EXPLORING THE IMPACT OF EXPORTS ON CLEAN ENERGY CONSUMPTION IN CHINA: AN EMPIRICAL STUDY

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Abdelrahim A. M. Yahia[1+]

Zhaohua Li[2]

Ebaidalla Mahjoub Ebaidalla[3]

Jun He[4]

[1]School of Economics, Huazhong University of Science and Technology, Wuhan, China and Department of Economics, University of Kassala, Kassala, Sudan.
Email: abdelrahim2uofk@gmail.com Tel: +249911202826
[2]School of Economics, Huazhong University of Science and Technology, Wuhan, China.
Email: zhaohuali@hust.edu.cn Tel: +8613100705171
[3]Department of Economics, University of Khartoum, Khartoum, Sudan.
Email: ebaidalla@gmail.com Tel: +249912636114
[4]School of Economics, Huazhong University of Science and Technology, Wuhan, China.
Email: 371638810@qq.com Tel: +8615671660175

(+ Corresponding author)

ABSTRACT

Understanding the influence of export volume in improving a country's clean energy consumption requires a systematic search method to characterize the crucial role to ensure environmental sustainability. The present study employed an autoregressive distributed lag (ARDL) bounds testing approach and vector error correction model (VECM), by using data from 1985-2018. The analysis revealed that in the long-run an increase in exports per capita and technological innovation can enhance clean energy consumption, and overcome environmental issues. Surprisingly, economic growth does not display significant effect. In the short run technological progress reduces clean energy consumption. The outcome of causality tests reveals a unidirectional from technological innovation to clean energy consumption in the short term. Along similar line, the results prove a feedback link among exports per capita and clean energy consumption, indicating that an increase in exports per capita is a core factor driving and improve energy use, among technological innovation and clean energy consumption, and among economic growth and clean energy consumption in the long run. To enhance clean energy and enable success in environmental improvement, policymakers in China should take proper initiatives to increase the clean trade, adjust the export pattern, and patent incentive technology, to ensure sustainable economic development.

Contribution/ Originality: This study is one of very few studies which have investigated the role of exports in clean energy consumption in China, and contributes to the existing literature by employing the ARDL bounds testing approach and VECM to investigate the short-run and long-run interconnections.

1. INTRODUCTION

Energy pervades in most sectors of the economy, therefore, to achieve adequate and reliable energy consumption depends on economic growth. As the countries move along its growth path, China enjoys energy-led growth, it is demand for energy consumption rises with economic growth. So, China remained in the largest energy

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consumer in the world until 2009, with almost 22 percent of total global energy consumption in 2018 (GESY, 2019). According to the National Bureau of Statistics of China, the most portion of this energy comes from the consumption of coal, they represent about 59 percent of China's energy consumption in 2018. Therefore, the use of this type of energy has the related effect of harming the environment which causes global climate change through an increase in carbon dioxide (CO_2) emission, sulfur dioxide, etc. As a nation becomes more interested to follow the path of international trade, growth and green investment, this situation provided policymakers in China, the opportunity to pay more attention to increase exports as important factors to driver clean energy consumption.

Clean energy, indicates the energy that does not emit pollutants, such as solar energy, hydropower, wind power, tidal energy, and nuclear energy. While China is the largest in coal consumption, it also is greener than anyone else. It was responsible for 32 percent of all global sources of renewable energy in 2018, such as hydropower, solar photovoltaic (PV) and wind. The debate on the role of export plays in determining clean energy consumption has at times generate more heat than light. The series identifies the hypotheses linking exports and clean energy consumption has been successful in theoretical work, but it is seriously lagged in empirical verification. In recent, the most studies focusing on the relationship between exports/trade and energy consumption (Chen, Wang, & Zhong, 2019; Dedeoğlu & Kaya, 2013; Nasreen & Anwar, 2014; Sadorsky, 2011; Tiba & Frikha, 2018). However, the recent literature review has not given sufficient attention to the linkage between exports/trade and clean energy consumption. A study conducted by Sebri and Ben-Salha (2014); Shahbaz, Khan, and Tahir (2013); Sohag, Begum, Abdullah, and Jaafar (2015) revealed that an increase in export volume contributes to economic activity and this might increase energy consumption, therefore, exports, income, and energy tend to move together over time. Moreover, some scholars focused widely on renewable energy consumption e.g., (Ben Jebli, Ben Youssef, & Apergis, 2014; Chen et al., 2019). In addition, some researches tend to use the ARDL bounds test to analyse the link between that international trade and renewable energy consumption such as Alam and Murad (2020); Brini, Amara, and Jemmali (2017) but authors do not discuss their results in terms of specification tests of the ARDL bounds to investigate the role of exports volume in clean energy sources such as hydropower, nuclear power, and wind. Therefore, our study aims to fill the gaps. China is well endowed with renewable sources of energy; therefore it is important to investigate the relationship between clean energy consumption and international trade. Thus, the paper provides significant contributions as follows:

First, employ the autoregressive distributed lag (ARDL) bounds testing approach and vector error correction model (VECM), to investigate the role of exports in clean energy consumption in China in terms of the short and long-run links, as well as explain Granger causality between the variables. To the best of our knowledge, the kind of this research has not given sufficient attention in China, and this will offer new empirical evidence for the policymaker to improve clean energy use. Second, clean energy sources such as hydropower, nuclear power, and wind power have been neglected in international trade literature abroad, so far probably due to the lack of long-time series data in most countries, such as China.

