



Testing the effect of sustainable energy and military expenses on environmental degradation: evidence from the states with the highest military expenses

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Abstract

This paper aims to define the effects of military expenses and renewable energy consumption on carbon dioxide emissions for the ten countries with the highest military expenses, namely, Saudi Arabia, Israel, Russia, the USA, South Korea, India, France, Australia, China, and the UK from 1993 to 2017. The research applied the common correlated effects mean group estimator (CCEMG), dynamic CCEMG, and cross-sectional augmented autoregressive distributed lag (CS-ARDL) approaches. These dynamic techniques elucidate slope heterogeneity and cross-sectional dependency and solve the problem of unit root bias. It is found that the environmental Kuznets curve (EKC) hypothesis does not apply for this region. The findings demonstrate that military expenses increase carbon dioxide emissions; thus, the treadmill theory of destruction is valid for the panel of these countries, and it is also found that the consumption of sustainable energy decreases CO₂ emissions. This suggests that a reduction in pollution can be achieved by increasing sustainable energies in the use of military vehicles to decrease emissions. Further important policy implications for the 10 countries with the highest military expenses are provided at the end of the paper.

Keywords Treadmill theory of destruction · Dynamic CCEMG · CS-ARDL · Renewable energy

Introduction

Environmental degradation is an important issue that has captivated the attention of governments' around the world because it affects the warming of the planet and also can affect the global carbon cycle. Warming of the planet and climate change can cause substantial health problems and physical and ecological impacts in the form of severe weather events such as floods, storms, and sea-level upsurge, disruptions of the water systems, and disruptions of growth of plants. Thus, the protection of the environment is now a global topic, and it is included in the political agendas of many regions.

Different research papers have been completed to define pollution determinants (Bekun et al. 2019; Al-Mulali et al. 2015). In the econometrics field, the subject was expanded by studies that used supplementary variables and concentrated

on different countries (Zhang et al. 2019, Hao et al. 2019). Nevertheless, an important variable that is the impact of military expenses on environmental degradation has not been given the required emphasis. Military expenses are a critical cause of degradation of the environment since the military is the highest oil-consuming sector in the world (Hynes 2011). Particularly, war and military strategies increase the degradation of ecosystems and land. War and nuclear bomb testing are examples of environmental degradation created by military processes. Previous experiments conducted using nuclear and atomic bombs created radioactive fallout that was widely spread by water, wind, and living creatures (Commoner 1967, 1971).

On the other hand, militarization is linked to the degradation of the environment during periods of both war and peace. The military impact on the environment has been enlarged by high-tech military technologies, demand for resources to support the military, weapons testing, as well as the transportation of machinery, weapons, and military personnel to different parts of the world.

World military expenses are now 76% higher in comparison with the post-Cold War period. Global military expenses accounted for 2.1% of global GDP in 2018 or \$239 per

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person. Developments in the military have increased exposure to environmental degradation. The treadmill of destruction (TD) is the outcome of militarization, which has an inverse influence on the environment. Militaries that are more capital intensive use a greater number of resources such as oil and more land for their operations. Therefore, military growth has increased the treadmill of destruction theory and expanded environmental degradation generated by the military institutions.

The environmental effects of the military are not only restricted to periods of war. Military interests, geopolitical interests, and continuous war preparations increase the scale of military operations. Thus, even if there is no military conflict, the military activities deplete huge amounts of non-renewable resources to develop, research, and maintain the infrastructure. This is to suggest that militaries use more funds and resources than the other sectors (Shaw 1988; Kentor et al. 2012). Bigger and faster planes and ships as well as other types of vehicles allow more equipment and soldiers to be transferred around the world (Collins 1981).

Deriving from these points, the main objective of this paper is to focus on the ten states with the highest military expenses (Saudi Arabia, Israel, Russia, the USA, South Korea, India, France, Australia, China, the UK) and the impact of militaries on environmental sustainability. There are five main reasons for this. First of all, to our knowledge, there is no study on GDP, sustainable energy, and military expenses on environmental degradation in the ten countries with the highest military expenses. Secondly, based on the military-environment nexus, it is crucial to validate the existence of the EKC and the treadmill theory of destruction for these states and derive the necessary policies for them. The significance of these theories for these states is that they made up 72.58% of military expenses of the world in 2018 (World Bank 2019). Therefore, the expected impact of military expenses on the environment is of high importance and significance. Thirdly, the USA, China, India, Russia, and South Korea in particular are in the category of the ten highest energy consumers and environmental pollution producers in the world (Statista 2020). Fourthly, the use of energy for military bases and military transport is continually rising in the countries with the highest military expenses. Finally, this research used the CCEMG (Pesaran 2006; Kapetanios et al. 2011) and dynamic CCEMG (Chudik and Pesaran 2015) approaches, which take into account heterogeneity, cross-sectional dependency (CSD), and the latter is robust to structural breaks. Furthermore, the CS-ARDL (Chudik et al. 2016) approach is used to reveal robust results. This newly developed technique deals with cross-dependency and unit root bias.

