JSEG

JOURNAL OF SMART ECONOMIC GROWTH

www.jseg.ro ISSN: 2537-141X Volume 9, Number 2, Year 2024

THE ASYMMETRIC IMPACT OF TRADE OPENNESS ON RENEWABLE ENERGY CONSUMPTION IN SOUTH AFRICA

Glenda Maluleke

University of South Africa

malulg@unisa.ac.za

Abstract: *The present study examines the asymmetric impact of trade openness on renewable energy consumption in South Africa. The study used a nonlinear ARDL model and three proxies of trade openness: total trade (imports plus exports), imports, and exports from 1990 to 2020. The positive shocks in total trade and exports are found to be negative and statistically significant in the long run, while the negative shocks are not significant. The negative and positive shocks in imports were found not crucial in the long run. In the short run, the positive shocks in all three proxies of trade openness were found not to be significant. The negative shocks for total trade and imports lead to decreased renewable energy consumption. The negative shocks in exports from the previous period were found to have negative and statistically significant effects on renewable energy consumption in the short run. The findings from the study suggest that renewable energy consumption in South Africa is not mainly influenced by the openness of the economy. Therefore, there is a need to initiate policies promoting renewable energy consumption and moving production activities from being heavily dependent on non-renewable energy.*

JEL classification: F10, Q40

Key words: Renewable energy consumption, Trade openness, NARDL, South Africa

1. INTRODUCTION

Relevant literature indicates that trade openness positively impacts renewable energy consumption (Topcu & Payne, 2018; Rafindadi & Ozturk, 2017). At the same time, energy is essential in producing any country's exported and imported goods and services. Several studies have examined the relationship between trade openness and renewable energy consumption, but much previous literature has generated inconclusive findings regarding the impact of trade on renewable energy consumption (Lin et al., 2016; Amri, 2019; Zeren & Akkus, 2020; Zhang et al., 2021; Han et al., 2022).

Other studies have assumed that the relationship between the variables 'trade openness' and 'renewable energy consumption' is linear, which may not be accurate (Akar, 2016; Wang & Zang, 2021). As such, the studies that have focused on exploring the nonlinear relationship between these two variables, specifically in South Africa, are both scant and limited. To fill this gap, the current study used three proxies of trade openness and decomposed trade openness into positive and negative shocks.

Studies that have examined the dynamics of energy consumption in South Africa include a study by Odhiambo (2021), which focused on the causal relationship between trade openness and energy consumption in sub-Saharan African (SSA) countries (which included South Africa), and a study by Sebri and Salha (2014), showing causality between economic growth and renewable energy consumption in BRICS (Brazil, Russia, India, China, South Africa) countries. Also relevant was a study by Nyoni and Phiri (2020) on the impact of renewable energy on economic growth.

Studies that have specifically examined the relationship between renewable energy consumption and trade openness in South Africa include the work of Zeren and Akkus (2020) and Qamruzzaman and Jianguo (2020), among others. However, these studies used panel data analysis, arriving at the same conclusion about more than one country. Thus, It is difficult to conclude whether such findings apply exclusively to South Africa. Although the study by Qamruzzaman and Jianguo (2020) examined the asymmetric impact of trade openness on renewable energy consumption, it also examined the asymmetric effect of financial development and foreign capital flows in a single study. To be noted is the study by Rafindadi and Ozturk (2017), which examined the effects of trade openness on energy consumption using the Autoregressive Distributed Lag (ARDL) approach within the South African context.

However, the present study differs from previous studies in two distinct ways. Firstly, the study examined the asymmetric impact of trade openness using three proxies of trade openness, which

JOURNAL OF SMART ECONOMIC GROWTH
JSEG
www.jseg.ro ISSN: 2537-141X Volume 9, Number 2, Year 2024

are total trade (imports plus exports), imports, and exports. Secondly, the study used the Nonlinear Autoregressive Distributed Lag (NARDL) methodology that allows for data to be decomposed into negative and positive shocks to examine how the negative and positive shocks of trade openness affect the consumption of renewable energy in South Africa, using data from 1990 to 2020. The present study contributes to the literature in the field by extending the current knowledge related to the impact of the openness of the economy on renewable energy consumption. To our knowledge, this may be the first study to explore the asymmetric effect of trade openness on renewable energy consumption in South Africa.

The study's findings should aid policymakers in designing trade policies and strategies that can promote the use of renewable energy and, ultimately, the growth of the South African economy. The primary current source of energy in South Africa is coal, while some other energy sources include gas, solar, wind, nuclear power, solar power, and hydropower.

In South Africa, the high greenhouse gas emissions in the country are mainly from the conventional electricity generating plants, and in a pursuit to mitigate the CO2 emissions and provide a reliable electricity supply for its people, the government is gradually developing its renewable energy sector (Akinbami et al., 2021). However, challenges remain in renewable energy development, including technical, financial, policy, and environmental challenges (Akinbami et al., 2021). As of 2020, South African renewable energy consumption was 9.8 percent (World Bank, 2023).

