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Examination of carbon dioxide emissions and renewables in Southeast Asian countries based on a panel vector autoregressive model

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ABSTRACT

Recently, the increasing energy consumption for economic growth has resulted in higher carbon dioxide (CO2) emissions. In this regard, the reduction of such emissions has become one of the main targets of economic planning for both developed and developing countries. Thus, this study determines whether economic growth and increased energy consumption can have a significant impact on CO2 emissions and whether this relationship is mutual, bidirectional, or unidirectional. For this purpose, we employ a panel autoregressive (VAR) model and focus on a group of developing countries in Southeast Asia in which their economic and population growth are expected to increase CO2 emissions in the future. Additionally, we examine their difficulties in meeting the CO2 emission targets and consider modern renewable energy sources (RES) in our quantitative research. Based on the results, there have been various rebound effects and rising expenses for modern RES in these countries, which have hampered their long-term goal of reducing CO2 emissions. The implication of the findings is that it is important to tailor subsidy schemes and energy policies to the specific needs of developing countries and their respective populations.

1. Introduction

In recent decades, the increasing energy consumption for economic growth in many developed and developing countries has resulted in increased carbon dioxide (CO2) emissions. Such emissions from energy combustion by traditional fossil fuels (i.e., coal, gas, oil, etc.) are released into the atmosphere, not only raising global temperatures and causing climate change, but also ultimately threatening the existence of human life. In this regard, policymakers around the world are becoming increasingly concerned about these primary energy sources and their ramifications, thus establishing higher emissions standards. For example, in 2015, 196 parties representing nations around the world signed an international treaty, called the Paris Agreement (Paris, 2015). Through the stated nationally determined contributions, the participating countries committed to reducing their greenhouse gas (GHG) emissions, building the infrastructure to overcome the difficulties of rising global temperatures, and meeting the carbon neutrality target by 2050. As for the latter, this refers to achieving an overall balance between the GHG emissions produced and removed from the atmosphere, also known as a zero carbon footprint. According to previous research (Lenaerts et al., 2021), since the decoupling rate of CO2 emissions per unit of the gross domestic product (GDP) between 1995 and 2018 was only −1.8%, countries around the world must dramatically increase this rate in order to achieve the target set for 2050.

However, the world is gradually shifting from carbon-emitting fossil fuels to renewables, as a pathway to carbon neutrality. For instance, according to the monthly energy statistics of the International Energy Agency (IEA) (2021a), the total electricity production from solar energy in Organization for Economic Cooperation and Development (OECD) countries was 52.7 TWh in August 2021 (an increase of 15.5% from the previous year) and that from wind energy was 65.7 TWh in August 2021 (an increase of 12.8% from the previous year). These findings clearly indicate that OECD countries are committed to using clean and resilient technologies for the future. Conversely, Eurostat stated that GHG emissions from the European Union totaled 867Mt of CO2 equivalent from April to June 2021, which is an 18% increase from the same period in the previous year.[1]

Meanwhile, a new energy economy is emerging around the world, since solar, wind, and other renewables are becoming increasingly used as energy sources, and electric vehicles and other low-carbon technologies are being introduced in the market. However, this clean energy

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[1] For more details, see https://www.reuters.com/markets/europe/eus-greenhouse-gases-rise-by-nearly-fifth-economic-rebound-eurostat-2021-11-29/.

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Abbreviations

AIC	Akaike Information Criteria
BIC	Bayesian Information Criteria
CO2	Carbon Dioxide
EICT	Environment-related ICT Innovations
EKC	Environmental Kuznets Curve
ENT	Energy Transition
EU	European Union
FD	Financial Development
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GHGE	Greenhouse Gas Emissions
HD	Human Development
HQ	Hannan-Quinn Information Criteria
Mt	Million Tones
NDCs	Nationally Determined Contributions
OECD	Organization for Economic Cooperation and Development
PGN	Pollution-economic Growth Nexus
RES index	Renewable energy consumption Rate index
SDG	Sustainable Development Goal
TWh	Terawatt Hour
US$	United State Dollar
VAR model	Vector Autoregression Model

momentum is facing the stubborn incumbency of fossil fuels in the energy system. Specifically, even though the social and economic benefits of expediting clean energy transitions are apparent, it can create financial losses for the frontrunners in the fossil fuel industry. In this regard, the low carbon economy is a concept that includes low energy consumption and pollution, while green financing is supposed to cover the related financing needs, both through public financing and various capital market elements (Yu et al., 2021). In other words, these are the tools that can help mobilize financial resources and make green investments in order to mitigate the negative effects of climate change (Khan et al., 2021). According to the IEA (2021b), annual green financing will increase to US$ 5 trillion by 2030, which can potentially add an extra 0.4% to the global GDP growth per year.

Since energy plays a pervasive role in economic development, climate change has become a significant concern for global leaders. In this regard, the Environmental Kuznets Curve (EKC), which claims that an inverted U-shaped relationship exists among energy use, economic growth, and the environment, has become increasingly important. An extension of this theory includes accelerating the mitigation of climate change and the transition to clean energy.

As stated earlier, the majority of the countries around the world have committed to the Paris Agreement and plan to achieve carbon neutrality by the stated target year of 2050 (Jahanger et al., 2023a; Alola and Adebayo, 2023a,b; Dong et al., 2022). However, the key message of the 2022 United Nations Climate Change Conference (COP27) was "much homework and little time."[2]Similarly, previous research has indicated that the advancements in decarbonization are still too slow,[3] partly due to the significant deficiencies in the system itself (Sun et al., 2022), the unsuitable institutional backgrounds, the political and financial risks, urbanization, trade openness (Adebayo et al., 2023a,b), and the sectoral impacts (Jahanger et al., 2023b). In this regard, countries around the world, regardless of whether they are developed or developing, should implement certain measures to mitigate CO2 emissions and climate change.

Overall, the objective of the present study is to determine the impact of different measures for decreasing or at least keeping CO2 emissions at a certain level, especially in developing countries. Despite their commitment to sustainable development, less attention has been given to how developing, open, and dynamic economies [4] with growing international significance can effectively deal with these issues. In this regard, sustainable development relies on appropriate energy use, which on the one hand, can accelerate socioeconomic progress and economic productivity, but on the other hand, can adversely contribute to a social ecosystem (Munus et al., 2010). Meanwhile, developing countries, especially those in our study, often lack the assurance to obtain financial and technological support (Sun et al., 2022). Therefore, we add to the current literature by examining the use of renewable energy sources (RES) with respect to economic growth in seven developing economies in Southeast Asia (Bangladesh, Indonesia, Malaysia, the Philippines, Sri Lanka, Thailand, and Vietnam).[5] For this purpose, we employ a panel autoregressive (VAR) model and apply annual data from 1990 to 2021.

The remainder of this study is structured as follows. The following section provides the theoretical background and highlights selected articles with similar methodologies, while Section 2 focuses on the data and methodology. Section 3 discusses the results, while Section 4 and presents the conclusion. It also provides information regarding the novelty of our approach and research focus, as well as policy recommendations and implications for the reduction of CO2 emissions.