Following the “Introduction” section, the “Literature review” section presents a detailed literature review on military expenses, carbon dioxide emissions, and other determinants. The “Data and analysis” section covers the data, model, and

the methodology that is used throughout the research. The results are discussed in the “Empirical results” section, and the “Conclusion” section presents the conclusion.

Theoretical concept

The association between expansion and inequality was introduced for more than 60 years. Simon Kuznets analyzed the association and originated the economic hypothesis of the Kuznets. Kuznets (1955) stated that, at the initial stage of the expansion of the economy, inequality in income rises until it reaches a peak point, and then inequality in income declines with the expansion of the economy. The theory of the EKC hypothesis derived from the Grossman and Krueger (1991), by employing the theory of Kuznets (1955) as a basis. The EKC states that “the view that greater economic activity inevitably hurts the environment is based on static assumptions about technology, tastes, and environmental investments” and “as incomes rise, the demand for improvements in environmental quality will increase, as will the resources available for investment.” Later on, Beckerman (1992) indicated that “there is clear evidence that, although economic growth usually leads to environmental degradation in the early stages of the process, in the end, the best and probably the only way to attain a decent environment in most countries is to become rich.” By using the theory of the EKC, Grossman and Krueger (1991) and Grossman and Krueger (1994) endorsed the association between income (per capita) and the degradation of the environment as being in the inverted U-form.

The association between the military and environment is complicated, and the negligence of it might be problematic. It was stated by sociologist Kenneth Gould (2007) that “militarization” is “the single most ecologically destructive “human endeavor.” Singer and Keating added that “from depleting resources, eroding the physical environment, destroying natural flora and fauna, or leaving behind a vast array of toxins and radioactive elements, all aspects of military activity defile our environment in some way” (Singer and Keating 1999). Also, “in the name of national security,” the production of military weapons and military operations can be exempted from environmental regulations (Gould 2007; Koplow 1997). Therefore, all these make the world’s armed forces as a single largest polluter in the world (Renner 1991).

The perspective of treadmill destruction directly refers to the military and environment association and reveals the dynamics of the military to create substantial impacts on the environment. This theory is linked to the treadmill of production approach, which refers to “the inherent nature of competition and concentration of capital” that raises the ecosystem’s demand and environmental degradation (Jorgenson and Clark 2009). The TD theory is linked to the treadmill of production approach, but it concentrates on the states’ militaries. Clark and Jorgenson (2012) stated that “militarism produces a

treadmill of destruction that effectively limits environmental protection.”

The basis of the theory of treadmill production is market competition, which creates continuous expansion and increases consumption and production. The basis for the treadmill of destruction approach is the competition of the international systems, whose aim is to obtain the advantage over the other system or state. Hooks and Smith (2005) state that the TD theory refers to the actions where militaries make the destruction of the ecology and increase consumption of fossil fuels and high amount of toxic wastes. The TD theory suggests that, as states have more “capital-intensive militaries,” their influence on the environments rises. The TD theory also states that military expenses increase the impact on the environment and carbon emissions.

Literature review

This part concerns the empirical literature on the EKC and the treadmill theory of destruction theories and interconnections between sustainable energy and emissions. The empirical literature revises different studies which have different case studies, data types, series, and methodologies that have reinforced and opposed the EKC and TD theories. Even though the sustainable energy-growth-environment nexus has been intensively researched in recent decades, the association between sustainable energy, pollution of the environment, military expenses, and growth of the economy is relatively new and studied by a limited number of researches.

The first part of the literature on the EKC shows that an inverted U-shaped association exists between the growth of the economy and the pollution of the environment. Pollution rises as the national income increases and subsequently decreases as income reaches a certain threshold. Many research articles have confirmed the EKC hypothesis. For instance, Hanif (2017) used a GMM estimator to investigate the Latin American region from 1990 to 2015, and it was found that an inverted U-shaped association between carbon dioxide emission and GDP exists. Another study by Sapkota and Bastola (2017) investigated the EKC in the research of 14 Latin American states, from 1980 up to 2010. The inverted U-shaped association between the expansion of the economy and carbon emission was reinforced in the study for twenty-seven advanced economies. The study provided the policies to reduce the pollutants of the environment and the promotion of the sustainable expansion of the economy (Al-Mulali and Ozturk 2016). Zaman and Moemen (2017) studied the association between CO₂, the consumption of energy, and the expansion of the economy for states with high, middle, and low incomes and reinforced the EKC’s existence during 1975 to 2015. The study by Zhang et al. (2019) used the ARDL technique for China, and the outcomes also validated the EKC

existence. Similar outcomes were found by Samour et al. (2019) for Turkey by using the ARDL technique. The study by Chen et al. (2019) stated that the EKC was not valid for China from 1980 to 2014 in the model with the expansion of the economy and conventional energy while adding sustainable energy to the model supported the EKC in the long run. Another study by Isiksal et al. (2019) validated the EKC for Turkey from 1980 to 2014 by adding interest rates and the consumption of energy series. The EKC in 30 out of 50 states was supported in the USA by applying the augmented mean group estimator, while the CCEMG technique supported the EKC in ten states in the USA (Atasoy 2017).