A literature review follows the impact of trade openness on renewable energy consumption, followed by an outline of the methodology employed and a description of the data. The final sections report on the findings of the study, its conclusions, and implications.

2. LITERATURE REVIEW

There is extensive literature exploring the impact of trade openness on renewable energy. However, the findings from the studies on the effect of trade openness on energy consumption have produced mixed results. For instance, a study by Kyophilavong et al. (2014), which focused on the relationship between energy consumption, trade openness, and economic growth in Thailand for the period 1971 to 2012, used the Bayer and Hanck cointegration test and the VECM Granger causality approach to determine causality. Findings showed that there is cointegration between the variables and that trade openness Granger causes energy consumption and, in return, energy consumption Granger causes trade openness. In addition, using the ARDL approach, Sbia et al. (2014) found that trade has a negative impact on energy demand in both the short and the long run in the United Arab Emirates. Omri and Nguyen (2014) examined the determinants of renewable energy consumption using a dynamic panel model for a panel of 64 countries from 1990 to 2011. The study found that increased trade openness is one of the main drivers of renewable energy consumption.

Al-Mulali (2015) investigated the effects of economic growth, urbanisation, trade openness, financial development, and renewable energy on CO_2 emission in 23 European countries for the period 1990 to 2013 and found that trade openness has a positive causal influence on renewable electricity production using the Granger causality test. Azam et al. (2015) examined the factors determining energy consumption in Indonesia, Malaysia, and Thailand using the least squares method with time-series data from 1980 to 2012. They found that trade openness has a positive and statistically significant impact on energy consumption.

Shahbaz *et al.* (2015) examined the effect of urbanisation, affluence, and trade openness on energy consumption in Malaysia from 1970Q1 to 2011Q4. They found that trade openness leads to affluence and increases energy consumption. In a study in China, Lin *et al.* (2016) investigated the factors influencing renewable electricity consumption using the Johansen cointegration technique and vector error correction model (VECM) with data from 1980 to 2011. The study found that trade openness undermined the share of renewables in total electricity consumption in China. In a study of Balkan countries, Akar (2016) examined the determinants of renewable energy consumption from 1998 to 2011 and found that trade openness positively affects renewable energy consumption. For the US economy, Shahbaz *et al.* (2017) re-examined the specification of the environmental Kuznets curve (EKC) over the period 1960 to 2016. The VECM Granger causality test findings showed that the causality runs from trade openness to biomass energy consumption.

Topcu and Payne (2018) re-examined the impact of trade on energy consumption for 34 OECD, and results from the CCEMG and AMG estimators indicated a positive effect of trade on energy consumption, while the results from the MG estimator revealed that the impact of trade on energy consumption is insignificant. Also, using panel NARDL investigation in a study of low-income countries, middle-income countries, and upper-middle-income countries, Qamruzzaman and Jianguo (2020) found that there is an asymmetric relationship between financial development, trade openness, capital flows, and renewable energy consumption in the long and short run for the countries, except for lower-income countries, in which the relationship was only confirmed in the long run.

Wang and Zang (2021) conducted a study on the effects of free trade on renewable energy in 186 countries with data from 1990 to 2015. It was found that the influences of free trade on renewable energy vary depending on the different income levels. For example, free trade positively affects renewable energy in high and upper-middle-income countries, while the effect negatively affects lower-middle-income countries. Along the same lines, Zhang *et al.* (2021) examined the impact of trade openness on renewable energy consumption in 35 OECD countries from 1999 to 2018. They found a strong nonlinear relationship between trade openness and renewable energy consumption. For specific countries, they discovered that exports and total trade substantially impacted renewable energy consumption in Mexico and exerted the least impact on renewable energy consumption in the United States.

Chen *et al.* (2021) investigated the determinants of renewable energy consumption. They found that in less democratic countries, an increase in trade openness leads to lower growth rates in renewable energy consumption. Sebri and Salha (2014) used the ARDL bounds testing approach and the Granger causality test in BRICS countries. The study's findings for South Africa showed that trade openness has an insignificant impact on renewable energy consumption. In another study in South Africa, Rafindadi and Ozturk (2017) examined the effect of financial development, trade openness, and economic growth on energy consumption from 1970 to 2011. Using the ARDL approach, it was found that trade openness increases energy consumption.

Therefore, empirical evidence on trade openness's impact on renewable energy consumption proves inconclusive. The literature reviewed indicates that some studies show a positive effect, while others found a negative relationship impact. These variations depend on the measure of trade openness, country of study or group of countries, methodology used, and the study period. Few studies have focused exclusively on South Africa as a single country, and the literature on the asymmetric relationship between renewable energy consumption and trade openness in South Africa is limited.

