly correlated with each other. However, the response of energy consumption to a shock of renewable energy declines dramatically from 0.04 to 0 after only a year, while the response of renewable energy to a shock of energy consumption is negative; it reduces to -0.02 in the first year before turning to zero in the second year.

Figure 3. The impulse response functions



Notes: The response of one variable to a shock of itself or another endogenous variable is depicted by a solid middle line, and the standard error bands are covered with two shaped lines. The response is statistically significant when the bands do not cross the zero line.

Table 6. The forecast error variance decomposition (FEVD)

Forecast horizon	Impulse variable				
	dlnc2pc	dlngdppc	dlnpop	dlnrec	dlnec
dlnc2pc					
1	1.000	0.000	0.000	0.000	0.000
2	0.944	0.040	0.003	0.011	0.001
4	0.889	0.091	0.003	0.014	0.002
6	0.883	0.094	0.006	0.014	0.002
8	0.879	0.097	0.008	0.014	0.002
10	0.877	0.099	0.008	0.014	0.002
dlngdppc					
1	0.035	0.965	0.000	0.000	0.000
2	0.045	0.909	0.037	0.006	0.003
4	0.062	0.816	0.113	0.006	0.003
6	0.057	0.817	0.114	0.007	0.005
8	0.056	0.820	0.111	0.008	0.005
10	0.056	0.817	0.113	0.008	0.005
dlnpop					
1	0.003	0.000	0.997	0.000	0.000
2	0.051	0.257	0.685	0.000	0.007
4	0.034	0.560	0.388	0.006	0.012
6	0.032	0.601	0.346	0.009	0.012
8	0.035	0.593	0.351	0.009	0.012
10	0.034	0.597	0.347	0.009	0.012
dlnrec					
1	0.016	0.007	0.007	0.000	0.970
2	0.017	0.014	0.034	0.020	0.915
4	0.017	0.050	0.042	0.019	0.872
6	0.017	0.066	0.041	0.019	0.857
8	0.017	0.066	0.042	0.019	0.855
10	0.017	0.067	0.043	0.019	0.854
dlnec					
1	0.098	0.055	0.007	0.474	0.366
2	0.113	0.062	0.063	0.429	0.331
4	0.101	0.190	0.082	0.353	0.274
6	0.095	0.237	0.078	0.332	0.258
8	0.096	0.237	0.081	0.330	0.256
10	0.095	0.240	0.082	0.328	0.254

Note: The results are based on orthogonalized impulse responses with 10 periods.

The IRFs functions can provide information in relation to the impact of variations of on endogenous variables on itself and other remaining variables in the model. However, the magnitude and the degree of such impacts do not take into account. As such, we perform the variance decomposition to provide more details. From Table 6, it is observed that a shock in CO₂ emissions does significantly cause variations in economic activity rather than in population, energy consumption and renewable energy usage. After ten periods, CO₂ emissions explain approximately 10 per cent of the variation in economic growth and a minority of the variations in three remaining variables. The fluctuations in economic growth explain about 11.3 per cent of variations of population growth and around 5 per cent of the changes in CO₂ emissions. Notably, the variation of the population has a profound contribution to the variation of economic growth, taking up to nearly 60 per cent after ten periods (years).

The results confirm a profound influence of renewable energy usage on four remaining variables. After ten years, renewable energy usage explains a proportion of about 25 per cent in the variation of economic growth and energy consumption and it accounts for nearly 10 per cent of the fluctuation of CO₂ emissions and population. Our results imply that it is essential for the ASEAN countries to put more investment on renewable energy development, to promote the adoption of renewable energy in a wider scale, and to accelerate the proportion of renewable energy in the energy mix. The results of the traditional Granger causality test on the causal effect between CO₂ emissions, renewable energy consumption, population, energy consumption, and economic growth are shown in Table 7.