However, not all the studies supported the EKC hypothesis. For instance, solid waste of municipalities in the Chinese towns did not support the EKC from 2006 to 2015 (Gui et al. 2019). The research by using the GMM in the Chinese forests also showed that the EKC is not supported (Hao et al. 2019). Empirical outcomes indicated that the EKC is not valid in the Southeast and Northeast Asian states, and non-sustainable energy produces a high amount of carbon emission (Zhang and Liu 2019). Another study by Dogan and Ozturk (2017) examined the influence of sustainable and conventional energy on the emission of the USA during the 1980–2014 period by applying the ARDL model and found that the EKC was not validated for this state.

The second strand of the literature concentrated on sustainable energy and carbon dioxide emissions by applying different techniques, different variables, and methodologies. By studying the interconnections between sustainable energy and CO₂, the empirical studies found an adverse influence of renewable energy on emission. The study by Shafiei and Salim (2014) investigated sustainable energy and environmental pollution in OECD countries by employing the STIRPAT approach for the period from 1980 to 2011. The experimental findings showed that the consumption of sustainable energy has an inverse association with the pollution of the environment. Similarly, Chiu and Chang (2009) studied empirical panel data for all 30 member countries of the OECD that covered a period of approximately a decade from 1996 to 2005 within a multivariate structure. The experimental findings provided clear evidence that sustainable energy has a negative relationship with environmental pollution. Al-Mulali et al.’s (2015) findings showed that there was an inverse association between pollution of the environment and sustainable electricity produced from sustainable energy sources, waste, hydropower, and nuclear energy in European countries during the period 1990–2013. Boluk and Mert (2014) concluded that CO₂ emissions decreased by half per unit of sustainable energy consumed in the European Union (EU) during the period 1990–2008. Dogan and Seker (2016) also examined the association among sustainable energy and emissions using the EKC model for the EU for the period of 1980–2012 by using an ordinary dynamic squared estimator

(OLS). It is found that higher use of sustainable energy reduces CO₂ emissions. López-Menéndez et al. (2014) confirmed that the EKC theory expanded in the EU during 1996–2010, and environmental pollution decreased due to the increased use of renewable energy. Another study by Raza and Shah (2018) researched the G7 region by using the FMOLS technique from 1991 to 2016 period and found that sustainable energy reduces emissions. The recent study by Vo et al. (2020) tested the influence of nuclear and sustainable energy to lower emissions in the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP) states from 1971 to 2014. By utilizing FMOLS and Granger causality tests, it was found that adopting nuclear and sustainable energy would lead to mitigation of CO₂. In addition, the openness of trade had a crucial role in implementing healthier energy consumption. Zedirai et al. (2020) studied the effect of sustainable energy, stock market expansion, and innovation in technology on the intensity of carbon by applying cross-sectional autoregressive distributed lag (CS-ARDL) for the twenty-three European Union states during 1980 to 2016. It was discovered that the stock market raises the intensity of carbon. However, through the sustainable energy channel, the intensity of carbon declines. Moreover, by recommending the expansion of the stock market through better environmental and energy policies, the intensity of carbon would decline. In addition, the study by Saidi and Omri (2020) concentrated on fifteen sustainable energy-consuming states by employing FMOLS and VECM Granger causality tests. The results stated that sustainable energy raises the expansion of the economy while decreasing carbon emissions. It was also found that there was no association between emissions and sustainable energy in the long-term, but this causality was valid in the short run. Similarly, Rahman and Vu (2020) investigated the nexus between sustainable energy consumption, expansion of the economy, urbanization, trade, and CO₂ for Australia and Canada during 1960–2015. The ARDL bounds tests and (VECM) Granger causality tests were employed. The outcomes stated that the consumption of sustainable energy mitigates emissions. The VECM test of causality for Australia showed that there was a long-run causality among emissions and consumption of sustainable energy. It was also found in Canada, a bidirectional causality among emissions and consumption of sustainable energy in the long run.

The first and second strands of the literature review analyzed the EKC and the association between sustainable energy and CO₂ emissions. The aforementioned studies, however, did not analyze the influence of military expenses on the environment. The third strand of the literature has examined the association between CO₂ emissions and militarism; the findings of the studies were mixed with the majority of them supporting the treadmill theory of destruction. Jorgenson et al. (2010) tested the influence of

military institutions on carbon dioxide emissions by employing a fixed-effect model for 72 states for the period from 1970 to 2000. They found that militarization damages the environment. Givens (2014) investigated the association between GDP, growth of GDP, emissions, and military expenses. The author employed survival analysis and the Cox proportional hazards model for 191 countries. The findings also indicated that militarization destroys the environment. Jorgenson et al. (2012) tested the association between militarism and consumption-based CO₂ emissions. The authors analyzed panel data for 81 countries from 1990 to 2010 by employing the two-way fixed-effect model. They stated that military expenses had a larger impact in OECD countries that are more developed than those that are less developed. The results showed evidence of the treadmill of destruction suggesting that militaries are important institutions that instigate changes in the environment.

