Militarization of NATO Countries Sparks Climate Change? Investigating the Moderating Role of Technological Progress and Financial Development

Pata, Ugur Korkut and Destek, Mehmet Akif and Manga, Muge and Cengiz, Orhan

Osmaniye Korkut Ata University, Gaziantep University, Erzincan Binali Yıldırım University, Çukurova University

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Abstract

This study evaluates the effects of military expenditures (MEX) on environmental pollution, as well as the moderating role of factors such as financial development and technological progress for 15 NATO member countries under the environmental Kuznets curve (EKC) hypothesis. Using the CS-ARDL estimator, the study analyzes the effects of MEX, income, energy consumption, financial development, and technical progress on carbon emissions spanning the period from 1991 to 2018. Additionally, interaction terms are employed to regularize the moderating effects of financial development and technical advancement. The results show that income, energy consumption, and MEX all contribute to a rise in emissions. It is also found that the financial sector does not eradicate the detrimental ramifications of MEX on the environment, but that technological progress has a moderating effect. A 1% increase in the interaction of technological progress with the military sector reduces environmental degradation by 0.36, but a 1% augment in the interaction of the financial sector with the military sector increases carbon emissions by 0.41%. For this reason, it is imperative to evaluate and revise the financing of MEX of NATO countries from an environmental perspective for sustainable development. Furthermore, as long-run income elasticity in NATO countries is lower than the short-run one, the EKC hypothesis is valid. Based on the overall findings, the study suggests that NATO allies should incorporate the benefits of income growth and technological development into their environmental policies to offset the negative effects of MEX.

Keywords: Military expenditures; EKC; environment; energy consumption; technological progress, financial development

Abbreviations

Adj.: Adjusted
ARDL: Autoregressive distributed lag
ASEAN: Association of Southeast Asian Nations
BRICS: Brazil, Russia, India, China, South Korea
CADF: Cross-sectional augmented Dickey-Fuller
CIPS: Cross-sectional Im-Pesaran-Shin
CS-ARDL: Cross-Sectional ARDL
CSD: Cross-Sectional Dependence
CO_2: Carbon Dioxide
COP26: 2021 UN Climate Change Conference
DH: Durbin-Hausman
EC: Energy consumption.
ECT: Error correction term
EKC: Environmental Kuznets curve
FD: Financial development
FMOLS: Fully modified ordinary least squares
G-7: Group of seven
GDP: Gross Domestic Product
GMM: Generalized method of moments
IEA: International Energy Agency
IMF: International Monetary Fund
IPCC: Intergovernmental Panel on Climate Change
LM: Lagrange Multiplier
MEX: Military expenditures
Mt: Metric tons
NATO: North Atlantic Treaty Organization
NARDL: Non-linear ARDL
OECD: Organisation for Economic Co-operation and Development
R&D: Research and development
SIPRI: Stockholm International Peace Research Institute
Std. Dev.: Standard deviation
TEC: Technological innovation
USA: United States of America
VAR: Vector autoregression model

1. Introduction

Global warming is one of the most glaring issues facing the world today. The IPCC (2018) emphasizes that global warming has increased by 1.0°C above the pre-industrial levels. If the current situation continues, the global warming level could reach 1.5°C between 2030 and 2052. Ecological degradation has become a global issue largely due to economic advancements made at the price of the environment. In fact, while the global GDP has grown by more than sevenfold in the last 60 years (World Bank, 2021), global carbon dioxide (CO_2) emissions have quadrupled in the same time (Ritchie et al., 2020). The influences of anthropogenic actions on global climate change and environmental degradation are extensive, as shown by several scientific studies (Ahmed et al., 2018).

Researchers concentrate on the environmental effects of factors that maintain or enhance the level of fossil fuel use, as it is possible to implement the main green transformation policy by using fewer fossil fuel. On this basis, the environmental influences of some fossil-intensive factors such as economic growth (Shahbaz et al., 2015a), industrialization (Opoku and Aluko, 2021; Shahbaz et al., 2015b), international trade (Pata, 2019; Khan et al., 2021a), foreign direct investment (To et al., 2019; Christoforidis and Katrakilidis, 2021), and population (Yahaya et al., 2020) are intensively examined.

There is little research on how to lessen the potential negative consequences of the defense industry, which is one of the most fossil fuel dependent industries and least open to green transformation. The pessimistic view argues that MEX exaggerate environmental degradation through multiple channels, including energy use, production, and technological transformation. According to Bildirici (2017a,b;2018), military strategies of countries lead to a change in their production structure and increase energy use, which leads to environmental pollution. The link with militarization factors and pollution is also rooted in the Treadmill of Destruction Theory (Jorgenson et al., 2012). *The Treadmill of Destruction Theory* claims that the arms race between countries and the spread of militarization due to geopolitical competition not only have economic consequences, but also lead to ecological degradation (Hooks and Smith, 2004). Where geopolitical conflicts encourage arms race and technological developments (Jorgenson et al., 2012), technical tools and equipment, as well as the training of military personnel to adapt to military technology, require high-energy consumption. Besides, the use of advanced high-tech military vehicles such as aircraft, helicopters, and tanks and their large infrastructures cause a large amount of oil consumption (Clark et al., 2010). The improvement of technological and scientific dynamics, especially since the World War (II), directs the countries to have a more capital-intensive military structure that requires high-energy consumption (Bildirici, 2017b). Though armaments, military activities, the use of toxic or chemically reactive weapons, soil erosion, and fossil fuel usage all lead to environmental devastation (Clark et al., 2010), there are several other ramifications as well (Bargaoui and Nouri, 2017). Another significant factor that endangers both human life and the environment is nuclear weapons. Nuclear weapons have a substantially more detrimental effect on soil and water than fossil fuel pollution, even if they are not activated (Sanders-Zakre, 2020; Doolittle, 2003). Chemical explosions involving fissile elements such as radioactive materials in nuclear programs, studies, and tests, as well as the approaching of radioactive materials to critical levels, result in ionizing radiation and increased environmental harm (Bolton and Minor, 2021).