Table 7. The result of Granger causality tests

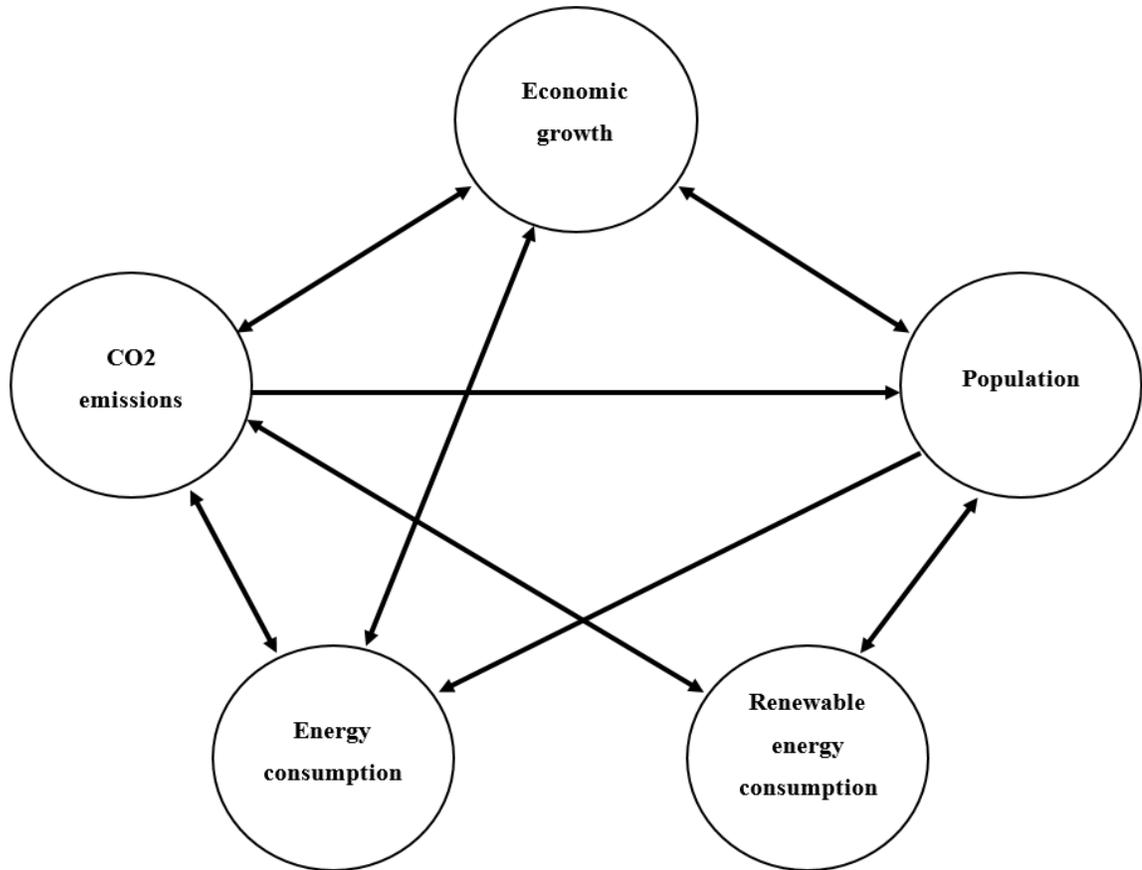
Null hypothesis	Traditional test		Dumitrescu and Hurlin test	
	Chi2-statistic	Prob.	Chi2-statistic	Prob.
dlnkdppc does not Granger-cause dlnco2pc	28.88	0.00	45.48	0.00
dlnpop does not Granger-cause dlnco2pc	1.97	0.16	0.27	0.60
dlnrecpc does not Granger-cause dlnco2pc	7.27	0.01	7.65	0.01
dlnecpc does not Granger-cause dlnco2pc	18.70	0.00	5.67	0.02
dlnco2pc does not Granger-cause dlnkdppc	8.41	0.00	195.50	0.00
dlnpop does not Granger-cause dlnkdppc	44.49	0.00	389.88	0.00
dlnrecpc does not Granger-cause dlnkdppc	0.34	0.56	16.06	0.00
dlnecpc does not Granger-cause dlnkdppc	13.60	0.00	16.15	0.00
dlnco2pc does not Granger-cause dlnpop	228.17	0.00	139.13	0.00
dlnkdppc does not Granger-cause dlnpop	88.80	0.00	221.83	0.00
dlnrecpc does not Granger-cause dlnpop	11.59	0.00	8.05	0.01
dlnecpc does not Granger-cause dlnpop	0.02	0.90	7.05	0.01
dlnco2pc does not Granger-cause dlnrecpc	0.90	0.34	5.23	0.02
dlnkdppc does not Granger-cause dlnrecpc	0.55	0.46	18.38	0.00
dlnpop does not Granger-cause dlnrecpc	63.77	0.00	83.50	0.00
dlnecpc does not Granger-cause dlnrecpc	31.02	0.00	28.73	0.00
dlnco2pc does not Granger-cause dlnecpc	23.44	0.00	11.94	0.00
dlnkdppc does not Granger-cause dlnecpc	7.59	0.01	135.84	0.00
dlnpop does not Granger-cause dlnecpc	37.32	0.00	15.59	0.00
dlnrecpc does not Granger-cause dlnecpc	1.28	0.26	6.98	0.01