Therefore, this study also aims to fulfill this lack and contributes to the existing literature. Moreover, the linkage between export and clean energy use makes more theoretical sense due to the boom and the ability, to keep a green economy and has significant implications for China government and policymakers. To achieve these aims, the study used the ARDL bounds testing approach and VECM model to infer exports and clean energy consumption causal relationships. The rest of the paper is organized as follows. In section 2 we provide a brief history of clean energy consumption in China, while section 3 provides the methodology. In section 4 the study presents empirical results and section 5 conclusion and policy implementation.

2. OVERVIEW OF CHINA'S CLEAN ENERGY CONSUMPTION

China is an interesting state to study the role of exports in clean energy consumption because it has experienced rapid economic growth since the open door reform policy in 1978, the clear signs of growth were

driven by the volume of exports, and in 2010 it became the second-largest economy in the world. China's economy depends in large part on tertiary and secondary industries which together make up 95.80% of China's GDP growth in 2018, exports played a significant part in China's economic growth, the share of exports of goods and services accounted on average about (19.51% of GDP) in 2018, most China's exports rely heavily on of manufactured goods which represent by 80.12% of total exports. In 2018 total energy consumption in China reaches 4.49 billion tce, which increased by the annual growth rate is 33.58% more than at the beginning time which has become the largest country consume energy in the world in 2009. Due to its rising energy consumption, China has had to become more demanded clean energy sources to meet its emissions'. Therefore, China has a relatively extensive set of policies applied to improve the environment and energy use, the real attention of its policies have their roots in 2011 during the 12th Five-Year-Plan (FYP) Period, to control greenhouse gas emissions from 2011–2015 (Yuan, Xu, Zhang, Hu, & Xu, 2014). In June 2014 China's president made calls for an "energy revolution", this program guidance for Energy Production and Consumption Revolution Strategy (2016-2030), target to cover energy demand incremental mainly by clean energy (WEO, 2017). After this implementation, the miracle of China's clean energy consumption was enabled at a two-digit growth rate Figure 1.
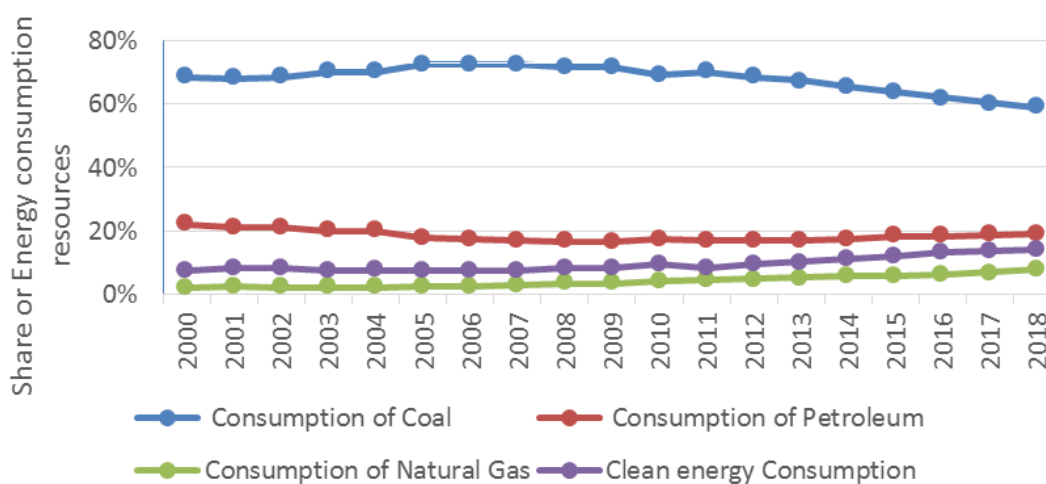

Figure-1. China's Energy consumption by a resource (2000–2018).
Source: Based on NBS (National Bureau of Statistics) (2018).