1.1. *Theoretical background*

To date, there have been extensive empirical studies on the pollution-economic growth nexus, with inconsistent findings. Meanwhile, a second wave of empirical studies have investigated the relationship between energy consumption and economic growth. Thus, these two strands of research must be examined together, since the causal relationship between economic growth, energy consumption, and carbon emissions are likely to have important policy implications (Soytas and Sari, 2009). However, since energy consumption also has a direct impact on carbon emissions (Ang, 2007), understanding the mutual relationship between these variables can help solve the potential impacts that economic, environmental, and energy conservation policies can have on one another (Acheampong, 2018).

As stated earlier, the EKC is an explanatory model of the relationship between energy use, economic growth, and the environment. EKC-related research started with Kuznets (1955), who initially examined the relationship between income inequality and economic growth. More recently, Munir et al. (2020) extended his hypothesis by stating the following:

CO2 emissions will continue to increase until average income reaches a turning point, then environmental quality will begin to improve. A conventional EKC exhibits an inverted U-shaped relationship between environmental quality and economic growth/development, suggesting that environmental pressure increases up to a certain level as the economy grows, after which it decreases.

[2] According to UN Secretary-General António Guterres at the United Nations Climate Change Conference in Egypt (COP27).

[3] As concluded by the United Nations Climate Change Conference in Egypt (COP27).

[4] The selected countries have populations ranging from 18 to 212 million, and rankings ranging from 74th to 16th based on their overall GDP (www.worldometers.info).

[5] Among the seven countries, Indonesia, Malaysia, the Philippines, Thailand, Vietnam are the member countries of Association of Southeast Asian Nations and Bangladesh and Sri Lanka are the member countries of South Asian Association for Regional Cooperation.

Previous studies have also shown that the environmental pressure appears to be higher in the early stages of development, whereas it visibly decreases in relation to GDP growth at a higher income level (Panayotou, 1993; Arrow et al., 1995). Considering the relationship between the GDP and CO2 emissions, it is important for policymakers to determine if their respective economies have a conventional EKC and whether the turning point has already been reached. If so, then a higher GDP will not necessarily result in higher CO2 emissions (Munir et al., 2020).

However, according to Stern (2004), since the EKC does not exist, the impact of economic growth and technological advances on environmental quality must be evaluated in a different way. In this regard, most indicators of environmental degradation are monotonically rising with income, even though the income elasticity is less than 1.0. He also stated the following:

Time-related effects, intended to model technological change common to all countries, reduce environmental impacts in countries at all levels of income. However, in rapidly growing middle-income countries, the scale effect, which increases pollution and other degradation, overwhelms the time effect. In wealthy countries, growth is slower and pollution reduction efforts can overcome the scale effect. This is the origin of the apparent EKC effect (Stern, 2004, p. 518).

Hence, in line with Ang (2007), we examine the relationship between economic growth, energy consumption, and carbon emissions.

At this point, we refer to the work of Jevons (1865), which revealed the contradicting impact of technological development (energy efficiency) on energy consumption. With economic growth and development, one would expect that a decrease in energy consumption can result in lower GHG emissions. However, as shown in the 19th century's coal market of England (and to a certain extent, the present day) (Alcott, 2005; Sorrell, 2009; Ceddia and Zepharovich, 2017), the decrease in energy costs due to energy efficiency and overall economic development can actually increase energy consumption. More recently, other extensions of this theory have emerged. For instance, in the Khazzoom-Brookes Postulate, both researchers claimed that since people tend to grasp energy efficiency gains as price reductions, the demand for energy increases, either directly through price elasticity effects or indirectly through purchasing and utilizing more energy-using goods and services (Khazzoom, 1980; Brookes, 1990, 2000; Saunders, 1992).

Finally, York and McGee (2016) formulated the well-known paradox in which the rebound effect exceeds 100%, indicating that there is an actual increase in resource consumption. This effect is expressed as a percentage of the forecasted reduction in energy use that is "lost" due to consumer and market responses (Gillingham et al., 2015). It can also be defined as the recurring energy consumption that emerges based on behavioral changes and other systemic responses to energy efficiency improvements (Fouquet and Pearson, 2006; York and McGee, 2016; Cansino et al., 2019), or the calming awareness of using RES, due to energy transition (Gunderson and Sun-Jin, 2017).

1.2. Literature review

At this point, new empirical evidence on the causal relationship between economic growth, energy consumption, and carbon emissions based on the multivariate framework has already been provided (see Antweiler et al., 2001; Cole, 2006; Ghani, 2012; Ren et al., 2014; Sadorsky, 2011; Sadorsky, 2012; Shahbaz et al., 2014; Acheampong, 2018). In these studies, trade openness was calculated by the sum of the imports and exports normalized by the GDP. However, in the present study, we exclude this indicator as a factor of CO2 emissions, since we mainly rely on the World Bank's report [6] on the decreasing role of international trade in the economic development of the selected countries.

Along with the EKC theory/model, we begin by focusing on the link between overall energy use, economic growth, and the environment. Alom (2014) revealed a short-term causal link between energy consumption and CO2 emissions, and between CO2 emissions and the GDP for five South Asian countries (Bangladesh, India, Pakistan, Sri Lanka, and Nepal) from 1972 to 2010. However, the author failed to find any causality in the long run from the GDP and CO2 emissions to energy consumption. In related research, Ahmed et al. (2016) found a positive relationship between energy consumption (total energy, gas, oil, electricity, and coal) and carbon emissions, with a feedback effect between economic growth and carbon emissions. Basically, the authors investigated the short and long-term relationships among carbon emissions, energy consumption, and economic growth in India from 1971 to 2014 (at both the aggregated and disaggregated levels). They not only found a long-term cointegration relationship, but they also validated the EKC. Moreover, Ullah et al. (2023) conducted a panel data analysis for G-7 countries from 1990 to 2020, examining their cross-sectional dependencies and variations in slopes. Based on their findings, there was a significant positive influence of environment-related information and communication technology innovations (EICT), financial development (FD), and human development (HD) on long-term energy transition (ENT) in the G-7 economies. Conversely, they found that long-term ENT, EICT, FD, and HD played a supportive role in reducing GHG emissions, while FD emerged as a key factor for fostering ENT and reducing such emissions.

As for the results of additional research, they are as follows. First, Adebayo et al. (2023) found a significant correlation between economic growth and the consumption of non-renewable energy, leading to increased CO2 emissions. However, the consumption of renewable energy showed a weaker association with CO2 emissions. Thus, the empirical findings, as confirmed by the wavelet coherence analysis for Brazil, the Russian Federation, India, China, and South Africa, underscore the significance of economic growth and both non-renewable and renewable energy consumption in influencing CO2 emissions.