3. METHODOLOGY

The study employed the NARDL approach developed by Shin *et al.* (2014). In this model, the three proxies of trade openness were decomposed into negative and positive partial sums. The positive partial sum series captures the increase in trade openness, while the negative partial sum series indicates the decrease in trade openness. Therefore, the first step in the NARDL specification method is to decompose the various proxies of trade openness in equation (1) into partial sum processes to account for the asymmetries in the relationship between renewable energy consumption and trade openness. The study also conducted some diagnostic tests, which included normality, heteroskedasticity, and serial correlation associated with the model. The Cumulative Sum of Recursive Residuals (CUSUM) and Cumulative Sum of Squares of Recursive Residuals (CUMUMSQ) were also performed to check the stability of all three models estimated.

To determine the impact of trade openness on renewable energy consumption, the study has three different proxies of trade openness, which are total trade (TO1), exports (TO2), and imports (TO3). Other variables, such as economic growth, financial development, and urbanisation, are included in addition to trade openness as control variables. Therefore, following Zhang *et al.* (2021), the model is expressed as follows:

$$RE = f(TO, Y, FD, URB) \quad (1)$$

The NARDL specification of equation (1) is as follows:

Model 1: $RE = \alpha_0 + \alpha_1 TO1_t^+ + \alpha_2 TO1_t^- + \alpha_3 Y_t + \alpha_4 FD_t + \alpha_5 \Delta URB_t + \mu_t$ (2)

JOURNAL OF SMART ECONOMIC GROWTH

www.jseg.ro ISSN: 2537-141X Volume 9, Number 2, Year 2024

Model 2: $RE = \alpha_0 + \alpha_1 TO2_t^+ + \alpha_2 TO2_t^- + \alpha_3 Y_t + \alpha_4 FD_t + \alpha_5 \Delta URB_t + \mu_t$ (3)

Model 3: $RE = \alpha_0 + \alpha_1 TO3_t^+ + \alpha_2 TO3_t^- + \alpha_3 Y_t + \alpha_4 FD_t + \alpha_5 \Delta URB_t + \mu_t$ (4)

Where:

RE = Renewable energy consumption

TO1 = Imports plus exports

TO2 = Imports

TO3= Exports

Y = GDP per capita growth

FD = Financial development

URB = Urbanisation

The three proxies of trade openness included in the study are decomposed into their positive and negative partial sums as follows (Shin *et al.*, 2014):

$$X_t^+ = \sum_{j=1}^{t} \Delta X_t^+ = \sum_{j=1}^{t} \max(\Delta X_j; 0) \quad (5)$$

$$X_t^- = \sum_{j=1}^{t} \Delta X_t^- = \sum_{j=1}^{t} \min(\Delta X_j; 0) \quad (6)$$

The NARDL approach uses negative and positive changes and captures the asymmetries in the short-run and long-run relationship. Based on equations 5 and 6, the NARDL model for equations (2) to (3) can be presented as follows:

$$\begin{aligned}\Delta RE_t = \delta_0 &+ \sum_{i=1}^{k} \delta_{1i} \Delta RE_{t-i} + \sum_{i=0}^{k} \delta_{2i} \Delta TO_{t-i}^+ + \sum_{i=0}^{k} \delta_{3i} \Delta TO_{t-i}^- + \sum_{i=0}^{k} \delta_{4i} \Delta Y_{t-i} \\ &+ \sum_{i=0}^{k} \delta_{5i}\, \Delta FD_{t-i} + \sum_{i=0}^{k} \delta_{6i}\, \Delta URB_{t-i} + \beta_1 RE_{t-1} + \beta_2 TO_{t-i}^+ + \beta_3 TO_{t-i}^- \\ &+ \beta_4 Y_{t-1} + \beta_5 FD_{t-1} + \beta_6 URB_{t-1} + \mu_{1t} \quad (7)\end{aligned}$$

Cointegration in the NARDL approach is the same as in the ARDL approach. To confirm cointegration in the long run, the computed F-statistic is compared to the upper and lower critical values by Pesaran *et al.* (2001). If the F-statistic is above the upper critical bounds, then the null hypothesis is rejected, and if it is below the lower bounds, then the null hypothesis of no cointegration is accepted (Pesaran *et al.*, 2001). After cointegration is confirmed, the error correction model (ECM) for the NARDL is specified as follows:

$$\Delta RE_t = \delta_0 + \sum_{i=1}^{k} \delta_{1i}\Delta RE_{t-i} + \sum_{i=0}^{k} \delta_{2i}\Delta TO^{+}_{t-i} + \sum_{i=0}^{k} \delta_{3i}\Delta TO^{-}_{t-i} + \sum_{i=0}^{k} \delta_{4i}\Delta Y_{t-i} + \sum_{i=0}^{k} \delta_{5i}\,\Delta FD_{t-i} + \sum_{i=0}^{k} \delta_{6i}\,\Delta URB_{t-i} + \theta_1 ECM_{t-1} + \mu_t \quad (8)$$