Clean energy consumption (Hydro Power, Nuclear Power, and Wind Power) in China has increased steadily simultaneously with the rapid increase in energy consumption. It is increased fivefold from 10,728.37, million tce in 2000 to 66,352 Mtce in 2018, this is one of the important observations which excites the interests of our study. Since 2000, however, other energy sources such as natural gas do not feature as a significant energy source Figure 1. Shows that between 2000 and 2017 clean energy increased steady, its share of energy consumption increased from 7.3 to 13.8 percent. The increase in coal share due to the abundance of coal in China and exist advanced industrialization, hence, industries were used more energy resources such as coal, oil, use of private automobiles, etc. As illustrated in Figure 2 Recently, China became one of the largest exports in the global and its path of emissions from CO2, for example, has closely followed the path of energy consumption. Thus, the sharp increase in export volume caused by the economic structure and the manufacturing industry. The state data also exhibits some remarkable patterns, the average of China's annual growth rate of export is 15.30% during the period "between" 2000 to 2018, this will reflect in China's energy structure. It can be clearly shown that exports grow strongly and consistently with an upward trend, also clean energy consumption increases consistently with exports trend Figure 2. Although the government regulations continue in playing a curial role in energy use, and economic growth this will reflect on international trade.
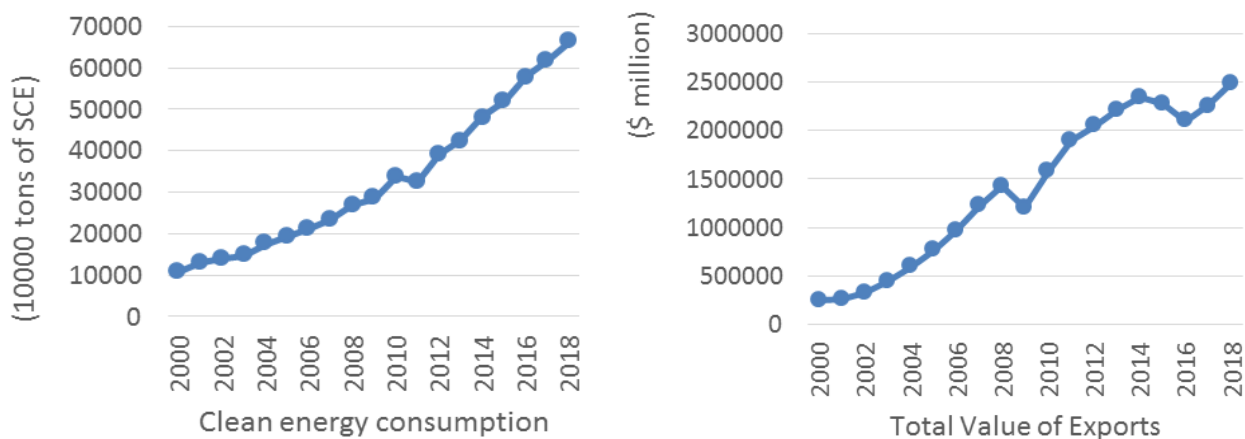
Figure-2. China's total exports and clean energy consumption.
Source: NBS (National Bureau of Statistics) (2018).

3. METHODOLOGY

3.1. Model Specification

The study focuses on China because it is leading the way in clean energy use, as well as the high technical level for the efficient use of energy recently. For example, the consumption of clean energy in China increased more than five times in 18 years from 10,728.37 million tce in 2000 to 66,352 Mtce in 2018 (NBS, 2019). To test whether the export volume has a systematic relationship with the clean energy in China, the study depends on time series data, and adopt the ARDL technique using an error correction model (ECM). Following the methodology of Pesaran, Shin, and Smith (2001) and Narayan (2005) the present work considers the effect of exports on clean energy in the presence control variables in a multivariate framework. Thus, the functional form of the model as follows:

$$CEC = f(EX, TI, GDPG) \tag{1}$$

Where CEC is the clean energy consumption, EX denotes export volume, TI is technological innovation, and GDPG represents the economic growth.

The specific form of Equation 1 might be transformed into log-linear functional as follows:

$$LnCEC_t = \beta_0 + \beta_1 LnEX_t + \beta_2 LnTI_t + \beta_3 LnGDPG_t + \varepsilon_t \tag{2}$$

Where Ln, CEC, EX, TI, and GDPD indicate the natural-log of those variables as defended earlier, while "ε" is a residual error term, it assumed to be a normal distribution with zero mean and constant variance, and "t" refers to time. The parameters β_i (i= 0, 1, 2, 3) are the long-run elasticities corresponding to each explanatory variable. Thus, Equation 2 is a basic equation for the level of PM2.5 in provinces at time t. Therefore, our study included important variables and their sources according to the following evidence and items:

First, technological innovation; mostly improves the clean energy use by technological progress, while it reduces energy consumption slightly, i.e., through allow the economy to produce a certain level of output depending on a lower level of energy by augmenting energy efficiency. Furthermore, it provides opportunities for the economy to transfer into the demand of renewable energy sources (Brock & Taylor, 2005; Chen, Cheng, & Dai, 2017; Pan, Ai, Li, Pan, & Yan, 2017; Yuan & Zhang, 2020) emphasized that technological innovation is beneficial for protecting the environment and contributes to the protection of natural resources.