Second, Zhang et al. (2021) used provincial data of China from 2000 to 2017 and investigated the aggregate effects of low-emission electricity. They found that if the ratio of low-emission electricity to total electricity is increased by 1%, then the GDP will increase by 0.16% and CO2 emissions will decrease by 0.848%. Literally, it can be stated that low emissions can help meet the target of low-carbon economic development (Shahi, 2022). Similarly, Shahi (2022) examined the competitiveness of a specific country in the international arena and found that energy consumption and energy efficiency are highly interrelated, especially in regard to consumption in the industrial sector. Moreover, there are high implications for using extended amounts of renewable energy to change the competitiveness of a nation and having an accumulated beneficial return at the global level (Simelyte and Dudzeviciute, 2017).

Third, Dogan (2015) confirmed the causal relationship between renewable energy, CO2 emissions, and the GDP, while Saidi and Omri (2020) focused on 15 countries who are major consumers of renewable energy and found a bidirectional causality between economic growth and renewables. However, they only detected a causal link between carbon emissions and renewables in the long run, but not in the short run. In related research, Yao et al. (2019) conducted panel cointegration tests and found a long-term relationship between economic growth, the renewable energy consumption rate (RER), and carbon emissions. The authors also tested the dynamic relationship hypothesis between the RER and the EKC by applying two panel datasets (1990–2014) for 17 major developing and developed countries, along with six geo-economic regions of the world. More recently, Adebayo and Ullah (2023) investigated the causal effects of economic growth, financial development, nuclear energy utilization, government stability, and socioeconomic factors on China's environmental quality by utilizing quarterly data from 1984 to 2018. Based on the results, the increasing use of nuclear energy, in combination with environmentally supportive financial policies that foster both economic growth and improved socioeconomic

[6] For more details, see https://data.worldbank.org/.

conditions, is an effective strategy for improving overall environmental quality. Furthermore, Dong et al. (2018) found that from 1980 to 2015, both economic and population growth played a crucial role in the increase of CO2 emissions in more than 100 countries. Meanwhile, upper-middle-class income countries contributed a significant amount (at least 70%) to global CO2 emissions growth over the past 35 years.

Finally, the study by Alola and Adebayo (2023a,b) found that domestic biomass consumption in Iceland from 1990 to 2019 contributed to an overall reduction in GHG emissions. Based on these findings, biomass can play an important role in preserving ecological integrity in Iceland, resulting in decreased GHG emissions. This observation also underscores the potential of biomass as a tool for mitigating ecological degradation and facilitating the realization of Sustainable Development Goal (SDG) 13, one of the 17 SDGs established by the United Nations General Assembly in 2015.

Based on this literature review, implementing numerous variables may not necessarily provide additional factors that can increase CO2 emissions. Instead, it can disturb the results and their interpretations. Meanwhile, our initial findings are consistent with those of Valadhkani et al. (2019), in which RES have no significant impact on CO2 emissions. Consequently, we divide the renewables into two sub-groups (traditional and modern biofuels). In this case, Table 1 presents the variables implemented in this study.

1.3. Theoretical model

The present study assumes the following extended Cobb-Douglas function in order to approximate the broad economic activities (Thompson, 2006; Moyer et al., 2013) of the Southeast Asian countries in our sample:

$$Y_t = (1 - D_t)A_t L_T{}^{1-\alpha-\beta} * K_t^{\alpha} * E_t^{\beta}, \tag{1}$$

where A_t is a time-dependent technology parameter, (K_t) represents capital formation, (L_t) represents labor, (E_t) represents energy, and (D_t) represents the damages due to GHG emissions. In this case, the countries are motivated to mitigate D_t by transforming their economies toward lower GHG emission levels. In order to determine the theoretical model behind the CO2 emissions of the economies in our sample, we must distinguish between the globally and locally determined variables, since our focus is on relatively small, emerging, and open economies. Since countries can be both net crude or refined commodity importers, the West Texas Intermediate oil price ($P_{WTI,i,t}$) was added to represent fossil fuel pricing and better describe the broad global energy market environment.

Meanwhile, capital formation (in terms of K_t) and funding conditions for such countries are mainly determined by the global market sentiment, which can be influenced by local monetary policies. Hence, the sovereign spread ($10Y_{i-US,t}$) between the i^{th} sample country and the US. 10-year bond is considered a benchmark for describing the relative ease of funding, in which higher values indicate liquidity scarcity (Shimbar-Ebrahimi, 2020; Capelle-Blancard et al., 2019).

In terms of economic output (Y_t), since small economies tend to be less robust and have more price takers on the global market, a gravity proxy is used to describe the difference between the GDP of the sample country and that of the world economy ($GDP_{i-W,t}$), in which higher values indicate relative smallness. In this regard, the EKC suggests that there is a level of economic development in which GHG emissions do not increase in parallel with economic growth (Kuik et al., 2019).

Regarding primary energy consumption ($E_{i,t}$), it represents the energy intensity of the economy, indicating that there is a level of development in which an economy becomes more energy efficient and output formation requires less energy. As for RES, they can be categorized into two main groups: solar and wind energy ($R_{s-w,i,t}$), both of which have no direct carbon emissions after they are produced and installed, whereas biofuels, biomass, biogas, and geothermic resources ($R_{co2,i,t}$) provide continuous emissions. However, their higher usage can support the concept of a circular economy, ultimately reducing the use of fossil fuels.

In order to represent exogeneous shocks in the model, an International Monetary Fund (IMF) dummy ($d_{IMF,i,t}$) variable is added to represent country-specific crisis periods when i^{th} country requires funding from the IMF. Moreover, GHG emissions have a negative impact on the economy in the form of damages (D_t), which is not solely determined by local CO2 emissions ($CO2_{i,t}$). However, this study focuses on the identification of country-specific factors in such emissions to better understand the i^{th} country's ability to meet the objectives of the Paris Agreement. For this purpose, we apply the Cobb-Douglas specifications under the following theoretical model:

$$\Delta CO2_{i,t} = const. + \alpha_1 \Delta P_{WTI,t} + \alpha_2 \Delta 10Y_{i-US,t} + \alpha_3 \Delta ln\ GDP_{i,t} + \alpha_4 \Delta E_{i,t} + \alpha_5 \Delta R_{i,t} + \alpha_6 \Delta R_{co2,i,t} + \beta_1 d_{IMF,i,t} + \varepsilon_t \tag{2}$$

Overall, we can anticipate the following outcomes from our model: 1) high global oil prices can divert the use of fossil fuels ($\alpha_1 < 0$) in net energy importer economies; and 2) high sovereign spread levels can hinder investments and growth, causing sluggish economic growth and low CO2 emissions ($\alpha_2 < 0$). Since economic output mainly relies on energy usage, the GDP growth should provide positive feedback on CO2 emissions ($\alpha_3 > 0$), at least until a country reaches a certain post-industrial level of development. Meanwhile, primary energy consumption has a similar influence, since RES have a relatively low share in the overall energy mix and their load factors are lower than those of fossil fuels ($\alpha_4 > 0$). Thus, solar, wind, and combustible renewables offer an alternative for reducing fossil fuel usage, since they can potentially reduce CO2 emissions ($\alpha_5 < 0$). It is important to note that biofuels, biomass, and other combustibles still emit various gases into the air, but their circular nature allows them to operate in a binding-release cycle. Consequently, their influence should be (at the most) neutral ($\alpha_6 \approx 0$). At this point, only the last variable has the potential to systematically reduce GHG emissions in our model.