Another factor contributing to climate change is the role of the military industry, which reaps large profits from the arms race caused by military conflicts. Military companies that support the creation of the perception of insecurity believe that the solution to climate change solution depends on tightening security policies. Thus, cooperation between military institutions and military companies that profit from the expansion of military activities is increasing, and pressure on the environment is also rising (Steichen and Koshgarian, 2020). Although various research points to the adverse influence of militarization on the environment, some researchers have paid attention to the favorable effects of militarization. For instance, Solarin et al. (2018) have argued that the adoption of technologies in the militarization process contributes to consume fewer resources influencing the environment negatively. In addition, some research evaluate mentioned nexus in feedback perspective as investigating the effect of climate change or the influence of policy implementations against climate change on militarization (Sweijs et al., 2022; Destek et al., 2022; Sovacool et al., 2023).

Opposite to the above causes of ecological degradation from the perspective of militarization, in the energy and environmental literature, technological innovation (TEC) is seen as one of the crucial ways to mitigate pollution through several mechanisms (Villanthenkodath and Mahalik, 2022). As we recall the seminal work of Grossman and Krueger's (1991), in the last stage of the EKC hypothesis, the structural change of production type shifting from conventional methods to the technology-intensive process helps reduces CO_2 emissions (Destek and Manga, 2021). Besides, TEC helps to improve the potential capacity of renewables (Adebayo et al., 2022). Thus, the policies targeting a clean environment must adopt TEC (Tahir et al., 2021); in this line, investment in R&D becomes the main influential factor in ensuring environmental quality (Sinha et al., 2020).

Concerning TEC, financial development (FD) is accepted as a crucial factor in combating environmental degradation (Dar and Asif, 2018). Financial facilities are closely related to environmental degradation, with inverse effects. On the one hand, literature emphasizes the negative influence of FD on environmental degradation. Notably, FD provides funding for renewable energy policies and enhances energy efficiency (Baloch et al., 2021). On the other hand, through income impact, FD is like an open door to encouraging people to consume more commodities and services (Lahiani, 2020; Khan et al., 2021a). As for the defense industry, it is common knowledge that the public sector is responsible for the majority of defense industry products and MEX. The fact that the private sector has begun to rise its in the defense industry in recent years, and that the private sector carries out more innovative activities than the public sector, which is relatively more cumbersome in terms of production, is closely linked with the access of this sector to financial resources. Similarly, the influence of enterprises' access to financial resources on their production techniques, or the amount of ecologically friendly production, is questionable.

Considering the theoretical assertions about the effect of military activities on pollution, this paper aims to explore the influence of militarization on CO_2 emissions for the NATO. Fig. 1 shows the CO_2 emissions of the 15 NATO countries examined in the study in 1991 and 2018. With the exception of Turkey, Slovenia, and Portugal, 12 NATO countries have succeeded in reducing their CO_2 emissions. Do TEC and FD play an important role in this success by minimizing the adverse ecological impacts of the military sector? Our study aims to answer this research question.

<Insert Figure I here>

We choose the NATO countries for two reasons. First, NATO consists of 30 countries with a significant defense expenditure. For estimated data, NATO defense expenditure of has risen from 910,241 billion dollars in 2014 to 1,050,780 trillion dollars[1] in 2021 (NATO, 2022a). Thus, NATO can substantially affect environmental quality. Second, most countries of NATO have both advanced technologies and developed financial system that may affect the military activities and environmental quality nexus.

The scientific contributions of the study to the current literature can be described as follows: i) This study evaluates the environmental effects of MEX of NATO countries for the first time. ii) To account for shock propagation among NATO nations, the study employs panel data approaches that account for CSD. iii) In building empirical models, variables such as financial and technological development, as well as the interaction effects of MEX, are included as independent variables to determine the mitigating factors for the potentially environmentally harmful effects of MEX. iv) The efficacy of MEX and their interactions with technological and FD on CO_2 emissions are analyzed using the CS-ARDL approach. v) The study analyzes the EKC using the approach of Narayan and Narayan (2010) for the first time for NATO countries and avoids potential multicollinearity problems.

This work has the following sections: Section 2 is dedicated to the literature review. A description of the empirical strategy can be found in Section 3. The empirical findings are presented and discussed in Section 4. Finally, the section 5 concludes with recommendations for policy.

2. Literature Review

There is an extensive literature analyzing the determinants of CO_2 emissions (Kartal et al., 2023a; Adebayo et al., 2023). The EKC hypothesis has been generally analyzed using quadratic and cubic models. However, Narayan and Narayan (2010) argued that including the square or

[1] It represents constant 2015 prices and exchange rates.

cubic of income in the analysis causes a multicollinearity problem, and to avoid this problem, inferences about EKC can be made by comparing the short- and long-term income elasticities. In the few studies that test the EKC using this approach, there is no consensus (Pata and Hizarci, 2022). Researchers examining the influence of MEX, FD, and technological development on pollution also reach different findings. None of these studies focus on NATO countries and do not consider the moderating role of FD and technological progress. We attempt to address this gap in the literature.