China has considerable experience in technological innovation that leads to achieving a developed country in the near future. Therefore, the patent index is a fundamental index to measure technological innovation as a proxy because the patent it indicated the outcome of research and development which found concern from most organizations and industry to explore new technology (Acs, Anselin, & Varga, 2002; Pan, Uddin, Han, & Pan, 2019; Sohag et al., 2015). Accordingly, patent applications in China will use to measure technological innovation in this study. It is natural to expect that a larger economic growth country to have better technologies. Therefore, we

argue that technological innovation levels in China should be allowed to depend positively on clean energy consumption. Second, economic growth; understand the role of economic growth on clean energy consumption it is more important for policymakers to design rational clean energy policies according to the economic level of a certain country. Many scholars argued that the country's economic growth has resulted in an expansion in economic activities, which is strongly related to energy use, for example (Amri, 2017; Lean & Smyth, 2010; Ocal & Aslan, 2013) pointed out that economic growth has a positive impact significant on clean energy consumption. Some scholars argued exists a unidirectional causality running from economic growth to clean energy use (Rahman & Velayutham, 2020; Shahbaz & Feridun, 2012) others declare a bidirectional causality exists between both variables (Lin & Moubarak, 2014; Sebri & Ben-Salha, 2014) and some outcomes contradict, i.e. there is no exists causality between the two variables under consideration (Menegaki, 2011). Thus, unlike previous literature that has mostly analysed the impact of energy use on economic growth, this study examines whether economic growth can affect clean energy use as well as stimulate policies that aim to reserve energy use. Accordingly, the study uses GDP growth as a proxy for economic growth. Earlier studies have been proved that economic growth positively correlated with clean energy, therefore, we also expect the same.

In the recent literature regard with co-integration analysis between the variables I(1), is no longer applicable to the traditional ARDL approach (Pesaran & Shin, 1998). Consequently, Engle and Granger (1987); Johansen (1991); Phillips and Hansen (1990) and others, are the pioneer scholars who have been developed co-integration for analysis of I(1) variables. Pesaran and Shin (1998) re-examine the form into traditional identity labelled ARDL model, to test whether there is a relationship between variables considering first-order integrated I(1) and level order variables or not. In order to address this limitation, Pesaran et al. (2001) developed the form into the ARDL bounds test technique, which is applicable nevertheless of whether the regression models are purely I(0), purely I(1) or jointly co-integrated, and it permits to find short-run and long-run elasticity through estimate the ECM. Moreover, this identity will avoid the problem of endogeneity in the model. In addition, this model is appropriate for a small sample size (Narayan, 2005). Thus, The ARDL bounding testing approach for the standard log function among the variable of interest is specified as follows:

$$\Delta LnCEC_t = \beta_0 + \sum_{i=1}^{k} \beta_1 LnCEC_{t-i} + \sum_{i=1}^{k} \beta_2 LnEX_{t-i} + \sum_{i=1}^{k} \beta_3 LnTI_{t-i} + \sum_{i=1}^{k} \beta_4 LnGDPG_{t-i} + \lambda_1 LnCEC_{t-1} \quad (3)$$
$$+ \lambda_2 LnEX_{t-1} + \lambda_3 LnTI_{t-1} + \lambda_4 LnGDPG_{t-1} + \varepsilon_t$$

Where Δ represents the first difference operator, while k is optimal lag lengths. In order to estimate co-integration among the factors, might be applied the ARDL bounds test based on the Joint F-statistics or Wald test, of the coefficients for the lagged levels in Equation 3, under the null hypothesis which assume that no co-integration among the series (H_0: $\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = 0$) against the alternative hypothesis of exist co-integration (H_1: $\lambda_1 \neq \lambda_2 \neq \lambda_3 \neq \lambda_4 \neq 0$).

In fact that, Pesaran (1997) and Narayan and Smyth (2009) were computed two bounds of critical values (CV) of F-statistics for large sample scope (500–1000 observations) and small sample size (as low as 30) respectively. Accordingly, if the value of F-statistics exceeds the upper critical bounds value, which means the study will confirm the co-integration among the series and vice versa, while if the estimated value of F-statistics falls between the two bounds (lower and upper) of critical values the test is inconclusive.