Another study by Bildirici (2017a) tested the association between CO₂ emissions, growth of the economy, consumption of biofuels, and militarization for the United States (US) from 1984 to 2015 by employing the ARDL, DOLS, CCR, FMOLS, and Toda Yamamoto's MWALD and Rao *F* tests. It was found that causality was valid for militarization and carbon dioxide emission. It was recommended that policies should be implemented to lower defense expenditures to reduce CO₂ emissions or to increase the use of biofuel energy. Bildirici (2017b) also tested the association among defense expenditure, consumption of energy, emissions, and the expansion of the economy in the US for the period of 1960 to 2013 by employing the MWALD and Rao's *F* tests. It was found that defense expenditure increased the demand for energy and CO₂ emissions. It was suggested that alternative sources of energy could be utilized. Another study by Sohag et al. (2019) analyzed the association between clean energy, innovation in technology, militarization, and green economic growth in Turkey by using both symmetric and asymmetric ARDL from 1980 to 2007. It was found that military expenses were detrimental to the green growth of the country, and an increase in militarization decreased green growth.

Interesting findings were stated by Solarin et al. (2018) who studied the influence of military expenses on emissions in the US during the time from 1960 to 2015 by utilizing the STIRPAT model. It was found that the military expenses had mixed results on emissions. Military expenses increase the emissions because of the high volume of fossil fuels consumed by military divisions. The authors stated that military expenses could decrease emissions due to the impact of internet technologies, which reduced the need for transportation.

Therefore, the third strand of the literature analyzed the association between militarism and the environment; the difference of this study in comparison with the previous research is that they did not consider the renewable energy series (Jorgenson et al. 2010), concentrated on the consumption of

conventional energy series (Bildirici 2017b), while Bildirici (2017a,c) concentrated on a single country; on the other hand, this study aims to investigate to the association between renewable energy, military expenses, and pollution of the environment for the case of the ten states with the highest military expenses. To sum up, based on the discussion put forward in the literature review above, the following observations could be put forward. First of all, it is evident that there are very rare studies on the nexus between military expenses, sustainable energy, and emissions. Secondly, none of the studies have investigated the environmental Kuznets curve and the treadmill theory of destruction for the ten states with the highest military expenses. Thirdly, the econometric techniques employed by these studies are those that have been recently developed which control cross-dependency, heterogeneity, and unit root bias.

Data and analysis

The structure for the methodology used for this research is presented in Fig. 1 below:

Data and methodology

In this paper, we use carbon dioxide emissions, growth of the economy, consumption of renewable energy, and military expenditures variables for the ten countries with the highest military expenses as a percentage of GDP (Saudi Arabia, Israel, Russia, US, South Korea, India, France, Australia, China, UK) retrieved from Statista (2020). The series was observed yearly from 1993 to 2017. This data was retrieved from the World Bank Development indicators and BP statistical review of 2019.

We can express the model in the form of panel data as follows:

$$LCO_{it} = \delta_i d_t + \beta_{1i} YL_t + \beta_{2i} YLS_t + \beta_{3i} LREN_t + \beta_{4i} LME_t + u_{it} \tag{1}$$

where $u_{it} = \gamma_i f_t + \varepsilon_{it}$
 $i = 1, 2, 3, \dots, N$ and $t = 1, 2, 3, \dots, T$

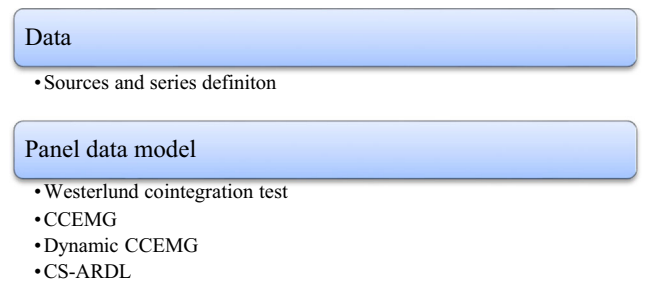


Fig. 1 Structure of the methodology

LCO_{it} denotes the i th country’s carbon dioxide emission per capita at time t , YL_t is the country’s real per capita GDP, YLS_t is the square of real per capita GDP, $LREN_t$ is renewable energy consumption (% of GDP), LME_t is military expenses (% of GDP) for the i th country; and the subscripts t and i represent time and individuals (countries).

In Eq. (1), d_t represents observed common effects, whereas f_t represents unobserved common effects. CSD is explained by the existence of the common factor effect (f_t) which is unobserved, and the effect is different across countries. Firstly, it is assumed that unexpected shocks have an impact on the cross-sectional units, and secondly, all of them are affected differently.

The test of cross-sectional dependence

When using panel data methods, testing for cross-sectional dependence (CSD) is significantly important, since ignoring this could lead to over-rejection of the null hypothesis of the unit root (O’Connell (1998)). In the cases where it is not considered, it might lead to misleading results. Since the countries used in this article have similar economic cooperation, we initially conduct the CSD test.