The coefficient of the error correction term (θ) is expected to be negative and statistically significant. Lastly, the Wald test confirms the asymmetric effects of trade openness on renewable energy consumption. The rejection of the null hypothesis confirms the presence of long and short-run asymmetry. The null and alternative hypothesis to test the presence of long-run asymmetry is expressed as follows:

$$H_0: -\beta_2^{+}/\beta_1 = -\beta_3^{-}/\beta_1;\ H_1: -\beta_2^{+}/\beta_1 \neq -\beta_3^{-}/\beta_1 \quad (9)$$

The null and alternative hypothesis to test the presence of short-run asymmetry is expressed as follows:

$$H_0: -\delta_{2i}^{+}/\delta_{1i} = -\delta_{3i}^{-}/\delta_{1i};\ H_1: -\delta_{2i}^{+}/\delta_{1i} \neq -\delta_{3i}^{-}/\delta_{1i} \quad (10)$$

The study period was limited to 1990-2020 due to the unavailability of data for South Africa and the data is obtained from World Bank Development Indicators. The summary of the measurement of the variables is presented in Table 1.

Table. 1 – Definitions of variables and data sources

Variables	Measurements of the variables
Renewable energy (RE)	Renewable energy consumption (% of total final energy consumption)
Trade openness (TO1)	Exports + Imports (% of GDP)
Trade openness (TO2)	Imports (% of GDP)

Trade openness (TO3)	Exports (% of GDP)
Economic growth (Y)	GDP per capita growth (annual %)
Financial development (FD)	Domestic credit to private sector (% of GDP)
Urbanisation (URB)	Urban population growth (annual %)

4. RESULTS AND DISCUSSION

The variables were first examined to determine whether they were nonlinear using the Brock-Dechert-Scheinkman (BDS) test proposed by Brock *et al.* (1996). The BDS test results indicate that the variables are nonlinear, confirmed by the statistical significance of the BDS test at the 1 percent level. The variables were tested for stationarity to ensure that none of variables are not integrated of order two or higher. The Dickey-Fuller Generalized Least Squares (DF-GLS) and the Phillips-Perron (PP) tests were used to test stationarity. The results show that the variables are integrated of either I(0) or I(1). Therefore, we could proceed with the NARDL analysis. The stationarity test results are presented in Table 2, and the results of the BDS test are in Table 3.

Table. 2 – Stationarity Test Results

Variable	**DF-GLS**		**PP**		**Decision**
	Level	Δ	Level	Δ	
RE	-1.509	-4.899***	1.357	-4.724***	I(1)
$TO1$	-2.753	-6.210***	-2.681	-7.335***	I(1)
$TO2$	-2.203	-5.947***	-1.833	-6.021***	I(1)
$TO3$	-3.409**	___	-3.409**	___	I(0)
Y	-1.707	-4.922***	-0.446	-5.175***	I(1)
FD	-1.509	-4.891***	-1.499	-4.689***	I(1)
URB	-2.474	-5.930***	-3.993**	___	I(0) I(1)

*Notes: *** and ** denote stationarity at 1% and 5% levels of significance, Δ which is the first difference*

Table. 3 – BDS Test Results

Variables	**BDS Statistic**				
	Dimension 2	**Dimension 3**	**Dimension 4**	**Dimension 5**	**Dimension 6**

	BDS Statistic	BDS Statistic	BDS Statistic	BDS Statistic	BDS Statistic
RE	0.166 [0.000]***	0.286 [0.000]***	0.362[0.000]***	0.410[0.000]***	0.439[0.000]***
$TO1$	0.141[0.000]***	0.230[0.000]***	0.268[0.000]***	0.281[0.000]***	0.282[0.000]***
$TO2$	0.144[0.000]***	0.238[0.000]***	0.278[0.000]***	0.284[0.000]***	0.285[0.000]***
$TO3$	0.121[0.000]***	0.207[0.000]***	0.243[0.000]***	0.254[0.000]***	0.244[0.000]***
Y	0.049[0.000]***	0.107[0.000]***	0.141[0.000]***	0.159[0.000]***	0.159[0.000]***
FD	0.141[0.000]***	0.222[0.000]***	0.261[0.000]***	0.267[0.000]***	0.272[0.000]***
URB	0.126[0.000]***	0.217[0.000]***	0.263[0.000]***	0.256[0.000]***	0.265[0.000]***

*Notes: *** denotes statistical significance at 1% level, [] are the p-values*

Since the variables are either I(0) or I(1), the study examined a possible cointegration relationship between renewable energy consumption and the variables included in the model. The results of the asymmetric cointegration tests show that all the models are cointegrated, as the F-statistics in the three Models are significant at a 1% significance level. Since cointegration has been confirmed, the study examined the short and long-run asymmetric relationships between renewable energy consumption and the various proxies of trade openness. The results of the NARDL cointegration results are presented in Table 4.