2. Material and methods

2.1. Data

Since 1990, the CO2 emissions in Southeast Asia have followed the global growth trend, with some setbacks when economic output dropped due to certain events such as recessions (see Fig. 1[7]). This study addresses this phenomenon by focusing on how financial, economic, and industrial conditions can influence this development and ultimately achieve carbon neutrality. Since the sample economies are still in their early stages of development and CO2 emissions, stopping or reversing this growth will be an enormous challenge for economic policymakers, both at the country and global levels.

However, renewable energy consumption, especially in the case of wind and solar energy, has been on the rise in the region, gaining momentum in the 2000s. Meanwhile, the more traditional combustible renewables are showing a steadier trend (see Fig. 2a and b[8]).

This study used annual data from 1990 to 2021, since the majority of the renewables were introduced and applied during this period. Overall, seven developing and open economies in Southeast Asia (Bangladesh, Indonesia, Malaysia, the Philippines, Sri Lanka, Thailand, and Vietnam) were added to the sample to represent the development in the region. This is in contrast to previous studies that mainly focused on large and more robust economies such as Japan, China, India, and Australia. As for our sample, all of these maritime countries are characterized by similar climates (e.g., monsoon seasons) and geographical (e.g., mountainous) characteristics, which is necessary for studying the potential of solar and

[7] http://www.bp.com/statisticalreview.
[8] http://www.bp.com/statisticalreview.

Table 1
The model variables in the literature and their influence on CO2 emissions.

variable name	appearance in the literature			
sovereign spread ($10Y_{i-US,t}$)	Shimbar -Ebrahimi (2020)	Capelle-Blancard et al. (2019)		
gravity ($GDP_{i-W,t}$)	Kuik et al. (2019)	Zhang et al. (2018)		
primary energy consumption ($E_{i,t}$)	Ang (2007)	Jahangir Alam et al. (2012)	Acheampong (2018)	Valadhkani et al. (2019)
renewable (biofuel, biomass etc.) ($R_{co2,i,t}$) renewable (wind, solar) ($R_{s-w,i,t}$)	Valadhkani et al. (2019)			

Source: Authors' edition

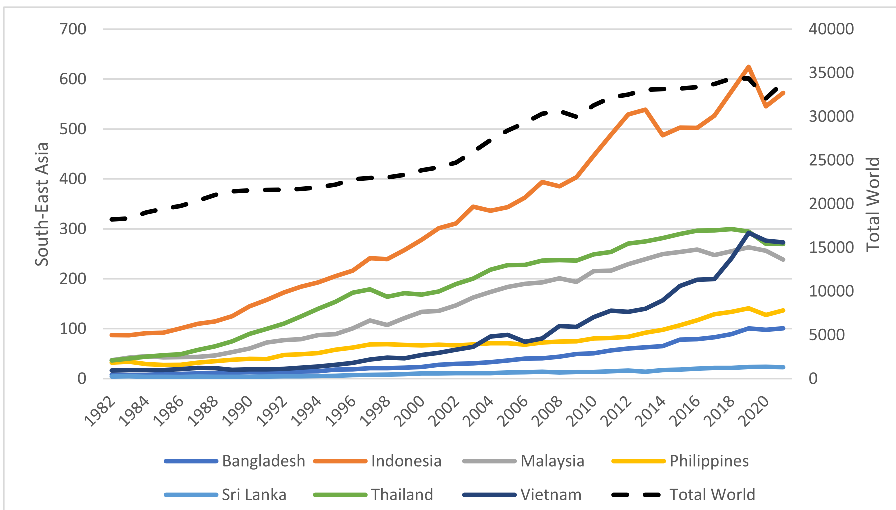

Fig. 1. Carbon Dioxide Emissions (Million tonnes).
Source: Authors' edition, bp Statistical Review of World Energy July 2022

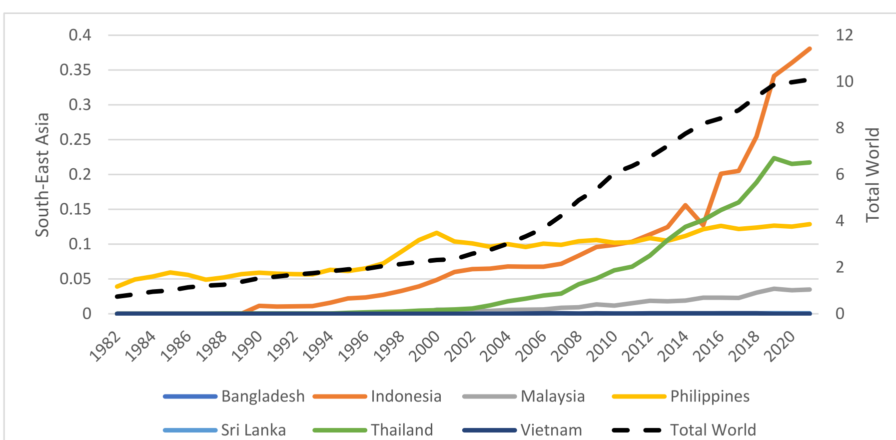

Fig. 2a. Renewable biofuel, biomass etc. energy consumption (Exajoules).

wind energy generation. Meanwhile, the majority of these countries were affected by the developing debt crisis of the 1980s and the East-Asian crisis of 1997, indicating their exposure to external funding conditions.

As for the energy sector-related data, it was obtained from the *Statistical Review of World Energy*, while the financial data was downloaded from the Refinitiv Eikon database. Additionally, the GDP data was obtained from the World Bank (see Table 2). Since the sample countries were participating in different IMF programs, only their general resources accounts were considered in the case of disbursement from the IMF toward the i^{th} country. In this case, the Poverty Reduction and Growth Trust were not considered, due to its different purpose.

Since renewables first appeared in the 2000s, it is possible that our panel data is somewhat unbalanced, due to missing figures. However, since there is no unit root in the data, the mean and standard deviations are time-invariant, thus meeting the stability conditions of the panel VAR model (see Table 3).

2.2. Methods

The panel VAR model provides an efficient estimate (with a priori endogeneity) for considering various dynamics (Jouida, 2018).