3.2. Long-Run and Short-Run Dynamics

After the confirming co-integration among the series, we continue to estimate (ECM) model, in this regard, Haider, Adil, and Ganaie (2019) argued that ignore the short-run model from the long-run estimation may lead to an instability problem, therefore, to avoid this problem we include short-run estimate in the ARDL model labelled the error-correction model based on Equation 3 by way of substituting the part of long-run relationships (in the last part) with a one-year lagged error correction term (ECM_{t-1}). Thus, Equation 3 provide short-term dynamic

coefficients as follows:

$$\Delta LnCEC_t = \beta_0 + \sum_{i=1}^{k} \beta_1 LnCEC_{t-i} + \sum_{i=1}^{k} \beta_2 LnEX_{t-i} + \sum_{i=1}^{k} \beta_3 LnTI_{t-i} + \sum_{i=1}^{k} \beta_4 LnGDPG_{t-i} + \theta ECM_{t-1} + V_t \quad (4)$$

Where ECM_{t-1} denotes the error correction term, while "θ" indicates the speed of adjustment to equilibrium. The ECM included in Equation 4 to capture the short-run deviations of clean energy consumption, exports per capita, technological innovation and economic growth from their long-run equilibrium path, to be interpreted well with the criteria of long-run equilibrium, the estimation coefficient of the ECM must be negative and statistically significant. Nevertheless, this model also allows us to calculate the short-run causality effects, by employing the Wald test statistic of the lag difference coefficient of all explanatory variables.

To check the stability of the ARDL model and to ensure outcomes for policymaking, this study applies robustness tests such as the cumulative sum of recursive residuals (CUSUM), the cumulative sum of the squares (CUSUMSQ), and Ramsey RESET test, etc.

3.3. Data Acquisition

Our key source of data in the annual time series comes from the China Statistics (2019) Specifically, the data of clean energy consumption, total exports, and technological innovation, while the data of economic growth comes from world development indicators, which gives us, for the period between 1985 and 2018, the unique feature of this data is the range of technological innovation during this time period.

4. RESULTS AND DISCUSSION

4.1. Unit Root Analysis

To obtain a consistent outcome across the variables, our empirical results begins with examining the stationarity properties of the variables, because the testing unit root is the preliminary condition for the ARDL bounds testing technique to co-integration analysis. To prevent spurious regression and unbiased estimates issues, we applied two unit root tests: tests of Augmented Dickey and Fuller (ADF) and Phillips Perron (PP) (Dickey & Fuller, 1979; Phillips & Perron, 1988). The results reported in Table 1 propose that in all variables except economic growth in ADF test and exports per capita and economic growth in PP test were found to be a unit root problem at level having intercept and trend, however, after the first difference, we found that all the variables are integrated at (I), i.e., no variable is stationary at level 2nd difference. The optimal lag order was selected automatically based on the Schwarz information criteria and the Bartlett Kernel using newly and West Band width in the ADF test and PP test respectively. Thus, an implication is that the variables under consideration are eligible to establish ARDL bounds testing approach to test whether the co-integration relationship exists among the series or not.

Table-1. Unit root tests analysis.

Variable	Augmented Dickey-Fuller tests		Phillips Pearson tests	
	Level	First difference	Level	First difference
LnCEC	0.881	−4.439*	1.091	−6.156*
LnEX	−2.589	−3.526**	−3.008**	−4.696 *
LnTI	0.819	−3.293**	1.551	−4.840*
LnGDPG	−3.769*	−6.401*	−3.189**	−4.976*

Note: * and ** indicates the significant levels at 1% and 5% respectively.

4.2. ARDL Bound Testing Results

To examine the ARDL bounds testing approach for the model and to test whether exist the co-integration relationship among the variables or not, we further investigate the model specification to determine the optimal lag length. The study based on Akaike Information Criteria (AIC) lags to select the suitable lag length, the optimal lags' portrayal for our regression model in a way (1, 0, 1, 0).

Table-2. Results of ARDL bound test.

Estimated Model	Bound testing to co-integration		
	Optimal lag length	F-Statistics	Remarks
CEC= f(EX , TI, GDPG)	1, 0, 1, 0	6.059*	Conclusive
The critical value for bounds test: unrestricted intercept and trend	Lower bounds I(0)	Upper bounds I(1)	
1% level	4.29	5.61	
5% level	3.23	4.35	
10% level	2.72	3.77	

Note: * indicates a significant level at 1%.

Table 2 revealed that there is strong evidence of co-integration, the value of bound F-statistic (6.059) for the model lies above the upper bounds' critical values of the 1% significance level, hence we reject the null hypothesis of no co-integration among the series. Thus, the results confirm the existence of long-run relationship among variables. In order to check the robustness of the Bounds test of co-integration, by constructing a multivariate co-integration approach (Shahbaz, Loganathan, Zeshan, & Zaman, 2015; Wang & Wang, 2018).