Table. 4 – Cointegration Test Results

	F-Statistic	Asymptotic critical values					
Model 1	6.448***	10%		5%		1%	
Model 2	5.508***	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
Model 3	5.417***	2.26	3.35	2.62	3.79	3.41	4.68

*Note: *** denotes statistical significance at 1% level.*

To confirm the asymmetric relationships between renewable energy and the various proxies of trade openness in the short and long run, the Wald test was computed for all three models. The results of the Wald test found an asymmetric relationship in the long and short run for Models 1 and 2. In Model 3, the findings indicate an asymmetric impact of exports on renewable energy consumption only in the long run. The Wald test results are presented in Table 5.

Table. 5 – Wald Test Results

F-Statistics [Probability]			
	Model 1	**Model 2**	**Model 3**
W_{LR}	22.122*** [0.000]	18.141*** [0.001	7.950** [0.013]
W_{SR}	7.576** [0.016]	7.818** [0.014]	2.256 [0.154]

*Notes: *** and ** denote statistical significance at 1% and 5% levels, respectively*

W_{LR} is a long-run asymmetric test; W_{SR} is a short-run asymmetric test.

The results of all three NARDL models are presented in Table 6. The NARDL results reported in Table 6 indicate that the effects of the negative and positive partial sums of trade openness on renewable energy consumption depend on the measure of trade openness used. In Model 1, positive shocks of total trade (imports plus exports) negatively and significantly impact renewable energy consumption in the long run. This suggests that an increase in trade openness will lead to a decrease in renewable energy consumption. In the short run, the negative shocks have a statistically significant effect, which means that the negative shocks in trade openness lead to a decrease in renewable energy consumption. The positive shocks are statistically insignificant in the short run, while the negative shocks have an insignificant impact in the long run.

In Model 2, the positive and negative shocks in trade openness measured by exports have no statistically significant effect on renewable energy consumption in the long run. However, the negative shocks significantly impact renewable energy in the short run. The findings suggest that in the short run, the negative shocks in exports lead to decreased renewable energy consumption. Furthermore, positive shocks in exports do not significantly affect renewable energy consumption in the short run.

In Model 3, trade openness is measured by imports, and the results show that in the long run, the positive shocks have a negative effect on renewable energy consumption while statistically insignificant in the short run. The negative shocks in imports have an insignificant impact on renewable energy consumption in the short and long run. However, the negative shocks in imports from the previous period led to decreased renewable energy consumption.

The study's overall findings show that trade openness negatively affects renewable energy consumption irrespective of the proxy used. However, some believe that trade openness leads to an increase in economic output and, therefore, an increase in energy consumption. However, the results from the present study found the opposite. The relationship between trade openness and renewable energy consumption is negative for South Africa. This could be because South Africa's energy is currently mainly sourced from non-renewables – renewable energy only accounts for about 10 percent of total energy production. The findings also suggest that trade with other countries is not an essential factor in determining renewable energy consumption and that trade activities such as import and export goods depend on different energy sources, such as non-renewables in South Africa.

In Models 1 and 2, the findings of the control variables show that an increase in economic growth has a negative impact on renewable energy consumption. At the same time, urbanisation is found to have a statistically insignificant impact, both in the short and long run. The increase in financial development positively impacts renewable energy consumption in the short run. Still, it is statistically insignificant in the long run., irrespective of whether it is in the long or short run. In Model 3, economic growth is found to have a statistically significant negative impact on renewable energy consumption in the short and long run. On the other hand, an increase in financial development only positively impacts renewable energy consumption in the long run and is statistically insignificant in the short run. Urbanisation is found not to be statistically significant in either the long run or the short run.

The diagnostics tests presented in Table 6 indicate that no problem of normal distribution of error term or serial correlation was found, and no problem of heteroskedasticity was found. Lastly, the CUSUM and CUSUMQ were conducted to establish whether the model parameters are stable or not. The CUSUM and CUSUMQ results, as presented in Figure 1, indicate that all three estimated models are stable, as confirmed by the plots within the confidence band at a 5 percent significance level.