2.1. Military expenditures and environmental degradation

Although there are numerous empirical studies on the economic, social and political effects of militarization (Gezer, 2022; Knight and Hastey, 2022; Zaman, 2023a), the association between MEX and the environment is not examined in depth. Empirical works mainly concentrate on the link between militarization and income (DeRouen Jr., 1994; Pieroni, 2009; Azam, 2020; Saba and Ngepah, 2020), investment (Smith, 1980; Hou and Chen, 2014; Aziz and Khalid, 2019), and debt (Azam and Feng, 2017; Khan et al., 2021b).

However, as discussed theoretically, MEX is one of the crucial factors affecting climate change in various ways (Jorgenson and Clark, 2009; Bildirici, 2017a, 2017b; Ullah et al., 2021). Recently, scholars have attempted to explore these relationships for different countries/country groups by using different empirical strategies. For example, Jorgenson and Clark (2009) used data from 1975 to 2000 for a panel of 53 countries and documented that there is a positive association between militarization and ecological footprint. Jorgenson et al. (2010) examined a similar relationship among the 72 countries from 1970 to 2000 and concluded that per soldier MEX increase environmental degradation. In another analysis, Bildirici (2017a) discovered a unidirectional causality from MEX to CO_2 emissions for G-7 countries over 1985-2015. Bildirici (2018) also found similar findings of environmental degradation measured by the greenhouse gases emissions for same country group and period.

Solarin et al. (2018) revealed the mixed effects of militarization on the pollution depends on estimators with the data spanning the period 1960 and 2015 for the USA. Zandi et al. (2019) highlighted that MEX and corruption increased pollution in ASEAN nations from 1995 to 2017. Bradford and Stoner (2017) noted that the link between MEX and CO_2 emissions varies depending on the development wealth of nations. According to the estimation findings conducted by Edmond and Boker (2019) for Africa with the VAR and GMM methods, MEX exaggerate ecological degradation measured by CO_2 emissions, nitrous oxide, and methane gas. Gokmenoglu et al. (2020) studied for Turkey from 1960 through 2014 by employing FMOLS. According to their estimation outcomes, MEX lead to a decline in environmental quality. Using CS-ARDL, Chang et al. (2023) reported that MEX have an increasing effect on CO_2 emissions for 15 countries. In contrast, Ullah et al. (2021) used NARDL technique for Pakistan and India from 1985 to 2018, highlighted that MEX reduce CO_2 emissions, and verified the asymmetric relationships between the two variables. Konuk et al. (2023) also concluded that MEX mitigate ecological degradation in G7 countries. To sum up, the first sub-research question that emerged as a result of this review is as follows: How does the militarization of NATO countries affect their environmental quality?

2.2. Financial development and the environment

The effect of FD on environmental degradation is controversial. However, two opposing views can be identified in the literature. The pessimistic view of the arguments expresses that access to financial sources stimulate environmental degradation because it creates an opportunity to obtain the cheapest credits for consumers. Therefore, most affordable financial sources increase consumption and cause intense pressure on the environment. Similarly, environmental degradation increases as firms build new activities and use more inputs by access to financial resources (Sadorsky, 2010). However, optimistic approaches suggest that environmental pollution decreases with FD because it encourages technology investments that increase energy efficiency (Abbasi and Riaz, 2016).

The findings of studies examining the impact of FD on the environment vary. Shahbaz et al. (2013) analyzed the influence of FD on pollution for South Africa and concluded that FD improves environmental quality. Similarly, Tamazian et al. (2009) inspected the effect of economic growth and FD on ecological degradation in BRIC countries between 1992 and 2004 and found out that FD mitigates pollution. Al-Mulali et al. (2015) used FMOLS estimator for 18 countries, verified the presence of the EKC, and concluded that FD improves environmental quality. The empirical analysis conducted by Saidi and Mbarek (2017) indicated that FD is negatively associated with CO_2 emissions for 19 developing countries. Zaidi et al. (2019) concluded that globalization and FD reduce CO_2 emissions in APEC countries during 1990-2016.

Furthermore, Katircioglu and Taspinar (2017); Dar and Asif (2018) also found an environmental friendly role of FD in Turkey, Destek (2019) for 17 emerging countries; Pata and Yilanci (2020) for Japan; Sheraz et al. (2021) for G-20 countries; Shahbaz et al. (2018) for France; Usman and Hammar (2021) for APEC countries, and Lahiani (2020) for China.

Another strand of literature addressing the effects of FD highlights environmentally damaging behavior. Esmaeilpour-Moghadam and Dehbashi (2018) documented that FD accelerates pollution, while technological investments mitigating environmental damage in Iran from 1970 to 2011. Pata (2018a, 2018b) used the widely known ARDL approach and showed that FD increases CO_2 emissions in Turkey. Shahbaz et al. (2020) found that both FD and income led to an increase in pollution for the United Arab Emirates from 1975q1 to 2014q4, but the association between FD and CO_2 emissions provides two different structures as a U- and inverted-N shaped. Likewise, Destek and Manga (2021) reported that FD have a positive impact on CO_2 emissions and ecological footprint in the case of Big Emerging Countries during the

1995-2016 period. Ahmad et al. (2022) showed that FD fosters environmental degradation, but it can increase environmental quality over the 1984-2017 period for 18 developing countries. In addition to these positive associations between FD and environmental degradation, Ahmad et al. (2020) for 90 countries, Tahir et al. (2021) for South Asian countries, Rjoub et al. (2021) for Turkey, Shen et al. (2021) for China, and Kartal et al. (2023b) for the United States revealed the same results.