Table 3 suggests that there are three co-integrating vectors by trace statistics and the maximum eigenvalue test. Thus, the presence of a co-integrating vector also confirms the existence of a long-run co-integration between the variables, suggesting that the bound test co-integration analysis is robust, effective and reliable.

Table-3. Results of Johansen tests for co-integration

Hypothesis	Trace statistic	Maximum Eigenvalue statistic
r = 0	86.0985*	43.8473*
r = 1	42.2511*	23.9676**
r = 2	18.2835**	17.5934**
r = 3	0.6901	0.6901

Note: * and ** indicates significant at 1% and 5% respectively.

4.3. Long-Run and Short-Run Elasticity

The main task is to assess whether exports have positive effects on clean energy consumption in this setting. Panel A of Table 4 presents the results of the long-run analysis, the results suggest that keeping other things constant, a 1 percent increase in exports per capita is accompanied by a 0.13 percent-improvement in clean energy consumption, an effect statistically significant at the 1 percent level. This finding indicates that promoting export volume can enhance clean energy consumption, and China benefited from international trade through technology used to promote clean energy use. This evidence is similar to Chen et al. (2019); Lee (2013); Sohag et al. (2015) who all report that the increase in exports spurs clean energy consumption.

The common belief about China's exports is that it leads to an increase in the level of income and technical used therefore an increase in clean energy consumption. In fact, after China joined in the world trade organization (WTO) in 2001, the size of exports and the rapid growth in industrialization has been identified as one of the significant factors that can explain the environmental status. Therefore, exports lead to energy use efficiency. Therefore, an increase in economic growth due to an increase in export volume may contribute to efficient technological use, thus, affect not only on economic growth itself but the clean energy consumption as well.

However, this finding differs from the result provided by Brini et al. (2017) for Tunisia, who argued that in the long- term, international trade variables did not lead to an increase in clean energy consumption. Similarly, Kahrl and Roland-Holst (2008) reveal that net export in China increases domestic energy consumption more than in the EU and U.S. As can be seen from Table 4, under an increasing proportion of technological innovation, China's clean energy consumption improved significantly by 0.33%, and it is coefficient is larger than the effect of export per capita. This result indicates that technological progress promotes the efficiency of clean energy consumption. This finding identifies that China focuses more on technological innovation to overcome environmental issues and ensure

clean energy use. This empirical result is consistent with the evidence of Aznar-Sánchez, Velasco-Muñoz, Belmonte-Ureña, and Manzano-Agugliaro (2019); Pan et al. (2019); Yuan and Zhang (2020) who revealed that technological innovation contributes to clean energy consumption.

With the rise of energy use, the effect of technological innovation on clean energy consumption will become more significant, and so the advantages of technological innovation will be more and more obvious than export advantages. In addition, energy waste caused by the use of technological innovation will subsequently gradually decrease. It is widely recognized that technological innovation in any country is paramount if clean energy use is to be promoted and implemented because it has less cost and less environmental emission.

Since China is a high-income country and enjoys a high level of technological innovation and encourages innovations and it is involved in international trade. Therefore, it can be easier to improve clean energy use to ensure a more sustainable environment.

Conversely, the coefficient of economic growth is positive and statistically insignificant, this result implies that in the long run, no effect has taken place in clean energy consumption due to changes in economic growth.

Table-4. Long run, short-run and stability analysis for clean energy consumption.

Variable	Coefficient	Std. error	t-Statistic	Prob.
Panel A. Long-run results				
LnEX	0.1329*	0.0339	3.92	0.001
LnTI	0.3335*	0.0255	13.08	0.000
LnGDPG	0.08816	0.0550	1.60	0.2010
Constant	-3.3663*	0.8215	-4.10	0.000
Panel B. Short-run results				
ΔLnTI	-0.1653***	0.0878	-1.88	0.071
ECM_{t-1}	-0.6355*	0.1408	-4.51	0.000
Diagnostic tests	χ^2 / F-statistics	Prob.		
ARCH LM	1.298	0.2547		
Breusch-Pagan / Cook-Weisberg	0.21	0.6505		
White	25.28	0.1908		
Breusch-Godfrey LM	0.021	0.8841		
Ramsey RESET	0.24	0.8675		
CUSUM	Stable	Stable		
Durbin-Watson		1.9293		

Note: * and *** indicates the significant levels at 1% and 10% respectively.

Although in short-run exports per capita do not appear any role to clean energy consumption, long-run effects should not be ignored. Currently, the challenges from global climate change are getting more serious, therefore, stimulate exports represents a strategic policy toward the future development of clean energy and environmental situations. Thus, without the consideration of the role of economic growth, an increasing proportion of export per capita and the development of technological innovation can significantly improve China's clean energy consumption which means to reduce emissions.