Note: We refers the traditional test as panel VAR-Granger causality Wald test and the Dumitrescu and Hurlin test as heterogeneous-panel Granger non-causality test proposed by Dumitrescu and Hurlin (Dumitrescu and Hurlin, 2012).

Figure 4 shows bidirectional Granger causality between population growth and economic growth and renewable energy usage, which further confirms the impact of population growth on

economic activity and the use of renewable energy. For renewable energy usage, the results show that renewable energy usage bi-directionally causes population growth and CO₂ emissions. The results do not support the causal relationship between renewable energy and economic growth in the ASEAN region, which is in line with previous studies (Bekhet and Othman, 2018).

Figure 4. Empirical results from a traditional Granger causality test



It should be noted that the traditional panel-based causality test often assumes a homogeneity of slope coefficients on estimated parameters when a joint causality restriction is imposed. However, this assumption would be rather strong (Granger, 2003). Also, assuming slope parameters to be homogenous does not capture country-specific characteristics, which can suffer the issue of the heterogeneity. The panel-based Granger non-causality test by Dumitrescu and Hurlin (2012) allows taking the nature of heterogeneity into account. The test simplifies the standardized average Wald statistics. However, their efficient outcome is increasing significantly

with the power of traditional Granger causality tests, even in circumstances of limited T and N dimensions. A minor drawback is that when the null hypothesis is rejected, the test does not provide how many cross units in the panel are rejected. This study utilizes the Dumitrescu and Hurlin Granger non-causality test for heterogeneous panels to clarify a causal direction among carbon emissions, energy consumption, renewable energy consumption, economic growth, and population growth as a robustness check.

The results of the Dumitrescu and Hurlin panel-based Granger non-causality test are reported in the last two columns of Table 7.² Interestingly, the results further support the conclusion from the traditional Granger causality. In particular, all pairs of selected variables are observed to be bidirectional Granger cause each other. The bidirectional Granger causality exists.

5 Conclusions

This study investigates the dynamic relationship between carbon emissions, economic growth, energy consumption, population and renewable energy usage. A panel of seven ASEAN countries using the panel VAR framework is utilized for the analysis. The main findings from the paper can be summarized as follows. *First*, our results reveal a positive effect of energy consumption on CO₂ emission; a 1 per cent increase in energy consumption will lead to an increase of about 0.34 per cent CO₂ emissions. The estimated value is significantly lower than in previous studies. *Second*, we confirm a negative marginal effect of renewable energy usage on energy consumption. However, it is observed that after ten periods (years), renewable energy usage explains a substantial proportion in the variation of economic growth and energy consumption and it accounts for nearly 10 per cent of the fluctuation of CO₂ emissions and population. *Third*, we find bidirectional Granger causality among emissions, economic growth, and energy consumption. Also, a bidirectional Granger causality between renewable energy and carbon emissions and population growth is found. Important policy implications for the ASEAN region have emerged on the ground of these findings.

² The Dumitrescu and Hurlin panel-based Granger non-causality test is obtained using the software of Eviews 9.

ASEAN region has its own characteristics, so an investigation of the relationship between economic growth, carbon emissions and energy consumption for this region should be conducted separately. The ASEAN region has been acknowledged as one of the most dynamic economic regions in the world, recorded the most significant growth rate, and made transforming progress towards regional economic integration. Our results indicate that energy consumption seems to be an indispensable element in boosting and maintaining economic growth, and as a consequence, an increase in carbon emissions.

To a larger extent at the regional level, a strong relationship among economic growth, CO₂ emissions and energy consumption is observed. This implies that any economic plans or strategies on economic growth would lead to the trade-offs with an increase in carbon emissions and energy consumption. Thus, if the ASEAN countries aim to achieve sustainability goals such as energy security, stable economic growth and sustainable environment, cooperation within the region is essential. Empirically, the impact of energy consumption on CO₂ emissions is significantly lower at the regional level than in a particular ASEAN country. This suggests if members of ASEAN states cooperate all together for the common goal of a sustainable environment, it would be more effective.