Moreover, some studies explore no substantial relationship between FD and pollution. For instance, the analysis conducted by the study of Charfeddine and Kahia (2019) found a weak link between FD and ecological quality in 24 countries. In Lithuania, neither the EKC nor FD and CO_2 emissions link existed during 1989-2018, according to Rahman et al. (2020). Similarly, Rasiah et al. (2018) for five ASEAN countries and Seetanah et al. (2019) for 12 countries reported that there is no link between FD and environmental degradation. Based on these studies, the second sub-research question is: What are the direct and indirect influences of FD on ecological quality?

2.3. Technology and environmental quality

In the literature, another component of the ecological quality is the technology. Although there exist mixed results in the relationship between technology and pollution, there is an extensive consensus about the green impact of technology on environmental degradation. Ali et al. (2016) noted that technological developments led to a decline in CO_2 emissions in Malaysia from 1985 to 2012. The study by Adebayo et al. (2021) showed that TEC mitigates CO_2 emissions in South Korea. Adebayo et al. (2022) found out that a positive shock of TEC is negatively related to CO_2 emissions in Sweden between 1980 and 2018.

The empirical findings of the study assessed by Rafique et al. (2020) with data of BRICS countries for the period 1990-2017 indicated that TEC reduces environmental degradation. Xinmin et al. (2020) analyzed the association between income, trade openness, CO_2 emissions, technology innovation, and adoption in China. According to the marginal effect, trade openness and technology innovation decrease CO_2 emissions. Chien et al. (2021) showed TEC negatively affect CO_2 emissions in Pakistan between 1980 and 2018. Destek and Manga (2021) found that nexus between TEC has non-significance link with ecological footprint, whereas TEC negatively influences CO_2 emissions in 10 countries from 1995 to 2016. Erdogan (2021) found that TEC has a mitigating effect on pollution in the building sector for BRICS countries between 1992 and 2018. Utilizing data from 1992 to 2016, Hussain and Dogan (2021) illustrated that environmental technologies improve ecological quality for BRICS. Aqib and Zaman (2023) confirmed that technological improvement reduces CO_2 emissions in Pakistan. Sharif et al. (2023) confirmed the pollution-reducing effect of technological progress for Nordic countries. Contrary to prevalent opinion, Adebayo and Kirikkaleli (2021) presented evidence that TECs in Japan lead to environmental degradation. A similar finding is highlighted by Fan and Hossain (2018) for China and India. Dauda et al. (2019) reported that technological development has the influence of increasing CO_2 emissions for 18 countries from 1990 to 2016. In the time-series examination of CO_2 emissions, Villanthenkodath and Mahalik (2022) also found that TEC increase environmental destruction in India. Khan (2023) also validated the emission increasing effect of technological innovations for Pakistan. Finally, the third sub-research question is: How does the technological development of NATO countries affect their environmental indicators? In a three-part, extensive literature review, it appears that there is no consensus among researchers on the ecological impacts of MEX, FD, and TEC. The key findings from the literature are shown in Fig. 2.

<Insert Figure II here>

Fig. 2 summarizes the findings of studies in the literature. Seven of 10 studies find that MEX have an increasing effect on CO_2 emissions. In terms of FD, 13 out of 24 studies show that FD plays an environmental role. Technological progress provides environmental benefits in 10 out of 16 studies. As can be seen from the literature, the main results indicate that MEX worsens environmental quality, while FD and TEC play a helpful role in CO_2 reduction, although the studies contain different results.

There is no study in the literature that analyzes the environmental effects of TEC, FD, and MEX by focusing on the interaction effects of these variables. Can the interaction of TEC and FD with MEX help minimize the environmental damage of the military sector? Aside from this initial research gap in the literature, no study to date has examined environmental degradation in NATO countries that lead the world in MEX. The lack of an empirical study on minimizing environmental degradation in these countries is the second research gap. This study aims to fill both research gaps by investigating the environmental interaction effect of FD and TEC on MEX using the CS-ARDL approach, thus contributing to the literature.

3. Data and methodology

3.1. Data

The study applies annual data for 15 NATO member countries for the period 1991-2018. Based on these data, CO_2 emissions is regressed with per capita gross domestic product (GDP), military expenditures (MEX), per capita energy consumption (EC), technology (TEC), and financial development (FD). The sources, units of measurement, and definitions of the data are listed in Table 1.