Regarding Pesaran (2004), the following technique is used when CS size is greater than time:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij} \right) \tag{2}$$

where $\hat{\rho}_{ij}$ shows the correlation among the errors.

The following LM statistic was developed by Pesaran (2004) to overcome the problem of large N ; it showed a good performance in small samples:

$$CDLM = \sqrt{\frac{1}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^N \left(T \hat{\rho}_{ij}^2 - 1 \right) \tag{3}$$

Baltagi et al. (2012) developed an alternative bias-corrected scaled LM test where the following equation is used:

$$CDBC = \sqrt{\frac{1}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^N \left(T \hat{\rho}_{ij}^2 - 1 \right) - \frac{N}{2(T-1)} \rightarrow N(0, 1) \tag{4}$$

$$H_0 = Cov(u_{it}, u_{ij}) = 0, \text{ no cross - sectional dependence}$$

$$H_1 = Cov(u_{it}, u_{ij}) \neq 0, \text{ cross - sectional dependence}$$

The null hypothesis is not accepted when the p value is lower than the significance value. Otherwise, we accept the null hypothesis. Additionally, it was investigated whether the

cross-sectional units are heterogeneous, which can be proved by the slope homogeneity tests introduced by Pesaran and Yamagata (2008). They derived the test statistics as:

$$\widetilde{\Delta} = N^{1/2}(2k)^{-1/2} \left(N^{-1}\widetilde{S}-k \right) \tag{5}$$

$$\widetilde{\Delta}_{adj} = \sqrt{N} \left(\frac{N^{-1}\widetilde{S}-E\left(\widetilde{Z}_{it}\right)}{\sqrt{\text{var}\left(\widetilde{Z}_{it}\right)}} \right) \tag{6}$$

The null hypothesis is that the slopes are homogeneous, which is checked against the heterogeneous slopes hypothesis.

Panel unit root and cointegration tests

If CSD exists, the suitable unit root test is the cross-sectional augmented Dickey-Fuller (CADF) panel unit root test (Pesaran 2007), as it provides results that are robust in the presence of cross-sectional effects.

Westerlund and Edgerton (2007) improved the error-correction model (ECM) panel cointegration test. It checks whether cointegration does not exist if there is an error correction for both individual countries and the whole panel.

The error-correction (EC) approach of Westerlund and Edgerton (2007) is represented as follows:

$$y_{it} = \delta_i d_t + \alpha_i y_{it-1} + \pi_i x_{it-1} + \alpha_i y \Delta_{it-1} + \sum_{j=1}^p \alpha_j X \Delta_{it-1} + \varepsilon_{it} \tag{7}$$

α in Eq. (6) represents the error-correction parameter, and $d_t = (1, t)$ contains the deterministic components.

Based on the above equation, Westerlund developed four tests, where two of them are group mean statistics test and can be presented as follows:

$$Gt_{\text{test}} = \frac{1}{N} \sum_{i=1}^N \frac{\widehat{\alpha}_i}{C.S.E\left(\widehat{\alpha}_i\right)}. \tag{8}$$

$$G_{\alpha} = \frac{1}{N} \sum_{i=1}^N \frac{T\widehat{\alpha}_i}{\left(\widehat{\alpha}_i\right)(1)}. \tag{9}$$

CSE($\widehat{\alpha}_i$) represents the conventional standard error for $\widehat{\alpha}_i$, where $(\widehat{\alpha}_i)$ represents the semi-parametric kernel estimator of $\widehat{\alpha}_i(1)$, and the alternative hypothesis of these tests is that the whole panel is cointegrated. The other two tests are as follows:

$$Pt_{\text{-test}} = \frac{\widehat{\alpha}_i}{C.S.E\left(\widehat{\alpha}_i\right)} \tag{10}$$

$$P_{\alpha} = \frac{T\widehat{\alpha}_i}{\left(\widehat{\alpha}_i\right)(1)} \tag{11}$$

The alternative hypothesis of the two tests is that there is at least one individual unit that is cointegrated.

CCEMG and dynamic CCEMG estimators

In this study, the CCEMG proposed by Pesaran (2006) and updated by Kapetanios et al. (2011) as well as the dynamic CCEMG proposed by Chudik and Pesaran (2015) are used to estimate the model indicated in Eq. (1). The dynamic CCEMG estimator adds the lagged values of the dependent variable and the lags of cross-sectional means as explanatory variables in the model. The CCEMG is powerful in the event of structural breaks in addition to CSD and slope heterogeneity.

To use the CCEMG approach, the CS means of the dependent and independent series are augmented in Eq. (1):

$$\begin{aligned} LCO_{it} = & v_i + \theta_{1i}YL_t + \theta_{2i}YLS_t + \theta_{3i}LREN_t + \theta_{4i}LME_t \\ & + \varphi_{1i}\overline{YL}_t + \varphi_{2i}\overline{YLS}_t + \varphi_{3i}\overline{LREN}_t + \varphi_{3i}\overline{LME}_t + u_{it} \end{aligned} \tag{12}$$

Afterward, every CS is measured by OLS. However, it should be noted that in cases where the residuals have heteroscedasticity and autocorrelation, White (1980) and Newey and West (1987) can be applied instead of using OLS. The CCEMG approach is the arithmetic mean of every coefficient for every regression.

$$CCEMG = N^{-1} \sum_{i=1}^N \widehat{B}_i \tag{13}$$

\widehat{B}_i 's are estimates of OLS for every country's coefficient in Eq. (13).