Table. 6 – Results of Long-run and Short-run Estimation

Long-run Results						
	Model 1		**Model 2**		**Model 3**	
Regressor	**Coefficient**	**T-ratio [p-value]**	**Coefficient**	**T-ratio [p-value]**	**Coefficient**	**T-ratio [p-value]**
$TO1^{+}$	-0.192*	-1.794 [0.094]	—	—	—	—
$TO1^{-}$	0.098	0.759 [0.461]	—	—	—	—
$TO2^{+}$	—	—	-0.333	-1.720 [0.107]	—	—
$TO2^{-}$	—	—	0.221	0.913 [0.377]	—	—
$TO3^{+}$	—	—	—	—	-0.981***	-3.553 [0.003]
$TO3^{-}$	—	—	—	—	-0.555	-1.733 [0.105]
Y	-0.804***	-3.586 [0.003]	-1.134***	-3.476 [0.004]	-1.010***	-4.111 [0.001]
FD	0.063	1.155 [0.267]	0.072	1.198 [0.251]	0.127*	1.869 [0.083]
URB	0.545	1.016 [0.327]	-0.098	-0.138 [0.892]	0.290	0.416 [0.684]
Short-run Results						
C	5.332***	7.250 [0.000]	5.418***	6.753 [0.000]	2.486***	5.919 [0.000]
$\Delta RE(-1)$	0.817***	7.713 [0.000]	0.808***	6.561 [0.000]	—	—
$\Delta TO1^{+}$	0.002	0.064 [0.950]	—	—	—	—
$\Delta TO1^{-}$	0.237***	8.316 [0.000]	—	—	—	—

JSEG
JOURNAL OF SMART ECONOMIC GROWTH
www.jseg.ro ISSN: 2537-141X Volume 9, Number 2, Year 2024

$\Delta TO2^{+}$	—	—	-0.011	-0.159 [0.876]	—	—
$\Delta TO2^{-}$	—	—	0.449***	7.048 [0.000]	—	—
$\Delta TO3^{+}$	—	—	—	—	-0.095	-1.122 [0.281]
$\Delta TO3^{-}$	—	—	—	—	0.115	1.666 [0.118]
$\Delta TO3^{-}(-1)$	—	—	—	—	0.128*	2.009 [0.064]
ΔY	-0.214***	-5.836 [0.000]	-0.314***	-6.365 [0.000]	-0.191***	-4.149 [0.001]
ΔFD	0.018**	2.217 [0.044]	0.022**	2.493 [0.026]	0.0004	0.047 [0.963]
$\Delta FD\ (-1)$	-0.077***	-6.631[0.000]	-0.058***	-4.803 [000]	-0.068***	-4.665 [0.000]
ΔURB	0.230	1.031 [0.320]	-0.039	-0.138 [0.892]	1.124	0.423 [0.678]
$ECM(-1)$	-0.421***	7.246 [0.000]	-0.399***	-6.697 [0.000]	-0.426***	-6.642 [0.000]
Test statistics and diagnostics tests						
R-Squared	0.872		0.836		0.793	
R-Bar-Squared	0.824		0.775		0.717	
Normality	0.492 [0.782]		0.311 [0.856]		1.654 [0.437]	
Serial Correlation	1.014 [0.392]		1.036 [0.385]		1.969 [0.182]	
Heteroscedasticity	0.702 [0.727]		1.211 [0.362]		1.128 [0.410]	

*Notes: ***, ** and * denote statistical significance at 1%, 5% and 10% levels, respectively; + and - denote the positive and negative shocks*