<Insert Table I here>

For testing the impact of MEX on CO_2 emissions concurrently with technological development and FD, the study analyzes both TEC*MEX and FD*MEX interaction terms. The modeling performed on this basis is shown in Eq. (1).

$$lnCO_{2,it} = \alpha_0 + \alpha_1 lnGDP_{it} + \alpha_2 lnMEX_{it} + \alpha_3 lnEC_{it} + \alpha_4 lnTEC_{it} + \alpha_5 lnFD_{it} + \alpha_6 lnTEC * MEX_{it} + \alpha_7 lnFD * MEX_{it} + e_t \quad (1)$$

In Eq. (1), if the technique effect and composition effect for the service sector is dominant, α_1 can be negative, but if the increase in production with the scale effect increases the environmental pressure, this coefficient is should be positive. MEX and EC are widely regarded as environmentally destructive (Clark et al., 2010) and therefore α_2 and α_3 are expected to be positive. The coefficient of TEC (α_4) is generally believed to be negative, but a few studies show the opposite (see e.g., Dauda et al., 2019; Villanthenkodath and Mahalik, 2022). α_5 can be positive or negative, depending on whether the funds go to environmentally friendly production processes or to polluter's production expansion. The signs of the α_6 and α_7 vary depending on the reflection and intersection of technology and FD with MEX on the environment.

3.2. Methodology

Following Fig. 3, the study employs a six-stage empirical analysis strategy. In the first stage, the descriptive statistics are examined, and then the CSD and slope homogeneity properties of the panel data are analyzed. In the third stage, the stochastic properties of the variables are explored employing the unit root approaches. In the fourth stage, a cointegration analysis is performed applying the DH approach. In the fifth stage, the environmental effects of MEX are explored with interaction terms using the CS-ARDL approach, and in the final stage, the Dumitrescu-Hurlin causality test is conducted.

<Insert Figure III here>

The relationship between the empirical methods in Fig. 3 can be explained as follows. If there is CSD and heterogeneity, the second-generation panel methods, such as CADF, CIPS, DH, and CS-ARDL can provide robust findings. In order for the DH and CS-ARDL tests to be applied, the dependent variable must be I(1), which can be tested with the CADF and CIPS unit root tests. Estimating elasticities with the CS-ARDL approach requires the existence of cointegration, which can be examined with the DH cointegration test.

3.2.1. CADF unit root test

The CADF unit root test considering CSD and heterogeneity proposed by Pesaran (2007) is applied with the Eq. (2):

$$\Delta GDP_{it}=\delta_i+\beta_i GDP_{it-1}+\alpha_i \overline{GDP}_{t-1}+\sum_{j=0}^{p}\varphi_{ij}\Delta\overline{GDP}_{it-1}+\sum_{j=0}^{p}\varphi_{ij}GDP_{it-1}+e_{it} \quad (2)$$

where Δ is the difference operator, δ_i is individual constant terms, $\overline{GDP}_{t-1}$= is the averages of lagged variable, $\Delta\overline{GDP}_{it-1}$ is the first difference of the averages of lagged variable, p is the lag length, and e_{it} is the error term. The CADF statistics are asymptotically similar regardless of factor loadings. Pesaran (2007) circumvents the CSD problem by using cross section averages for level and first difference values of GDP.

In Eq. (2), t-statistics ($t_i(N,T)$) of β_i are calculated, and using the cumulative form of these statistics, the CIPS statistics can be defined as in Eq. (3):

$$CIPS=N^{-1}\sum_{i=1}^{n}t_i(N,T) \quad (3)$$

where N is the number of observation. The H_0 and H_1 hypotheses for the CADF and CIPS tests can be formulated as follows:

$$H_0: \beta_i = 0 \ for\ all\ i,\ H_1: \begin{cases}\beta_i < 0, & i = 1,2,3,\ldots,N_1 \\ \beta_i = 0, & i = N_1+1,\ldots.N\end{cases}$$

The null hypothesis (H_0) of the CADF and CIPS tests indicates the presence of a unit root in the series, while the alternative one (H_1) suggests that at least one cross-section is stationary.

3.2.2. Durbin- Hausman cointegration test

A number of advantages have been identified in the DH panel cointegration test proposed by Westerlund (2008). They include accounting for CSD and heterogeneity, allowing a large number of independent variables to be analyzed because of its standard normal distribution, and including independent variables regardless of their degree of stationarity. In order to use the DH cointegration test, the dependent variable should be I(1). The DH_{panel} and DH_{group} statistics can be calculated as in Eq. (4):

$$DH_{panel} = \hat{s}_n(\varphi_1 - \varphi_2)^2 \sum_{i=1}^{N}\sum_{t=2}^{T} \hat{e}_{i(t-1)}^2 \,; DH_{group} = \sum_{i=1}^{N} \hat{s}_i\,(\varphi_{1i} - \varphi_{2i})^2 \sum_{t=2}^{T} \hat{e}_{i(t-1)}^2 \tag{4}$$

The DH_{panel} test assumes that the autoregressive parameter is same for panel and the DHgroup test assumes that the parameters are heterogenous. For both test statistics, the null hypothesis indicates no cointegration.