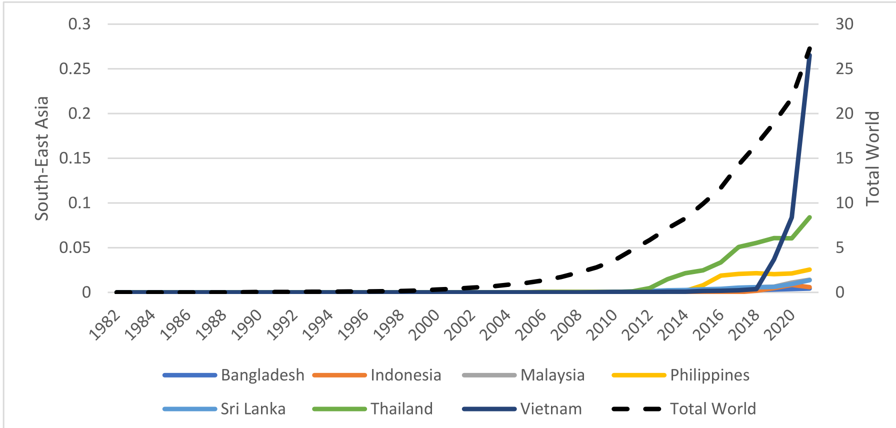

Fig. 2b. Renewable wind and solar energy consumption (exajoules).
Source: Authors' edition, bp Statistical Review of World Energy July 2022

Table 2
Data sources.

variable name	source
sovereign spread ($10Y_{i-US,t}$)	Refinitiv Eikon database
output ($GDP_{i,t}$)	World Bank
primary energy consumption ($E_{i,t}$)	bp Statistical Review of World Energy July 2022
CO2 emission ($CO2_{i,t}$)	bp Statistical Review of World Energy July 2022
renewable (biofuel, biomass etc.) ($R_{co2,i,t}$)	bp Statistical Review of World Energy July 2022
renewable (wind, solar, combustible) ($R_{i,t}$)	bp Statistical Review of World Energy July 2022
WTI oil price ($P_{WTI,i,t}$)	bp Statistical Review of World Energy July 2022
IMF dummy ($d_{IMF,i,t}$)	IMF country reports

Source: Authors' edition

Following Canova and Ciccarelli (2013), the panel VAR model is also useful for estimating the spillovers from idiosyncratic interdependences across the countries, markets, and sectors, as well as identifying the shocks among endogenous variables (Jouida, 2018). In this regard, it considers all variables as endogenous and interdependent (both in a dynamic and static sense), not only with a set of predetermined or exogenous variables, but also in a cross-sectional dimension. For instance, if y_t is the vector of G endogenous variables in time t ($t = 1,\ldots, T$), then its stacked version for the i^{th} ($i = 1,\ldots,N$) generic unit (country, sector, market, etc.) is y_{it}. Note the following equation:

$$y_{it} = A_{0i}(t) + A_i(\ell)y_{it-1} + Z_i(\ell)W_t + \varepsilon_{it} \quad (5)$$

where $A_i(\ell)$ is a polynomial in the lag operator, in which restrictions are imposed on the coefficient matrices A_i in order to make the variance of y_{it} bounded. In addition, the predetermined or exogenous M variables are represented by the W_t vector, which is common to all i units, while the existence of $A(\ell)^{-1}$ is secured because there are no roots of $A(e^{-\omega})^{-1}$ on or in the unit circle. Then, the standardized condition for stability is tested to determine if the modulus values are smaller than the one that implies the invertible interpretations and the interpretations of the infinite order-vector moving averages (Lütkepohl, 2005).

Regarding the optimal lag-length of the model, it is selected by either the Bayesian information criteria (BIC), the Akaike information criteria (AIC), or the Hannan-Quinn information criteria (HQ). Meanwhile, the impulse response functions are considered as the effects of a unit shock on a given model variable, in which the shock of variable i to variable j is determined. According to Sims and Zha (1999, p. 6), the confidence interval "bands that correspond to the 68% posterior probability (one standard error) are often more useful than 95% bands (two standard errors), and confidence intervals with such low coverage probabilities do not generally have posterior probabilities close to their coverage probabilities." In this case, the variance decomposition makes it possible to determine which shocks are decisive in the short- and long-term evolution of certain variables, i.e., the proportion of the uncertainty of variable i that can be attributed to the j^{th} shock after period h.

Finally, regarding the structure of the identification matrix (see Table 4), our theoretical model provides the highest global influence for the oil price rate (as an energy price proxy variable) and the smallest local influence for renewables. Hence, the shocks can be estimated with the Cholesky (d.f. adjusted) innovation.

Table 3
Descriptive statistics and unit-root tests.

	$P_{WTI,t}$	$10Y_{i-US,t}$	$\ln GDP_{i,t}$	$E_{i,t}$	$CO2_{i,t}$	$R_{i,t}$	$R_{co2,i,t}$
Mean	1,4074	−0,0010	0,0469	0,1125	6,7569	0,0118	0,0054
Median	4,8999	−0,0001	0,0522	0,0983	5,5881	0,0031	0,0011
Maximum	28,8508	0,1192	0,2510	0,5970	51,0917	0,2313	0,0869
Minimum	−44,5752	−0,1285	−0,1006	−0,5547	−79,1210	−0,0289	−0,0289
Std. Dev.	19,1003	0,0274	0,0353	0,1813	16,9156	0,0306	0,0140
Skewness	−0,8879	−1,5490	0,3513	−0,5829	−0,8900	4,7510	3,3794
Kurtosis	3,4270	15,6552	16,0819	6,6302	9,9709	30,5634	18,5838
Jarque-Bera	15	750	758	64	229	3754	1274
(p)	0,0006	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Unit-root test: Levin, Lin & Chu t							
(p)	0,0000	0,0000	0,0007	0,0000	0,0000	0,0000	0,0000
Observations	106	106	106	106	106	106	106

Source: Authors' edition, Eviews13

Table 4
Structure of the identification matrix of the short-term effects.

		shock						
		$P_{WTI,t}$	$10Y_{i-US,t}$	$ln\ GDP_{i,t}$	$E_{i,t}$	$CO2_{i,t}$	$R_{i,t}$	$R_{co2,i,t}$
variable	$P_{WTI,t}$	f_{11}	0	0	0	0	0	0
	$10Y_{i-US,t}$	f_{21}	f_{22}	0	0	0	0	0
	$ln\ GDP_{i,t}$	f_{31}	f_{32}	f_{33}	0	0	0	0
	$E_{i,t}$	f_{41}	f_{42}	f_{43}	f_{44}	0	0	0
	$CO2_{i,t}$	f_{51}	f_{52}	f_{53}	f_{54}	f_{55}	0	0
	$R_{i,t}$	f_{61}	f_{62}	f_{63}	f_{64}	f_{65}	f_{66}	0
	$R_{co2,i,t}$	f_{71}	f_{72}	f_{73}	f_{74}	f_{75}	f_{76}	f_{77}

Source: Authors' calculation in Eviews 13

3. Results and discussion

In this study, the lag length of the model was determined by the lag order selection criteria. However, 0–1 lags were used to meet the stability conditions. Based on this setup, none of the inverse roots of the characteristic polynomial were outside the unit circle (i.e., all of the moduli were less than 1), indicating that the VAR model satisfied these conditions (see Table 5)[9].

As for the impulse responses[10], they represented the development of each variable's influence on CO2 emissions, with 95% and 68% confidence intervals (see Fig. 3). In addition, global oil prices had no significant impact on CO2 emissions, indicating the neutrality of these variables. In other words, some of the countries in this study were both extractors or importers of this resource or its refined products. However, higher sovereign premiums decreased CO2 emissions, with a 68% confidence interval, indicating the instantaneous impact of funding costs. Meanwhile, the economic activity's CO2 embeddedness was visible, with a positive 95% short-term (near-instantaneous) impact on the GDP and primary energy consumption growth. This suggests that burning fossil fuels are necessary for the growth of these economies, even if the energy source is considered as renewable and generates CO2 emissions. It is important to note that the increased use of modern renewables only has a negative impact on CO2 emissions for a period of one to three years, since their growth is insufficient for fulfilling the ever-growing energy demands of these economies.