Our findings infer a potential role of using renewable energy on economic activity and environmental degradation. The role of renewable energy could be enhanced through international trade or foreign direct investment. A country can focus on energy sources that are abundant and low-cost production to optimize energy resources. The renewable energy source may supplement for an increasingly higher demand for energy consumption, and this source of energy can be a contributing factor of economic growth in the region in the long run. Yet, it is still an environmental-related concern in corresponding economic growth as well as energy consumption. As such, recent targets and commitments among the ASEAN member of states appear to be on the right track and efforts to keep on increasing the share of renewable energy in total primary energy supply should be encouraged. Alternative solutions towards technological advances in the process of adoption of renewable energy could be considered to reduce the amount of carbon emissions.

Declarations

Ethical Approval and Consent to participate

Not applicable

Consent for publication

The article is original, has not already been published in a journal, and is not currently under consideration by another journal

Availability of supporting data

The datasets analysed during the current study available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests

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Authors' contributions

All authors have made substantial contributions to the conception; design of the work; analysis; and drafting the paper. All authors have approved the submitted version and have agreed both to be personally accountable for the author's own contributions.

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Figures

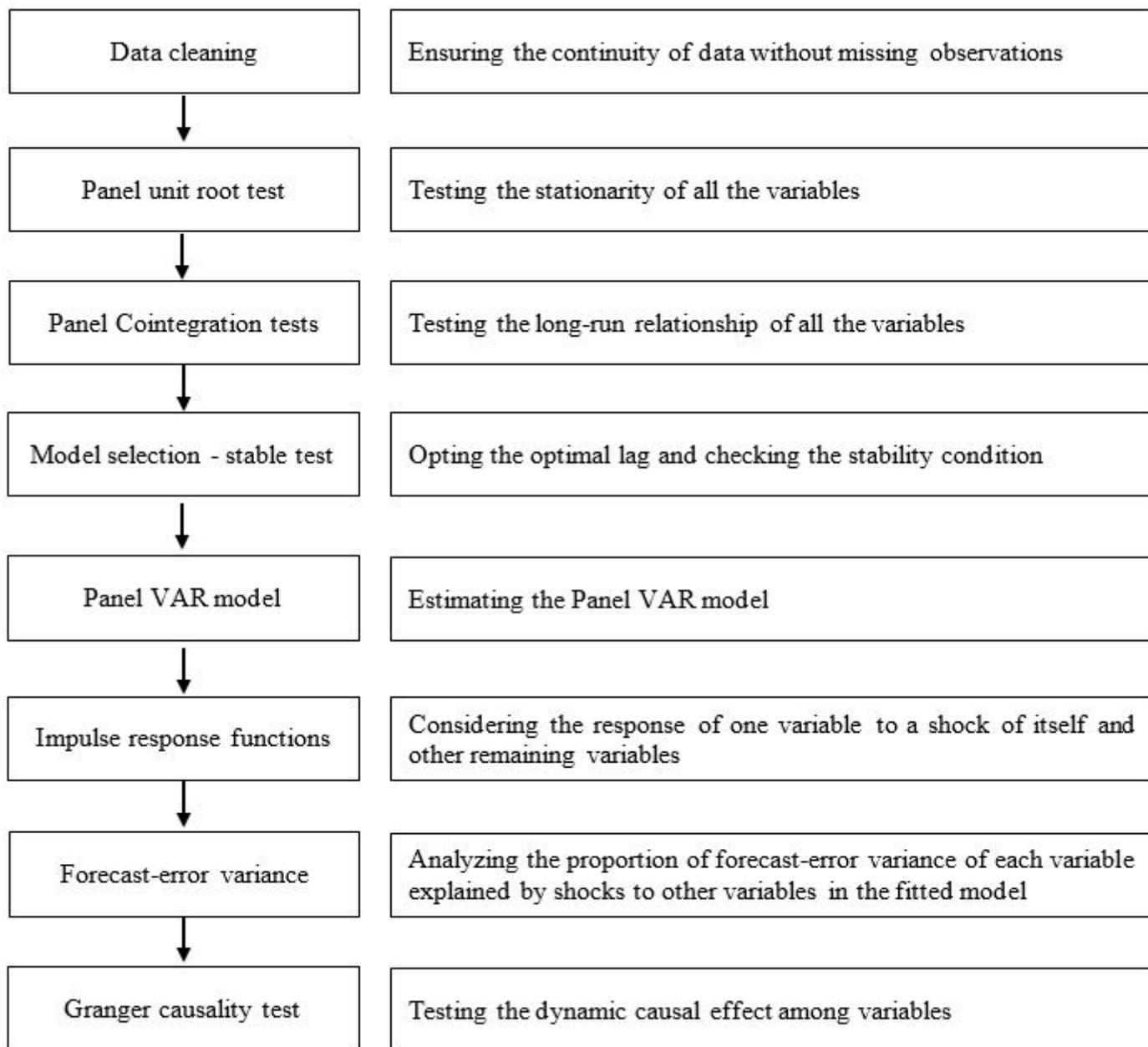


Figure 1

The procedure of data analysis

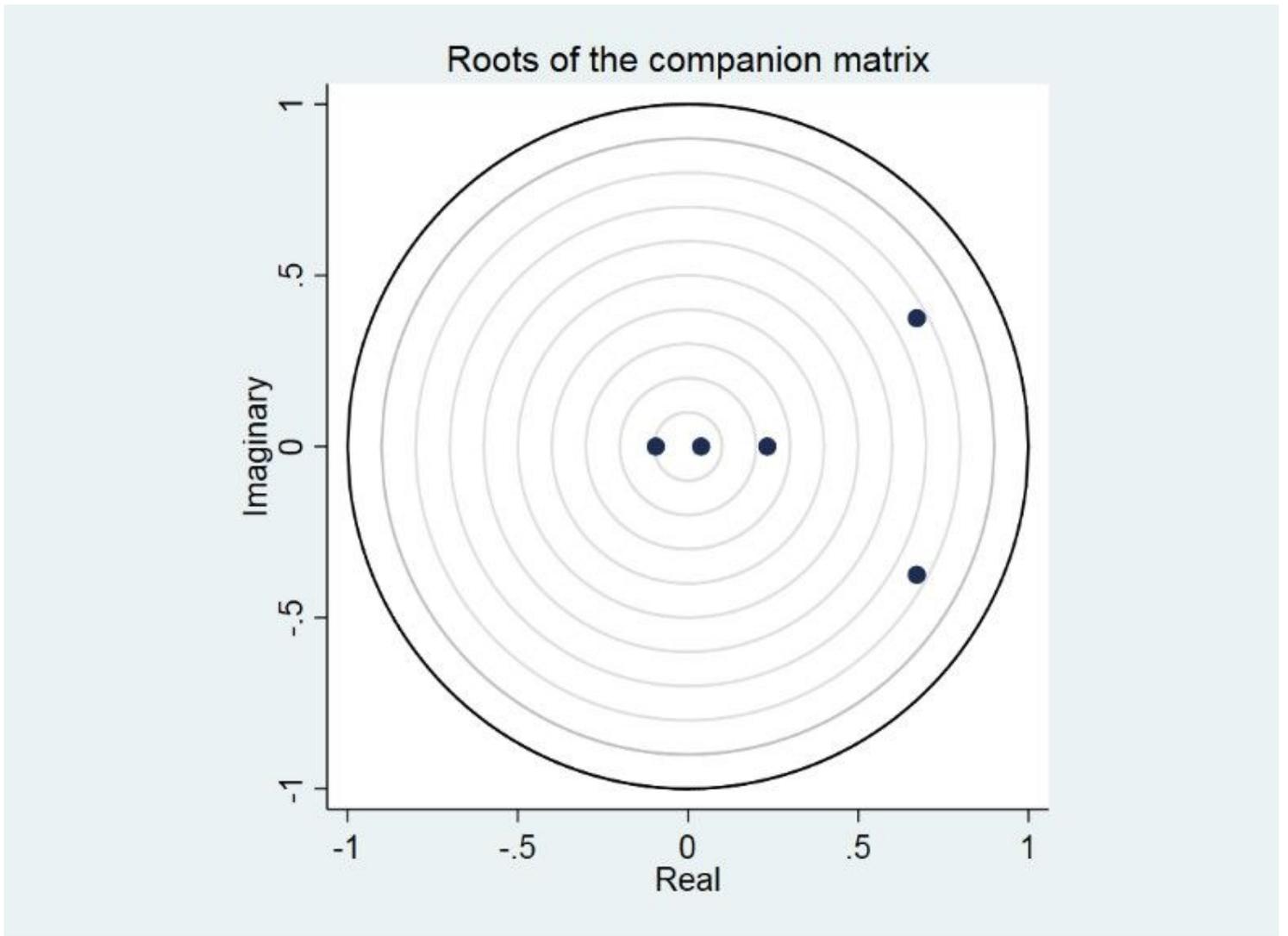


Figure 2

Roots of the companion matrix

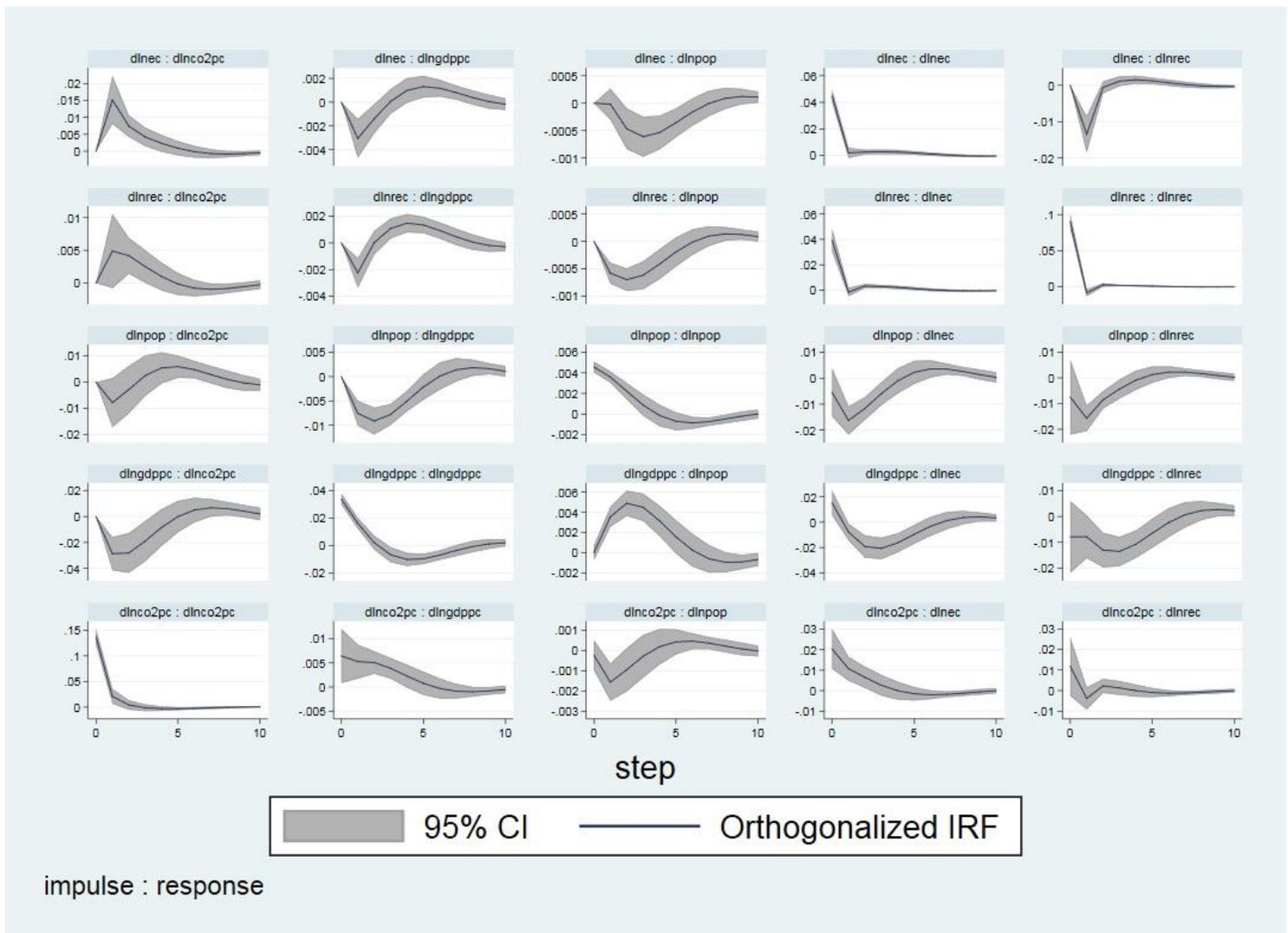


Figure 3

The impulse response functions Notes: The response of one variable to a shock of itself or another endogenous variable is depicted by a solid middle line, and the standard error bands are covered with two shaped lines. The response is statistically significant when the bands do not cross the zero line.