3.2.3. Cross-sectionally augmented ARDL

The CS-ARDL is an extended version of Pesaran et al. (1999) using the pooled mean group estimator and has a structure that includes a cross sectional mean, a long-term parameter, and a short-term parameter with an error correction coefficient for each variable. The CS-ARDL developed by Chudik et al. (2013) and Chudik and Pesaran (2015) accounts for CSD and heterogeneity phenomena by including dynamic common correlated effects in the analysis. This approach is also effective against potential problems such as serial correlations and endogenity (Zeqiraj et al., 2020). To eliminate the influence of unobserved common factors in the CS-ARDL estimation, the individual regressions are augmented with cross-sectional averages (Chudik, 2016). In the CS-ARDL approach, the estimated coefficients based on the mean group are also unbiased in the cases where $N \rightarrow \infty$ and $T \rightarrow \infty$. In Eq. (5), the CS-ARDL estimator first calculates the short-run elasticities and then uses these coefficients to derive the long-run elasticities.

$$Y_{i,t} = \beta_i + \mu_{ji} \sum_{j=1}^{ay} Y_{i,t-j} + \alpha_{ji} \sum_{j=0}^{bx} X_{i,t-j} + \mu_{ji} \sum_{j=0}^{c} \overline{Y_{i,t-j}} + \alpha_{ji} \sum_{j=0}^{d} \overline{X_{i,t-j}} + e_{i,t} \quad (5)$$

where $Y_{i,t}$ includes the dependent variable (CO_2 emissions), $X_{i,t}$ as a function of the independent variables (GDP_{it}, MEX_{it}, EC_{it}, TEC_{it}, FD_{it}, TEC_{it}*MEX_{it}, FD_{it}*MEX_{it}), ay and bx are the lags. In the CS-ARDL approach, long-term elasticies can be calculated using Eq. (6):

$$\hat{\theta}_{CS-ARDL,i} = \frac{\sum_{j=0}^{bx} \hat{\alpha}_{ji}}{\sum_{j=1}^{ay} \hat{\mu}_{ji}} \quad (6)$$

Finally, the CS-ARDL can be expressed with error correction form as in Eq. (7):

$$\Delta Y_{i,t} = \beta_i + \emptyset_i\left(Y_{i,t-1} - \omega_i X_{i,t-1}\right) + \mu_{ji}{}^{*} \sum_{j=1}^{ay-1} \Delta Y_{i,t-j} + \alpha_{ji}{}^{*} \sum_{j=0}^{bx} \Delta X_{i,t-j} + \gamma_i \sum_{j=1}^{c} \overline{Y_{i,t-j}}$$

$$+ v_i \sum_{j=0}^{d} \overline{X_{i,t-j}} + \rho_i \sum_{j=1}^{c-1} \overline{Y_{i,t-j}} + \sigma_i \sum_{j=0}^{d-1} \overline{X_{i,t-j}}\, e_{i,t} \quad (7)$$

where $\emptyset_i$=-(1-$\sum_{j=1}^{ay} \mu_{ij}$) is expected to take a negative value between 0 and -1 and to be statistically significant for the long-term relation. While ω_i, the vector of parameters, contains long-run relationships, ${\mu_{ji}}^{*}$ and ${\alpha_{ji}}^{*}$ provide calculation of short-run elasticities.

4. Findings and discussion

First, the study examines the descriptive statistics of the relevant variables. As seen from Table 2, the variable with the highest mean is EC, followed by GDP. The variables with the lowest standard deviation are FD*MEX, CO_2 and EC, respectively.

<Insert Table II here>

It is important to consider and control for heterogeneity among countries of the variables in the analysis. In addition, for panel data, CSD may exist between countries. CSD can be characterized as the effect of a shock that may occur in energy, finance, technology, military, and various sectors in one nation and affect other nations. In this case, traditional panel tests that do not consider heterogeneity and CSD can lead to biased results.

A number of CSD tests as well as delta and adjusted delta heterogeneity tests are applied to avoid this, and the outcomes provided in Table 3 show the results of each test.

The results of the LM and CD_{LM} tests of Breusch and Pagan (1980), LM_{adj} test of Pesaran et al. (2008), and weak CD test of Pesaran (2015) indicate that the null hypothesis of no CSD is rejected for all series. In this case, there is a pass-through between shocks between countries. In addition, the p-values of the Δ and Δ_{adj} tests of Pesaran and Yamagata (2008) indicate that the slope coefficient is heterogeneous. Therefore, the study uses second-generation panel unit root and cointegration tests that consider CSD and heterogeneity.

<Insert Table III here>

Table 4 presents the results of the panel CADF and CIPS unit root tests. The CADF test statistics illustrate that FD and FD*MEX are stationary at the level. The other six series contain a unit root. These series become stationary at their first difference. The results of the CIPS reveal that MEX, FD, and FD*MEX are stationary. CO_2, GDP, EC, TEC, and TEC *MEX contain a unit root. In other words, MEX, FD, and FD*MEX are found to be stationary at level, while the other series are stationary at first difference. Therefore, the study uses the DH cointegration test and CS-ARDL estimator, which allows for different orders of integration ((I(0) & I(1)) and considers the CSD.

<Insert Table IV here>

After investigating the stationarity of the variables, the study tests the long-run associations with the DH cointegration test and presents the outcomes in Table 5. The statistics and probability values of the panel and group test prove that the null hypothesis is rejected at the 1% significance level.

<Insert Table V here>

In light of the quantitative findings related to CSD, heterogeneity, unit root, and DH cointegration test, the study is directed towards the application of the CS-ARDL estimator. This process is visually represented in Fig. 4.