CS-ARDL estimator

The probability of CSD between the ten countries with the highest military expenses is high because they are interconnected by globalization, financial integration, and technology. Also, the series in this research are subject to unit root tests. Because of the CDS and non-stationary issues, this article applies the CS-ARDL estimator introduced by Chudik et al. (2016). The CS-ARDL approach uses a lagged dependent variable and accepts a weak exogenous regressor under the error-correction framework. CS-ARDL considers unit-specific specifications of ARDL to find the impact of unobserved common factors, which are used to evaluate the long-term impact. CS-ARDL is efficient at dealing with CSD in both the short and long runs. In this research,

we evaluate all three variations of CS-ARDL to deal with the CS issues in the short term and long term. The CS-ARDL equation is presented as follows:

$$\Delta LCO_{it} = \mu_i + \phi_t(LCO_{it-1} - \beta_i X_{it-1} - \phi_{1i} \overline{LCO}_{t-1} - \phi_{2i} \overline{X}_{t-1}) + \sum_{j=1}^{p-1} \delta_{ij} \Delta LCO_{it-j} + \sum_{j=0}^{q-1} \xi_{ij} \Delta X_{it-j} + \eta_{1i} \Delta \overline{LCO}_t + \eta_{2i} \Delta \overline{X}_t + \varepsilon_{it} \tag{14}$$

where ΔLCO is the dependent variable, X_{it} comprises all independent series, \overline{LCO}_{t-1} refers to the long-term dependent variable mean, ΔLCO_{it-j} refers to the short-run dependent variable, ΔX_{it-j} specifies the short-term independent variable, $\Delta \overline{LCO}_t$ is the short-term dependent variable mean, $\Delta \overline{X}_t$ is the short-run mean of the independent series, ε_{it} is the error term, j is the CR dimension, and $j = 1 \dots J$ and $t = 1 \dots T$, respectively.

Empirical results

The CSD results are indicated in Table 1. CDP, CDLM, and CDBC do not accept the cross-sectional independence null hypothesis. Therefore, there is a CSD in all the series. Thus, it shows that a shock in one country could be transferred to another country. Therefore, the second-generation panel data techniques should be used to consider CSD between the countries. The null hypothesis of homogeneity (Table 2) is not accepted by the delta and delta hat adjusted. Thus, the units' coefficients are heterogeneous.

We examined the stationary properties of the series by employing the CADF (Pesaran 2007) unit root test, as shown in Table 2. All the results infer that the series has a unit root in constant form. However, the first difference stationarity of the series is observed, and therefore, they have first-order integration.

Table 3 represents the Westerlund and Edgerton (2007) cointegration techniques outcomes. The results in Table 3 reinforce the presence of an association between the series. The

Table 1 CSD test results

Variables	Test statistics		
	CDP	CDLM	CDBC
LCO	5.035*	47.243***	47.035***
YL	29.452***	89.118***	88.909***
YLS	20.731***	73.259***	73.051***
LREN	1.805*	40.659***	40.451***
LME	2.026**	16.646***	16.438***

*, **, and *** indicate significance levels at the 10%, 5%, and 1%

Table 2 Panel unit root tests outcomes

Variable	CADF test statistics	
	Level	First difference
LCO	- 1.777	- 2.874***
YL	- 1.286	- 2.447**
YLS	- 1.609	- 2.361**
LREN	- 1.882	- 3.236 ***
LME	- 1.407	- 3.484***
Test results of slope homogeneity		
	LM statistics	p value
$\hat{\Delta}$	13.426	0.000
$\hat{\Delta}_{adj}$	15.308	0.000

*, **, and *** indicate significance levels at the 10%, 5%, and 1%

G_t and P_t and Pa statistics' values infer that the null hypothesis is rejected. This refers to the long-term association among emissions, growth of the economy, the square of the growth of the economy, REN, and military expenses.

The long-run coefficient outcomes based on CCEMG and dynamic CCEMG are given in Table 4. The positive sign of GDP and the positive/negative sign of GDP square (but not significant signs in both models) suggest that there is no inverted U-shaped EKC in the ten countries with the highest military expenses. This outcome might depend on the reason that the states with the ten states with the highest military expenses are economically active ones. Therefore, they might need more energy to augment the expansion of the economy, which is accompanied by the rise in CO2. The findings are in line with Dogan and Ozturk (2017), Liu et al. (2017), Dogan and Seker (2016), and Zhang and Liu (2019). Sustainable energy negatively affects emissions. It shows that a 1% rise in sustainable energy decreases the CO2 emission by 0.07–0.11%. These findings support the results of Dogan and Ozturk (2017) for the US, Solarin et al. (2018), Dogan and Seker (2016). This outcome is also in consonance with Bildirici (2017a) who found that sustainable energy in the form of biofuel decreases emissions in the USA. The movement to lower emission level could be achieved by utilizing more energy from sustainable energy and reducing the amount of energy used from fossil fuels. Also, to deal with the