Panel B of Table 4 shows the short-run analysis. The value of ECM_{t-1} coefficient reflects the speed of adjustment back to the long-run equilibrium after a short-run shock, i.e., how quickly or slowly variables return to the long-run equilibrium from the short-run changes in clean energy consumption. The sign of the ECM_{t-1} estimate is (-0.6355) negative and statistically significant at the 1% level, indicating that exists a long-run relationship among the estimated variables. The deviation in clean energy consumption within previous years is corrected by 63.55% speed towards the equilibrium level of exports per capita, technological innovation and economic growth.

Table 4 shows that in the short-run, a unit increase in technological innovation leads to a decrease in clean energy consumption by 16.53%, but as we mentioned above in the long-run was increased by 33.35%. Therefore, China must continue to speed up the development of energy use and improve the proportion of clean energy consumption depending on technological innovation.

The technological variable shows the divergent result in the short run, one probable reason for this result is that technology plays an essential role in the China industrialization process and it needs a long term to appear it is effected. Furthermore, in the short-run most industries emit some emissions that coming out from the industries, due to this reason in the short time most industries do not improve the environment in a short time duration respect to technological progress. i.e., when the level of technical progress is below than the threshold in the short run, the increase in energy use will increase some emissions, until the level of technical progress exceeds the turning point in the long run, then it will starts to play a crucial role in increasing clean energy use and reduce the emissions. Thus, when the level of technology innovation achieves a certain critical level, in the long run, it may not lead to decreased clean energy consumption. This evidence is similar to Alam and Murad (2020) who argued that technological reduce clean energy use in the case of France, Iceland, and the United States in the short-term. Furthermore, Gu, Zhao, Yan, Wang, and Li (2019) argue that when energy technological progress develops past in the long run, it could reduce emissions.

The outcome in Table 4 does not appear any role of exports and economic growth on the clean energy margin in the short-run. As evidenced by (zero) optimal lag length for both variables, we described earlier in Table 2. However, the coefficient of exports per capita, in the long run, is positive, and significant at 1 percent level, and consistent with our prior expectation. It also implies that our estimates are not affected by variables-selection bias. This result is in line with Sohag et al. (2015); Alam and Murad (2020) who showed that in the short-run, no effect has taken place in clean energy use due to changes in international trade.
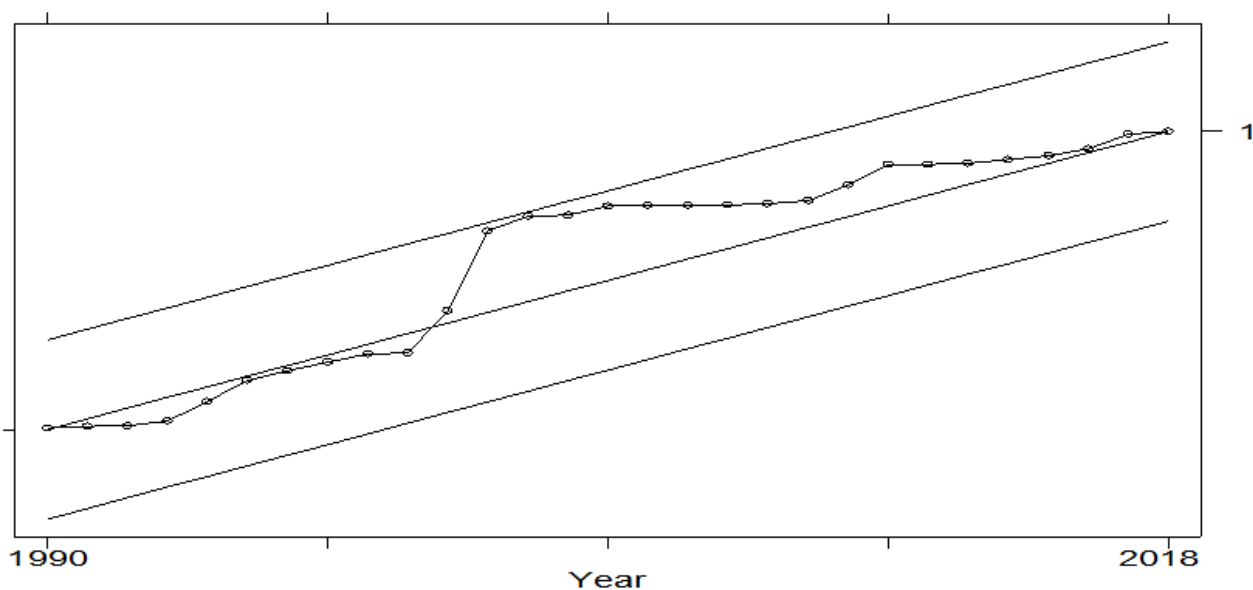

Figure-3. The plot of CUSUM Q. The straight lines indicate significant at 5%.