<Insert Figure IV here>

In the final stage, the study estimates elasticities using the CS-ARDL method. The CS-ARDL approach provides the short- and long-term coefficients and the short- and long-term cross-sectional means of each variable together (Usman et al., 2022). This approach estimates the long-term coefficients by means of individual short-term coefficients obtained by least squares estimation (Chudik et al., 2013). The CS-ARDL approach, which is based on the ARDL of Pesaran et al. (2001), decomposes the short- and medium-term coefficients using multiplier matrices. Table 6 report the outcomes of the CS-ARDL estimator. Since the logarithmic values of the variables are considered, the coefficients express elasticities of CO_2 emissions with respect to the independent variables. A 1% augment in the technology level stimulates CO_2 by 1.2% and 0.6% in the short and long term, respectively. The underlying reason for this could be the increase in production and consumption of polluting products in the member nations of NATO when the technology level increases. This finding supports the results of Fan and Hossain (2018), Adebayo and Kirikkaleli (2021), and Villanthenkodath and Mahalik (2022).

Adebayo and Kirikkaleli (2021) reported that TECs increase CO_2 emissions in Japan, which could be due to the country's failure to increase investment in green technologies. Similarly, Villanthenkodath and Mahalik (2022) stated that in the process of India's economic development, less importance is given to eco- friendly innovations and therefore technological development emits pollution. Since NATO countries do not primarily transfer their technological developments into green investments, technological advancement may lead to a rise in pollution.

A 1 % rise in per capita income increases CO_2 emissions by 0.5 percent in the short term and 0.2 percent in the long term. This finding indicates that in the assessed country group, wealth-generating activities are conducted in a manner that harms the environment. However, since long-term GDP coefficients are smaller than short-term coefficients, the EKC hypothesis is valid. This finding confirms previous research of Shittu et al. (2021) and Pata and Hizarci (2022). In addition, the results imply that a 1 percent increase in EC raises emissions by 0.6% and 0.3% in the short and long term, respectively. This is the foreseeable conclusion for NATO countries whose energy portfolios are still dominated by fossil fuels. Our findings are compatible with studies of Usman et al. (2019), Khan et al. (2021a), and Sheraz et al. (2021).

There are indications that FD benefits the environment. A 1% augment in the FD mitigates CO_2 emissions by 1.1% in the short term and 0.5% in the long term. The emission-reduction effect of FD suggests that the financial sector works successfully in supporting green transformation and gives funding assistance for the necessary researches required to produce environmentally friendly technology. In contrast to Pata (2018a, 2018b), Shahbaz et al. (2020), Ahmad et al. (2022), the eco- friendliness of FD supports the results of Tamazian et al. (2009), Al-Mulali et al. (2015), and Zaidi et al. (2019).

Consistent with the overall objective of the study, it is discovered that the coefficient representing the effect of MEX on the emission level is, as anticipated, positive. The primary explanation for this result is because the defense industry is one of the industries that consumes the most fossil fuels. The conclusion that MEX trigger pollution is compatible with Clark (2009), Edmond and Boker (2019), and Gokmenoglu et al. (2020).

Table 6 also presents the interaction effects of FD and technological advancement with MEX. It is intriguing to note that when the parameters of the interaction variables are examined, the direct impacts of the variables (FD and TEC) are inverted. First, the negative value of the TEC*MEX interaction variable implies that MEX may lower CO_2 emissions in NATO countries as a result of technological advancement. In another sense, defense investments contribute to environmental quality in countries with relatively high technology levels. This is due to the fact that the defense industry is the most technologically intensive industry in any country. It is well-known that no matter how much money is spent on technological R&D in the defense industry, the outputs of these investments spill over to other industries via the technological spillover effect. If this diffusion leads to green innovation initiatives, environmental quality may benefit. In contrast, the FD*MEX interaction term has a positive effect. This finding indicates that, if the financial sector develops in NATO countries, MEX may have adverse environmental repercussions. In other words, MEX in NATO nations with more robust finance sectors are detrimental to the environment. The primary reason for this situation is that defense industry companies, which in recent years have begun to reduce public dominance in the defense industry by acquiring funds from financial markets, prioritize military superiority production over energy-efficient production in the production of military equipment. In short, while the moderating influence of technology progress is relevant for NATO members, FD does not mitigate the adverse environmental impact of MEX.

<Insert Table VI here>

Fig. 5 visually summarizes the CS-ARDL results, which show that MEX, EC, technological development, and the orientation of the financial sector toward MEX cause environmental pressure. On the contrary, overall FD and technological development in the military sector contribute to the ecological quality. Similarly, an increase in income reduces CO_2 emissions in the long-run because the EKC hypothesis is valid in NATO countries. Due to a lower long-run income elasticity than in the short-run, the increasing effect of income on CO_2 emissions is less in the long-run, which reduces environmental degradation. Moreover, the TEC*MEX interaction term can reduce CO_2 emissions, while FD*MEX causes an increase in environmental pressure. For this reason, NATO countries should take advantage of technological development to reduce the harmful environmental effects of militarization and not use FD as a policy tool that can limit the environmental damage of MEX.

<Insert Figure V here>

Finally, the study performs Dumitrescu and Hurlin (2012) causality test to check the robustness and reliability of the findings. Following Agozie et al. (2022), Chen et al. (2022), and Hassan et al. (2022), the causal links between CO_2 emissions and the interaction terms are also tested; the findings are shown in Table 7.

<Insert Table VII here>

Table 7 shows that that there is a unidirectional causality relationship from MEX and FD*MEX to CO_2 emissions and bidirectional causality links for all other analyses. In other words, the increase in environmental degradation does not affect MEX and the interaction of FD and MEX, while the increase in CO_2 has an impact on macroeconomic indicators such as GDP, energy consumption, technological development and FD. Moreover, the fact that GDP, MEX, EC, TEC, FD and interaction terms have causal associations with CO_2 emissions verify the findings of the CS-ARDL test. Based on these results, NATO countries should consider the financial and technological aspects of MEX in their environmental policies.