Finally, as Table 6 shows, the variance decomposition of CO2 emissions indicates that primary energy consumption has a major influence (43%–60%), whereas economic activities (∼11%) and funding conditions and global oil prices (∼1%) have a marginal effect. However, the broad use of renewables (15%–21%), especially those with CO2 emissions (∼6%), has a relevant influence. Reinforcing our previous results, this data highlights the importance of the energy mix and energy-efficiency event to prevent the further increase of CO2 emissions. These results are also in line with our previously described anticipations in the theoretical model portion of this study.

Table 5
Roots of the characteristic polynomial.

Root		Modulus
real	imaginary	
0.5558	−0.3408i	0.6520
0.5558	0.3408i	0.6520
−0.4346		0.4346
−0.2736	−0.0868i	0.2870
−0.2736	0.0868i	0.2870
0.1518	−0.0570i	0.1622
0.1518	0.0570i	0.1622

Source: Authors' edition, Eviews13

4. Conclusion

In order to have a clean and livable environment, the transition to green energy must be highly prioritized. In this regard, renewable energy can provide many benefits such as ensuring energy security, reducing CO2 emissions, fostering a country's economic development, and mitigating poverty. However, the access to affordable, reliable, sustainable, and modern energy requires a substantial shift from fossil fuels to modern clean energy. In this process, it is important to focus on the roles of developed countries, since they tend to release more carbon emissions into the atmosphere. However, we cannot ignore their attempts to align with the carbon emissions reduction criterion. In fact, many of them have openly revealed and widely discussed the mutual impact of energy consumption, economic development, and environmental effects on their respective futures.

Therefore, the present study used the extended Cobb-Douglas function for seven developing Southeast Asian countries (Bangladesh, Indonesia, Malaysia, the Philippines, Sri Lanka, Thailand, and Vietnam), with CO2 emissions as the dependent variable. In addition, the panel VAR model was employed to scrutinize the exogeneous shocks (i.e., the environment for fossil fuel pricing and the IMF funding requirement during the various countries' crisis sessions), which affected all of the considered variables. Based on the findings of our study, the countries in our sample appear to have the ability to achieve the carbon neutrality target of 2050 set forth by the Paris Agreement. However, further details are as follows.

First, we identified a literature gap in the related research, after which the seven aforementioned relatively small, developing, open, and emerging economies from Southeast Asia were chosen to represent the relevant development in the region. We also considered them suitable research subjects for revealing the difficulties of the parallel challenges of economic growth, environmental impact, and energy consumption. After analyzing the data from 1990 to 2021 for the countries in question, the results indicated that the VAR model mollified the stability conditions. In addition, based on the expansion of each variable, including sovereign spread, country-specific economic size, and primary energy consumption, they had a direct influence on increasing CO2 emissions.

Second, since the current literature was also missing various aspects and factors of RES, we were forced to make a sharp distinction between these different sources. Hence, we divided them into two groups: traditional and modern renewables. Based on our research, we concluded that increasing the use of RES did not have a long-term

[9] There is no cointegration in the model as Appendix 1 illustrates with a Johansen-Hendry-Juselius test, which would require the further analysis of long-run effects. Only the Trace test suggested the presence of one cointegration relationship, but the results are similar to the panel VAR model, underlining the robustness of our results.

[10] It is hard to observe cross-sectional dependence in a panel VAR model, since the results are based on the shocks of each variables on the CO2 emission – instead of focusing on the coefficient of the model like in most econometric methods. However, residuals are quite homogeneous in Appendix 2, and the extreme time periods are represented with the IMF dummy exogeneous shock variable.

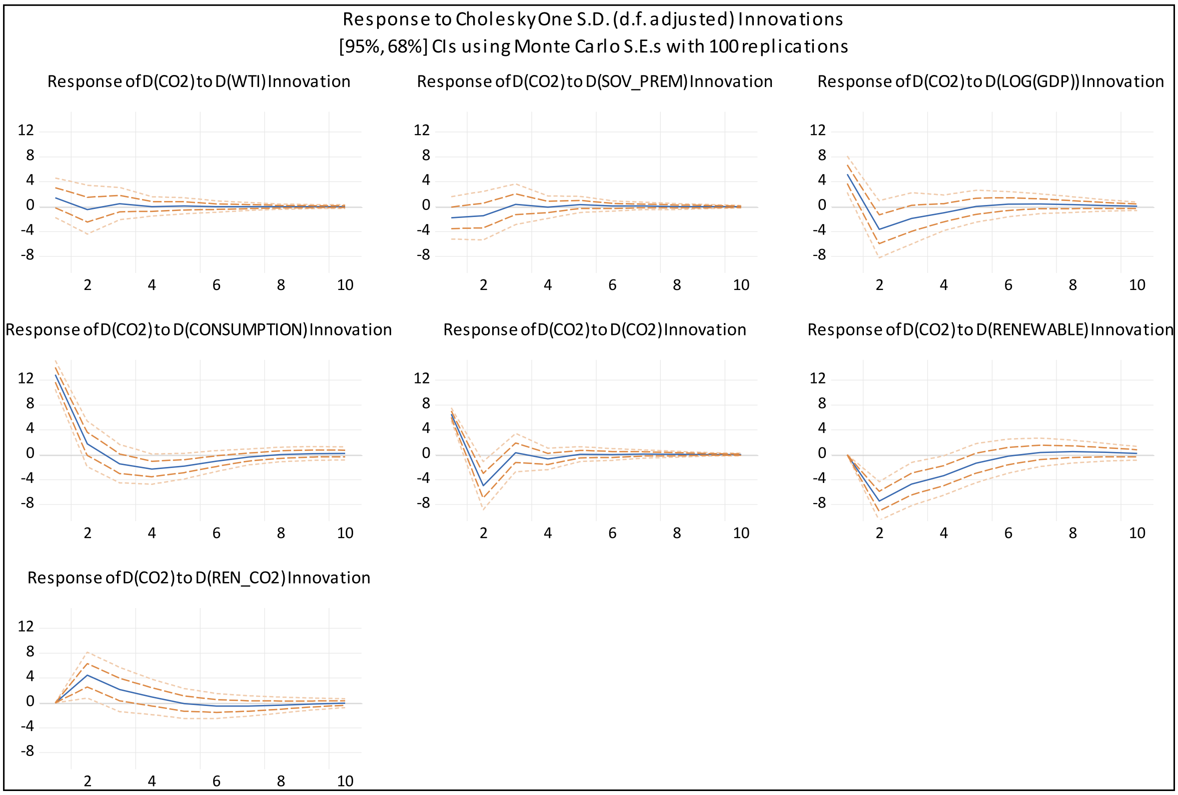

Fig. 3. Impulse response functions of the CO2 emission to model variables on the long run.
Source:Authors' edition, Eviews13