The study performs diagnostic tests to check whether the main findings are robust. The results revealed that the model passed all the diagnostic and stability tests. The study materialized, ARCH LM to detect autoregressive conditional heteroscedasticity, Breusch-Pagan/Cook-Weisberg test and white test for heteroskedasticity effects, Breusch Godfrey (B-G) LM test for serial correlation, and the test of Durbin-Watson (D-W) statistics for autocorrelation and Ramsey RESET test for a general specification test and the misspecification. In addition, the study used the tests of CUSUM and CUSUM of Squares to check the stability of the co-integration space in the residuals of the ARDL model, both tests confirmed the model's stability, Figure 3. Shows that the model is stable.

4.4. VECM Granger Causality Test

The existence of co-integration between the variables will confirm to exist at least one causal relationship without to give its direction. Hence, according to the results of Johansen tests for co-integration in Table 3, and following (Engle & Granger, 1987) for (VECM) model, the results of Granger causality among the series reported in Table 5.

In the short term, the study confirms only one evidence of causality running a unidirectional way from technological innovation to clean energy consumption, suggesting technological innovation can be a crucial role in clean energy. These results support the earlier results in Table 4 which explained that exports and economic growth have no influence effect to clean energy consumption in the short run. Furthermore, in the short-run, our findings detected a neutral effect between the main factor (exports per capita), and clean energy consumption.

Table-5. Results of VECM Granger causality tests.

Dependent variable	Short-run				Long-run
	ΔLnCEC	ΔLnEX	ΔLnTI	ΔLnGDPG	ECM_{t-1}
ΔLnCEC	…..	0.019 (0.819)	0.231** (0.029)	0.046 (0.407)	-0.6598* (0.000)
ΔLnEX	0.431 (0.318)	…..	0.074 (0.768)	0.126 (0.349)	-1.0340** (0.015)
ΔLnTI	0.219 (0.473)	0.054 (0.706)	….	0.164 (0.084)	-1.0504* (0.002)
ΔLnGDPG	0.493 (0.444)	0.426 (0.156)	0.257 (0.496)	…..	-3.8455* (0.000)

Note: * and ** indicates the significant levels at 1 and 5% respectively. The square brackets represent prob. Values.

In addition, economic growth does not cause clean energy consumption nor does clean energy consumption cause economic growth, which is consistent with the view of Lee. and Chiu (2011) who explained exist the neutrality hypothesis between economic growth and nuclear energy consumption in case of France and the U.S.

Empirical evidence of the long-run causality shows that all the ECTs' coefficients are negative and statistically significant indicating bi-directional causal flows among the variables. These results verify the co-integration test analysis, which was found later.

5. CONCLUSION AND POLICY IMPLEMENTATION

The present study is conducted to explore the effect of export volume and main variables on clean energy consumption in China. The results of the bounds test show that in the long-run exports per capita improve clean energy consumption i.e., changes in the volume of export need in China lead to changes in clean energy consumption in longer periods and at increasing rates. The results have several implications; the volume of clean energy consumption increased fivefold in 2018 compared it is the volume in 2000. China has experiences to use more clean energy sources over the years, mainly as China produce and export goods and services. The annual growth rate of China's export in the same period increase by 15.30% (NBS (National Bureau of Statistics), 2018). Therefore, this study proves that growth in export volume is a catalyst and a major driver of the increase in clean energy consumption in China. Thus, the response of clean energy to exports in the long-run leads to a more optimistic scenario, than what emerges of short-run effects. However, clean energy consumption also calls for important and decisive action as same as to several government priorities to sustainable economic indicators. The results also showed that in long-run technological innovation enhances clean energy use, as the largest emerging economic country, China has effective systems for the development of new technologies, including high energy technologies. Therefore, policymakers can take action to improve energy efficiency through national green technology policies.

The existing study also adapts VECM Granger causality tests. In the short-run, a unidirectional causal exists

from technological innovation to clean energy consumption. In the long-run a bi-directional causal flow exists between exports and clean energy consumption, indicating that an increase in exports per capita is a core factor driving and improve the energy sector, and the same is true among the variables, validating the feedback hypothesis. As we mentioned earlier, the Chinese government implemented many policies regarding with improvement of energy use, energy intensity, and reduce emissions. Therefore, an increase in clean energy use, which is the main goal of the sustainable economic development of the countries, and it is an alternative energy source that addresses the emission issues without compromising economic growth. Boosts policymakers to increase green energy use by taking some measures of relying more on clean energy from renewable sources and reduce fossil energy consumption, and must take proper initiatives to increase the clean trade, and develop and ease the market accessibility of renewable energy and patent incentive technology, to promote clean energy to ensure sustainable economic development. Our paper is the first step toward clean energy sustainability via international trade that can be considered as empirical analysis in our major.

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