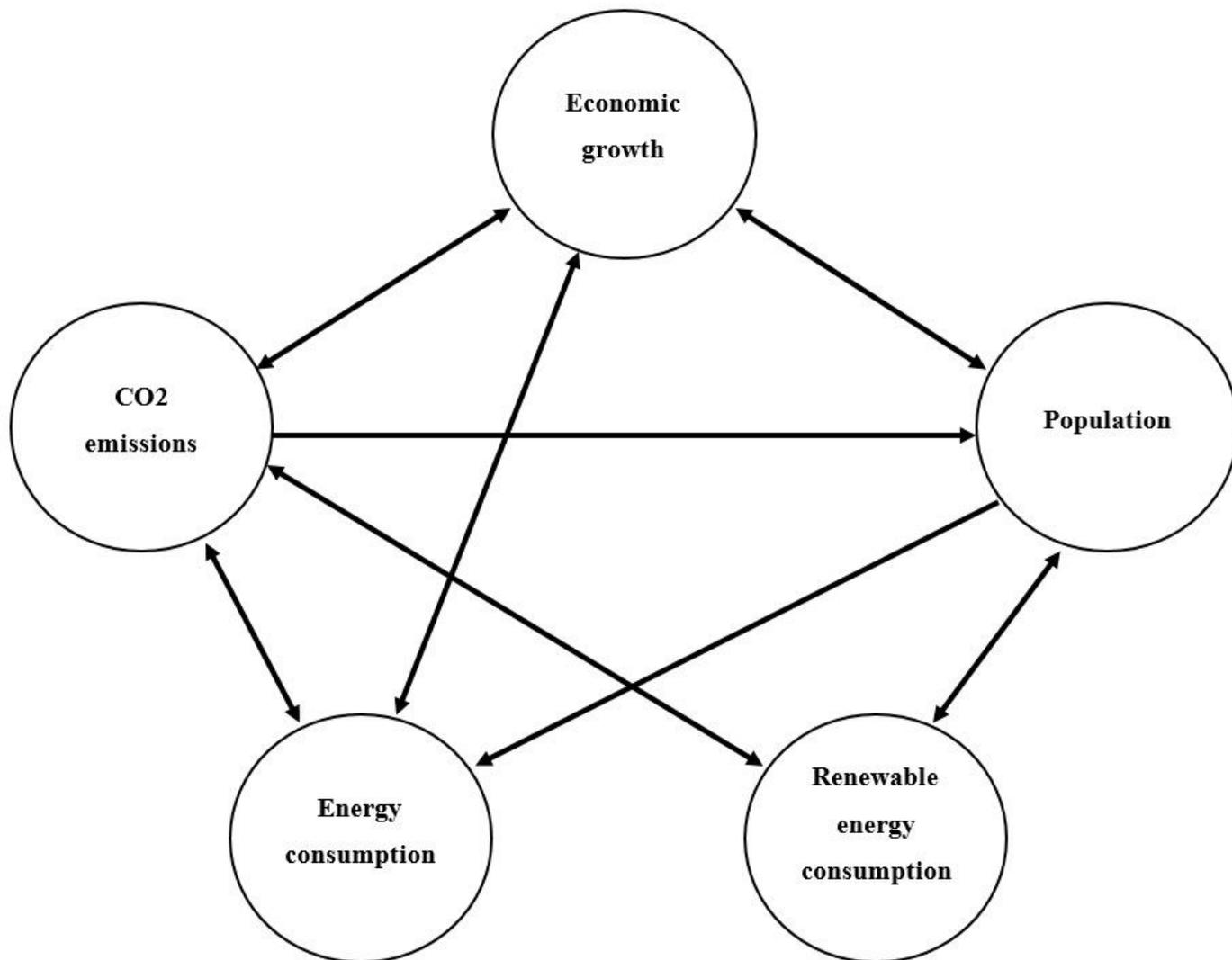


Figure 4

Empirical results from a traditional Granger causality test