Table 6
Variance decomposition of CO2 emissions based on structural VAR factors.

lag (year)	WTI	sovereign premium	GDP	primary energy consumption	CO2	renewable	renewable with CO2 emission
1	0,84	1,34	11,31	68,80	17,71	0,00	0,00
2	0,63	1,49	11,26	46,90	18,73	15,50	5,49
3	0,64	1,40	11,22	43,52	17,19	19,84	6,19
4	0,61	1,34	10,95	42,81	16,51	21,66	6,13
5	0,60	1,35	10,81	43,07	16,30	21,82	6,05
6	0,60	1,34	10,80	43,17	16,24	21,75	6,09
7	0,60	1,34	10,83	43,13	16,21	21,74	6,14
8	0,60	1,34	10,84	43,08	16,20	21,78	6,17
9	0,60	1,34	10,84	43,06	16,19	21,80	6,17
10	0,60	1,34	10,84	43,06	16,18	21,81	6,17

Source: Authors' edition, Eviews13

positive impact on CO2 emissions. The main explanation for this was the use of traditional biomass, which directly increased such emissions. This missing decrease in CO2 emissions can be explained with the initial findings of Jevons (1865) and its later amendments, which stated that lowering CO2 emissions can be hampered by the direct and indirect rebound effects of RES on lower prices (due to the learning curve and more affordable subsidies) and those of energy efficiency. Moreover, the funding shortages and the prices of such projects in these developing countries were recognized as additional reasons for the missing breakthrough in lowering CO2 emissions.

However, upon closer investigation of the impact of modern renewables, our findings were somewhat different. Due to the circular economy, the use of biofuels, biomass, etc. had an impartial stimulus on the CO2 footprint. In this regard, we concluded that, due to the lack of increasing the consumption of solar and wind energy, there is no long-term positive impact on the sample countries for achieving their carbon neutrality target, since their existing support is inadequate.

At this point, there are several limitations that should be noted. First, we limited our research by not focusing on additional related factors such as urbanization, energy efficiency, and technological development. Although the latter two aspects were somewhat addressed by the GDP, further research should involve indicators that cover the fields that influence both overall energy consumption and CO2 emissions. We believe that the negative impacts of the so-called Jevons paradox and the differences in funding can be handled by widespread improvements in these fields. In this regard, we welcome the message and initiative of the COP27 for mobilizing more financial support for developing countries to achieve lower CO2 emissions and become more climate resilient.

Based on our findings, the following question is raised: How can these countries reduce their dependency on GHG emitting technologies, while improving their economic development? Perhaps an effective green monetary policy can improve this condition by outlining various strategies that include abandoning market neutrality, achieving more favorable refinancing terms, obtaining better collateral conditions, and participating in asset purchase programs in the area of green bonds. As for supporting, functioning, and mixing the renewable energy generation market, a credit scheme with interest-free/negligible levels of interest (e.g., 2%–3%) may be a helpful approach. These results can even be considered in similar countries outside of the research focus of our study.

Finally, global policymakers are increasingly moving toward the deployment of RES, especially solar and wind energy, for the purpose of achieving the carbon neutrality target by 2050. It is important to note that, when producing 1kWh of electricity, solar emits 6g, wind emits 4g, and bioenergy emits 98g of CO2.[11] Based on these values (and without hampering their economic progression), the sample countries in our study should have no option but to add even more renewable energy into their energy mix. This also indicates that their present level of contribution is unsatisfactory, especially in the context of CO2 emissions reduction.[12] Therefore, it is important for these countries to gradually withdraw subsidies from fossil fuel industries and apply them to energy producers that solely focus on renewable energy generation. Ultimately, this will influence the consumers of the sample countries to become more energy efficient and more aware of RES in their everyday lives.

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CRediT authorship contribution statement

The first draft of the manuscript was written by Sarolta Somosi. Formal analysis, material preparation, data collection and analysis were performed by Gábor Dávid Kiss, Shahi MD Tanvir Alam and Sarolta Somosi. All authors contributed to the study conception and design, all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Declaration of competing interest

The authors have no relevant financial or non-financial interests to disclose.

The authors have no competing interests to declare that are relevant to the content of this article.

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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Data availability

Data will be made available on request.

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Appendix 1. Panel Vector Error Correction model estimation results

Johansen Cointegration test results

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.** Critical Value
None *	0,52	176,15	125,62	0,00
At most 1 *	0,30	104,10	95,75	0,01
At most 2	0,27	68,27	69,82	0,07
At most 3	0,18	37,07	47,86	0,34
At most 4	0,11	16,92	29,80	0,65
At most 5	0,05	5,43	15,49	0,76
At most 6	0,00	0,08	3,84	0,78

Trace test indicates 2 cointegrating equation(s) at the 0.05 level.
* denotes rejection of the hypothesis at the 0.05 level.
**MacKinnon-Haug-Michelis (1999) p-values.

Unrestricted Cointegration Rank Test (Max-eigenvalue)

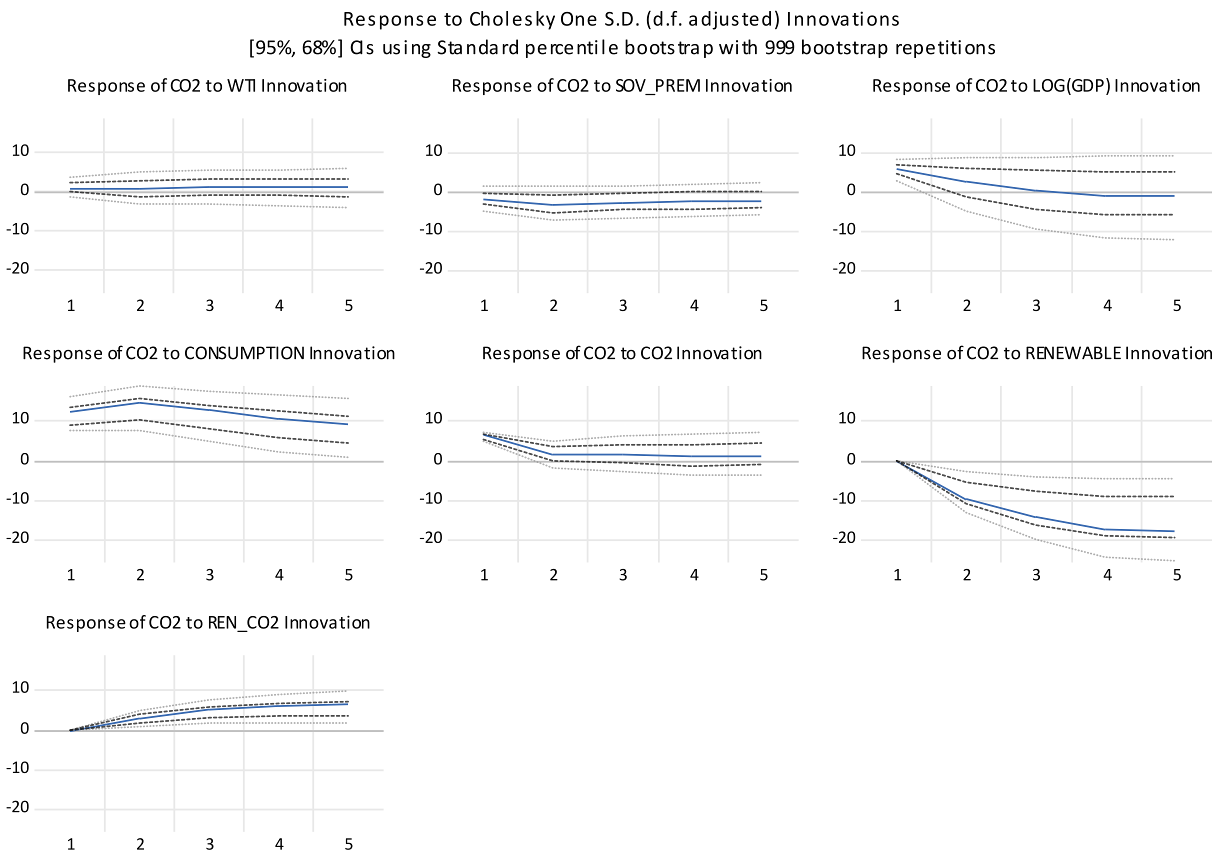
Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.** Critical Value
None *	0,52	72,05	46,23	0,00
At most 1	0,30	35,83	40,08	0,14
At most 2	0,27	31,20	33,88	0,10
At most 3	0,18	20,16	27,58	0,33
At most 4	0,11	11,48	21,13	0,60
At most 5	0,05	5,36	14,26	0,70
At most 6	0,00	0,08	3,84	0,78