Table 3 Westerlund and Edgerton (2007) cointegration technique results

Test	Value	z value	p value
$G_{t_{test}}$	- 3.623***	- 4.428	0.000
G_a	- 3.650	3.325	0.265
P_t	- 6.049*	- 0.081	0.092
Pa	- 4.457**	1.422	0.043

*, **, and *** indicate significance levels at the 10%, 5%, and 1%

Table 4 Dynamic CCEMG and CCEMG results

	Value	<i>p</i> value
Dynamic CCEMG results		
LCO (– 1)	0.365*	0.080
YL	24.155*	0.060
YLS	– 1.101	0.180
LREN	– 0.070*	0.070
LME	0.357**	0.020
Constant	– 7.484	0.110
CCEMG results		
YL	0.158	0.560
YLS	0.132	0.110
LREN	– 0.111**	0.040
LME	0.178*	0.060
Constant	– 0.952	0.570

*, **, and *** indicate significance levels at the 10%, 5%, and 1%

pollution, some regulatory actions should be applied that factories, building, and institutions should be encouraged to meet the needs for energy from non-conventional energy sources and to raise the proportion of sustainable energy utilization in the future.

Moreover, military spending positively affects emissions. It shows that a 1% increase in military expenses will cause emissions to rise by 0.18–0.36%. Military expenses raise emissions because of the high amount of fossil fuels consumed by this industry in the region. The military industry is the highest oil-consuming division in the world, and it increases with faster and bigger fuel consuming tanks and planes (Hynes 2011). Military interests, geopolitical

interests, and continuous war preparations increase the scale of military operations. Continuous preparations for possible conflicts with increased military spending support the treadmill theory of destruction in periods of both peace and war. These results are similar to Bildirici (2017c) and Clark and Jorgenson (2012). The findings support the treadmill theory of destruction.

Table 5 shows the CS-ARDL approach results, and we can interpret the findings when CDS is taken into the account in the short-term and long run. The error-correction coefficient is significant and negative, and it shows the long-run association between emissions and its regressors. The error-correction coefficient is – 0.655, implying that, after any exogenous shock, the speed of adjustment is 65.6% in a year to the long-term equilibrium. The CS-ARDL results confirm the earlier findings. Thus, GDP and carbon emission do not follow an inverted U-shaped association. The elasticity signs of YL and YLS are negative and positive; the latter is significant. It indicates that the EKC hypothesis is not supported in the ten states with the highest military expenses. Therefore, the partial influence of YL on emissions makes a negative (but not significant) impact at the earlier process of the expansion of the economy; however, it raises and becomes positive as these states shift to the higher levels. The findings are similar to Dogan and Ozturk (2017) and Zhang and Liu (2019). Also, we can observe the significant and positive coefficient of military expenses, which spurs emission. The amount of greenhouse emissions in the air rises because of the different military activities like military operations utilizing huge amounts of fossil fuels in tanks, ships, and planes. It is also used in air conditioning for the troops. Thus, it supports the existence of the treadmill theory of destruction. This result is also similar to Bildirici (2017b) and Sohag et al. (2019). The renewable energy coefficient is

Table 5 CS-ARDL estimator outcomes

LCO	CD in short-term		CD in short-/long-term		CD in long-term	
	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term
ECT		– 0.653***		– 0.655***		– 0.823***
ΔYL		– 0.652		– 0.726		– 0.599
ΔYLS		0.078**		0.076*		0.062
ΔLREN		– 0.088**		– 0.094**		– 0.112
ΔLME		0.249***		0.169**		0.439*
YL	– 0.514		– 0.573		– 0.057	
YLS	0.053**		0.053*		0.036	
LREN	– 0.061**		– 0.065**		– 0.065***	
LME	0.164***		0.117**		0.253***	
Constant	7.25		1.77**		1.40*	

*, **, and *** indicate significance levels at the 10%, 5%, and 1%. Source: researchers' calculation

significant in all three models, which implies that a 1% increase in sustainable energy will cause a 0.06% decrease in emissions. These results are in line with Shafiei and Salim (2014) and Chiu and Chang (2009). Therefore, the top ten countries with the highest military expenses must raise the amount of sustainable energy, like biofuel or biodiesel to reduce the deterioration of the environment.

To reveal the robustness of the model, it is tested without the quadratic form of economic expansion. Therefore, the association between carbon emissions, economic expansion, sustainable energy, and military expenses are retested. The outcomes are provided in the Appendix of the article. The null hypothesis of homogeneity (Table 6) is not accepted by the delta, and delta hat adjusted tests. The results in Table 7 reinforce the presence of cointegration between the variables. The YL has a positive association with carbon emissions in CCEMG and CS-ARDL models. Economic activity expansion leads to a higher demand for energy, and it raises carbon dioxide emissions; therefore, expansion of the economy makes a positive influence on emissions. This outcome is in accordance with Destek and Sarkodie (2019) and Zhang and Da (2015). The effect of sustainable energy on emissions is negative and statistically significant, and the effect of military expenses is also positive and significant in Tables 8 and 9. Thus, these outcomes are in line with our model and confirm its stability.