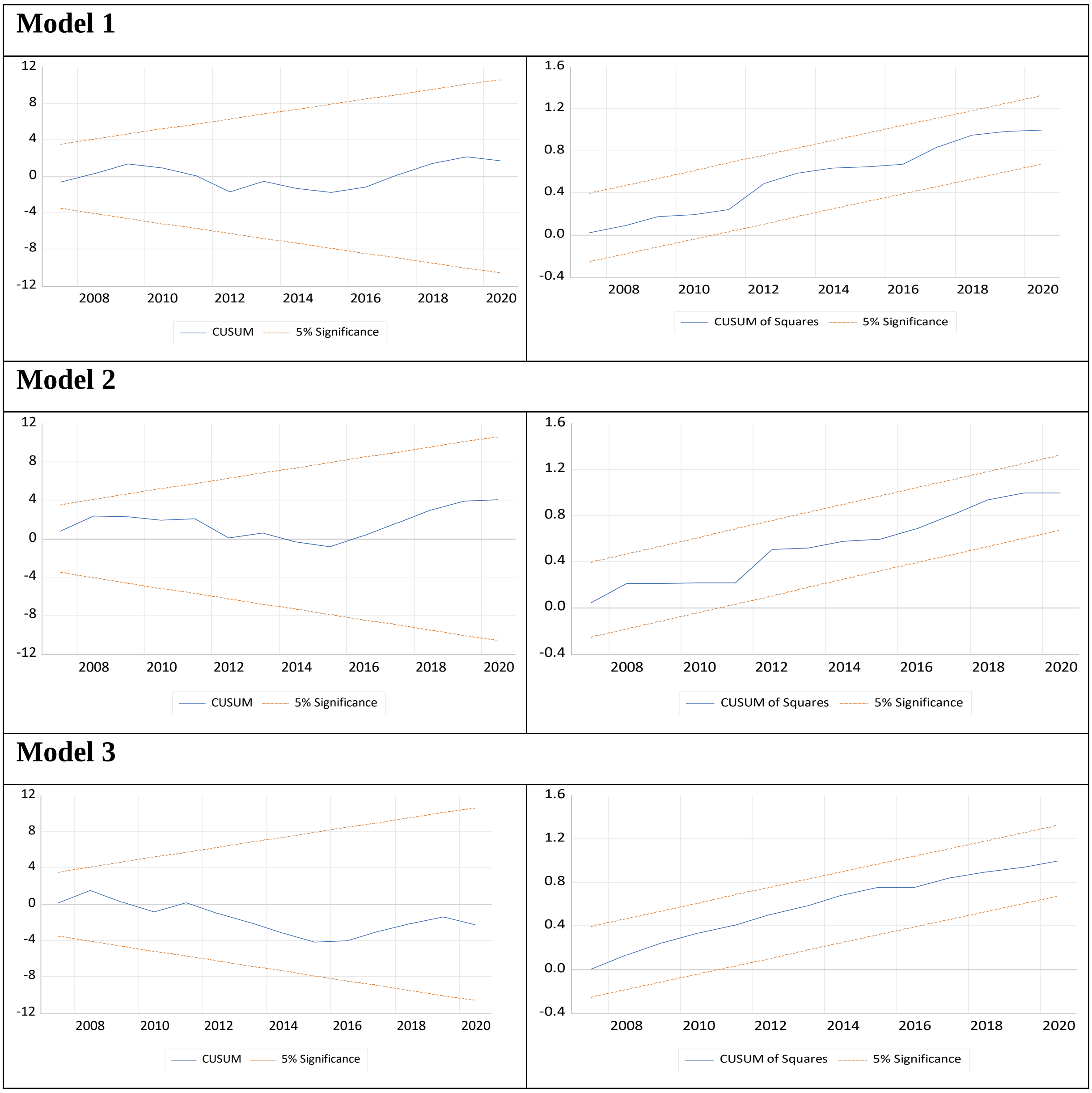

Fig. 1 – CUSUM and CUSUMQ

5. CONCLUSIONS

This study has examined how trade openness impacted renewable energy consumption in South Africa from 1990 to 2020, using the NARDL bounds testing approach to cointegration. The estimation results for the three models show that trade openness has a negative impact on renewable energy in South Africa. The positive shocks in total trade and exports were negative and statistically significant, while the negative shocks were not significant in the long run. The negative and positive shocks in imports were found not to be significant in the long run. In the short run, the positive shocks in all three proxies of trade openness were found not to be statistically significant. The negative shocks for total trade and imports are statistically significant and lead to a decrease in renewable energy consumption. The negative shocks in exports from the previous period have negative and statistically significant effects on renewable energy consumption.

The study's findings imply that authorities such as the South African government need to initiate policies that will promote renewable energy consumption and move production activities from being heavily dependent on non-renewable energy. This includes incentives and subsidies for businesses to invest in renewable energy. Such actions will assist the country in achieving its Sustainable Development Goals (SDGs) of affordable, reliable, and sustainable energy access for all. As solar, wind, hydroelectric, and biomass are important primary sources of energy in South Africa, future studies could investigate the effect of trade openness on these different types of energy sources. Such studies could also explore the impact of these sources on economic growth and CO2 emissions.

CONFLICTS OF INTEREST AND PLAGIARISM: The authors declare no conflict of interest and plagiarism.

REFERENCES

1. Akar, B.G. (2016). The determinants of renewable energy consumption: An empirical analysis for the Balkans. *European Scientific Journal*, 12 (11). https://doi.org/10.19044/esj.2016.v12n11p594
2. Akinbami, O. M., Oke, S. R., & Bodunrin, M. O. (2021). The state of renewable energy development in South Africa: An Overview. *Alexandria Engineering Journal*, 60, 5077–5093. https://doi.org/10.1016/j.aej.2021.03.065
3. Al-Mulali, U., Ozturk, I. & Lean, H.H. 2025. The influence of economic growth, urbanization, trade openness, financial development, and renewable energy on pollution in Europe. *Natural Hazards*, 79, 621–644. https://doi.org/10.1007/s11069-015-1865-9