[11] https://www.carbonbrief.org/solar-wind-nuclear-amazingly-low-carbon-footprints.

[12] With lacking the sufficient level of financial supporting their high energy demand growth and prompt capacity addition, renewable energy auction scheme can gain its momentum even in developing countries. This scheme attracts more bidders to offer competitive unit price for renewables that is now comparable with traditional fossil fuels.

Max-eigenvalue test indicates 1 cointegrating equation(s) at the 0.05 level.
* denotes rejection of the hypothesis at the 0.05 level.
**MacKinnon-Haug-Michelis (1999) p-values.

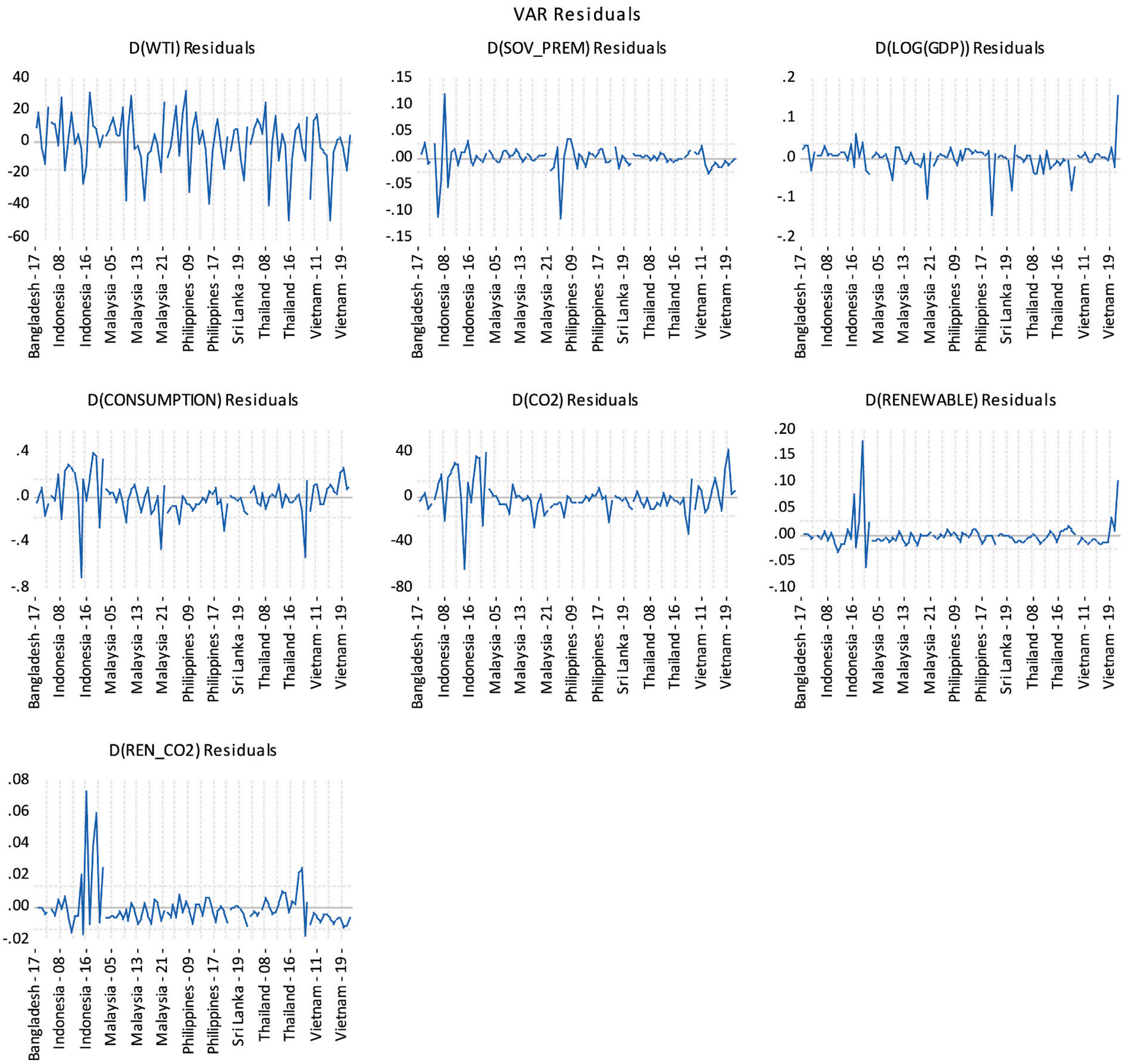
Impulse Response Functions of the Panel Vector Error Correction Method



Variance Decomposition							
Period	WTI	SOV_PREM	LOG (GDP)	CONSUMPTION	CO2	RENEWABLE	REN_CO2
1	0,66	1,29	15,53	64,80	17,72	0,00	0,00
2	0,46	2,18	7,63	64,39	7,78	15,99	1,58
3	0,45	1,95	4,48	54,31	4,85	30,19	3,76
4	0,42	1,70	3,08	44,98	3,39	41,18	5,25
5	0,41	1,49	2,38	38,66	2,64	48,17	6,26

Cholesky One S.D. (d.f. adjusted) Innovations.
Cholesky ordering: WTI SOV_PREM LOG(GDP) CONSUMPTION CO2 RENEWABLE REN_CO2.

Appendix 2. Panel VAR model residuals



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