Conclusion

This paper concentrates on the association between military expenses, growth of the economy, consumption of sustainable energy, and carbon dioxide emission for the top ten countries with the highest military expenses, namely, Saudi Arabia, Israel, Russia, US, South Korea, India, France, Australia, China, UK for the period from 1993 to 2017. It was found that there is a long-term association among the series by using the Westerlund test of cointegration test (2007). This paper used panel data techniques such as CCEMG (Pesaran 2006; Kapetanios et al. 2011) and dynamic CCEMG (Chudik and Pesaran 2015), the newly developed CS-ARDL (Chudik et al. 2016) approach.

It is found that the EKC hypothesis is not supported in the panel of these countries. There is an insignificant influence of GDP at the earlier process of the expansion of the economy; however, it raises and becomes positive as the 10 states shift to the higher levels. Moreover, it is found that military expenses increase carbon dioxide emissions; thus, the treadmill theory of destruction is valid for the panel of these countries. Hence, the countries with the highest military expenses play a detrimental role in environmental degradation. Even during peacetime, the consumption of fossil fuels by militaries continues, thus allowing carbon dioxide to accumulate in the air and producing toxic wastes.

It is found that sustainable energy mitigates emissions. Therefore, a reduction in pollution can be provided by increasing the consumption of sustainable energy by military transportation and by stimulating more innovation to decrease pollution.

The governments of the ten countries with the highest level of military expenses should maintain an appropriate balance between the expansion of the economy, military expenses, and CO₂ emissions. Expansion of the economy and military expenses should be appropriate with innovations in terms of the sustainability of the environment. A decrease in pollution without decreasing the expansion of the economy and military expenses can be achieved by increasing the amount of sustainable energy. The increased use of biofuels like ethanol could be another option as a substitute for diesel and gasoline in the military transport division. The bioenergy industry can be beneficial for declining emissions and preserving the environment. The conventional energy sources lead to environmental degradation and should therefore be substituted. Environmentally friendly attitudes should be established, and the governments should increase the usage of sustainable energy like biofuels to mitigate the pollution of the environment in the countries with the highest military expenses.

This indicates that these states should promote sustainable energy sources and economic projects that rely on this type of energy. Therefore, the following measures are recommended:

- To reduce pollution, it is important to boost sustainable energies in the use of military vehicles.
- Increase research and development projects in the sustainable energy sector.
- To increase direct lending for renewable energy research to enhance technological progress in the energy field, and to encourage economic activities that rely on sustainable energy.
- Implement policies that protect the environment from pollution by implementing strategies that support the use of sustainable energy, such as a lower cost of lending and a reduction in taxes to sustainable energy projects (biofuel production projects).

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Data availability The data that support the findings of this study is available on request.

Compliance with ethical standards

Conflict of interest The author declares that she has no conflict of interest.

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Appendix

Table 6 Slope homogeneity test outcomes

Test results of slope homogeneity		
	LM statistics	<i>p</i> value
$\hat{\Delta}$	15.483	0.000
$\hat{\Delta}_{adj}$	17.228	0.000

Source: researchers' calculation

Table 7 Westerlund and Edgerton (2007) test outcomes

Statistic	Value	<i>z</i> value	Robust <i>p</i> value
<i>Gt</i>	− 1.563	0.451	0.200
<i>Ga</i>	− 6.644	0.591	0.000
<i>Pt</i>	− 6.254	− 1.595	0.000
<i>Pa</i>	− 6.064	− 0.898	0.000

Source: researchers' calculation

Table 8 Dynamic CCEMG test outcomes and CCEMG test outcomes

	Value	<i>p</i> value
Dynamic CCEMG test outcomes		
LCO (− 1)	0.428**	0.02
YL	− 3.338	0.39
LREN	− 0.017*	0.07
LME	0.395**	0.02
Constant	1.46	0.19
CCEMG test outcomes		
YL	0.576**	0.01
LREN	− 0.092	0.13
LME	0.010	0.94
Constant	− 4.050	0.45

*, **, and *** indicate significance levels at the 10%, 5%, and 1%. Source: researchers' calculation

Table 9 CS-ARDL test outcomes

LCO	CD in short run		CD in short and long runs		CD in long run	
	Long run	Short run	Long run	Short run	Long run	Short run
Error correction		− 0.532***		− 0.673***		− 0.598***
Δ YL		0.267		0.605		1.158
Δ LREN		− 0.088**		− 0.075*		− 0.096*
Δ LME		0.097		0.37		0.053*
YL	0.151		0.370***		0.695	
LREN	− 0.058**		− 0.046***		− 0.063*	
LME	0.059		0.226***		0.032*	
Constant	3.173*		2.479		0.487***	

*, **, and *** indicate significance levels at the 10%, 5%, and 1%. Source: researchers' calculation

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