4. Amri, F. (2019). Renewable and non-renewable energy and trade into developed and developing countries. *Quality and Quantity*, 53, 377–387. https://doi.org/10.1007/s11135-018-0758-x
5. Azam, M., Khan, A.Q, Zaman, K., & Ahmad, M. (2015). Factors determining energy consumption: Evidence from Indonesia, Malaysia and Thailand. *Renewable and Sustainable Energy Reviews*, 42, 1123-1131. https://doi.org/10.1016/j.rser.2014.10.061
6. Brock, W.A., Scheinkman, J.A., Dechert, W.D. & LeBaron, B. (1996). A test for independence based on the correlation dimension. *Econometric Reviews*, 15(3), 197–235.
7. Cheah, S.-P., Yiew, T.-H., & Ng, C.-F. (2017). A nonlinear ARDL Analysis on the relation between stock price and exchange rate in Malaysia. *Economics Bulletin*, 37(1), 336-346.
8. Chen, C., Pinar, M. & Stengos, T. (2021). Determinants of renewable energy consumption: Importance of democratic institutions. *Renewable Energy*, 179, 75-83.
9. Han, J., Zeeshan, M., Ullah, I. Rehman, A., & Afridi, F.E.A. (2022). Trade openness and urbanization impact on renewable and non-renewable energy consumption in china. *Environmental Science and Pollution Research*, 29, 41653–41668. https://doi.org/10.1007/s11356-021-18353-x
10. Kyophilavong, P., M. Shahbaz, S. Anwar, & M. Sameen. (2015). The energy-growth nexus in Thailand: Does trade openness boost up energy consumption? *Renewable and Sustainable Energy Reviews*, 46, 265–274. doi: 10.1016/j.rser.2015.02.004.
11. Lin, B., Omoju, O.E., & Okonkwo, J.U. (2016). Factors influencing renewable electricity consumption in China. *Renewable and Sustainable Energy Reviews*, 55, 687-696. https://doi.org/10.1016/j.rser.2015.11.003
12. Nyoni, B. & Phiri, A. (2020). Renewable energy - economic growth nexus in South Africa: Linear, nonlinear or non-existent? *International Journal of Energy Economics and Policy,* 10(6), 635–644. https://doi.org/10.32479/ijeep.7706
13. Odhiambo, N.M. (2021). Trade openness and energy consumption in Sub-Saharan African countries: A multivariate panel Granger causality test. *Energy Reports*, 7, 7082-7089.
14. Omri, A. & Nguyen, D.K. (2014). On the determinants of renewable energy consumption: International evidence. *Energy,* 72, 554-560.
15. Qamruzzaman, M. & Jianguo, W. (2020). The asymmetric relationship between financial development, trade openness, foreign capital flows, and renewable energy consumption:

Fresh evidence from panel NARDL investigation. *Renewable Energy,* 159, 827-842. https://doi.org/10.1016/j.renene.2020.06.069

16. Rafindadi, A.A. & Ozturk, I. (2017). Dynamic effects of financial development, trade openness and economic growth on energy consumption: Evidence from South Africa. *International Journal of Energy Economics and Policy,* 7(3), 74-85.
17. Sbia, R., Shahbaz, M. & Hamdi, H. (2014). A contribution of foreign direct investment, clean energy, trade openness, carbon emissions and economic growth to energy demand in UAE. *Economic Modelling*, 36, 191–197. https://doi.org/10.1016/j.econmod.2013.09.047
18. Sebri, M. & Salha, O.B. 2014. On the causal dynamics between economic growth, renewable energy consumption, CO2 emissions, and trade openness: Fresh evidence from BRICS countries. *Renewable and Sustainable Energy Reviews,* 39. https://doi.org/10.1016/j.rser.2014.07.033
19. Shahbaz, M., Loganathan, N., Sbia, R. & Afza, T. (2015). The effect of urbanization, affluence and trade openness on energy consumption: A time series analysis in Malaysia. *Renewable and Sustainable Energy Reviews,* 47, 683–693. https://doi.org/10.1016/j.rser.2015.03.044
20. Shahbaz, M. Solarin, S.A., Hammoudeh, S., & Shahzad, S.J.H. (2017). Bounds testing approach to analyzing the environment Kuznets curve hypothesis with structural beaks: The role of biomass energy consumption in the United States. *Energy Economics,* 68, 548–565. https://doi.org/10.1016/j.eneco.2017.10.00
21. Shin, Y., Yu, B.C., & Greenwood-Nimmo, M. (2014). Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In Sickels, R. and Horrace, W. (Eds): *Festschrift in honor of Peter Schmidt: Econometric Methods and Applications* (pp. 281-314). New York: Springer.
22. Topcu, M. & Payne, J.E. (2018). Further evidence on the trade-energy consumption nexus in OECD countries. *Energy Policy,* 112, 160–165.
23. Wang, Q. & Zhang, F. (2021). Free trade and renewable energy: A cross-income levels empirical investigation using two trade openness measures. *Renewable Energy,* 168, 1027–1039.
24. World Bank. 2023. World development indicators [Online] https://databank.worldbank.org/ data/source/world-development-indicators#

25. Zeren, F. & Akkus, H.T. (2020). The relationship between renewable energy consumption and trade openness: New evidence from emerging economies. *Renewable Energy*, 147, 322–329.

26. Zhang, M., Zhang, S., Lee, S. & Zhou, D. (2021). Effects of trade openness on renewable energy consumption in OECD Countries: New insights from Panel Smooth Transition Regression Modelling. *Energy Economics*, 104, 1–16. https://doi.org/10.1016/j.eneco.2021.105649