5. Conclusion and policy recommendation

5.1. Conclusion

In 2021, members of NATO adopted a Climate Change and Security Action Plan to address climate change at the military and policy levels (NATO, 2022b). At the COP26, NATO allies also committed to supporting net-zero emissions targets in military emissions reductions and defense planning. Given the current environmental efforts of NATO countries, this study aims to analyze the moderating role of technological progress and FD in the impact of MEX on environmental degradation under the EKC hypothesis. The findings can be summarized as follows: (i) The long-run elasticities of GDP are less than the short-run ones, indicating the validity of the EKC. (ii) EC, MEX, and technological development increase pollution. (iii) FD plays a role in reducing CO_2 emissions. (iv) Technological development has a role to moderate the harmful environmental effects of MEX, while FD has no such effect in the military sector.

5.2. Policy inferences

The findings of this study provide crucial policy recommendations for NATO countries to address climate change and reduce CO_2. The validity of the EKC shows that income growth in NATO countries can help minimize environmental problems. For this reason, NATO countries should align their economic expansion with environmental growth models by taking advantage of techniques and composition effects and by putting their economic resources into implementing environmental policies that promote clean energy types, environmentally conscious education programs, and energy efficiency activities. Energy consumption negatively influences environmental conditions in NATO countries. NATO aims to enhance energy efficiency and the utilization of renewable energy in its operations (Bocse, 2020). NATO seeks to reduce environmental pressure by integrating smart grids that use renewable resources into military platforms, thereby reducing the use of conventional fossil fuels (NATO, 2022b). In addition, NATO has established The Specialist Team on Energy Efficiency and Environmental Protection to increase energy efficiency and provide solutions. Together with all these appropriate steps, the findings of our study emphasize the necessity of reducing the weight of polluting fossil fuels in energy use in NATO countries with environmental policies such as monitoring energy use in military camps, carbon tax, and renewable energy incentives.

Militarization of countries from NATO increases environmental degradation. High MEX are closely related to various environmental and sociocultural problems such as air pollution, access to electricity and drinking water, infant mortality, and low life expectancy (Elgin et al., 2022). NATO has high MEX and military equipment, weapons, and construction increase demand for fossil fuels. Even without war, military transportation activities lead to an expansion of CO_2 emissions from fossil fuel use. For this reason, NATO countries must use cleaner energy sources and production technologies in military activities to combat climate change. Above all, the use of clean technologies should be encouraged in military activities. For example, using well-equipped unmanned aerial vehicles can reduce the need for military personnel and energy sources that consume large amounts of energy.

Technological innovations in NATO countries negatively affect environmental quality as a whole. This could be due to the fact that NATO countries do not adequately transform their technological progress into clean and green investments. NATO countries should invest in green technologies to meet their CO_2 emission reduction targets. A review of the moderating effect shows that technological development helps to moderate the harmful effects of militarization on the environment. NATO's Science and Technology Organization promotes scientific research activities related to environmental issues (NATO, 2022b). Technological developments in the military field should be supported by governments to create a more sustainable ecosystem. To this end, governments and companies can increase the share of clean energy technologies and green innovation capabilities in R&D expenditures. To this end, governments of NATO countries should provide tax incentives and low-cost funding opportunities for scientific research to develop technological improvements. In addition, coordination between the public and private sectors should be strengthened with a view to establishing a common technology policy. In addition, NATO countries can encourage scientific research funding for technological advances that favor the use of green fuels in the military sector.

FD is an environmental friendly factor for NATO allies. This shows that pollution is reduced when the countries of NATO allocate some of their financial resources to environmentally friendly projects and investments. For this reason, it can be suggested that NATO countries transfer bank loans to investment projects that encourage clean energy and reduce energy intensity. In other words, policymakers should avoid financing polluting enterprises and set stricter financing conditions. Besides, the financial sector can procure incentives and credit facilities for companies interested in clean environment projects and innovations. These policy options are crucial. Because renewable energy investments, in particular, are costly and require a large amount of financing. NATO should allocate its financial resources to the use of environmentally friendly forms of energy. An examination of the moderating effect shows that FD does not help mitigate the harmful effects of militarization on the environment. Financial institutions should be more selective and encourage R&D projects in militarization to solve this problem, not all military activities. Therefore, it is critical for members of NATO to provide financial incentives only for clean energy projects.

5.3. Limitations and future directions

In light of the findings and policy recommendations, we discussed the influence of various factors on CO_2 emission reduction policies in NATO. Future works can analyze the impact of other factors such as education, urbanization, geopolitical risk, democratization, and nuclear energy on environmental degradation in NATO countries. In addition, further researchers can focus on broader environmental indicators in NATO countries, such as ecological footprint and load factor, to provide a comprehensive environmental assessment.

Although this study makes an crucial contribution to the field, it has some limitations. First, only the CO_2 indicator is employed as the basis for considering the environmental implications of MEX. Indicators such as a larger ecological footprint or load capacity factor can be used in addition to CO_2 emissions as a basis to examine the link more consistently. Second, the study only examines how MEX affect NATO countries' environments. However, it is well known that there has been significant MEX in recent years, particularly by China and Russia. This study can therefore be expanded with examples of nations that allow for comparison. MEX, technological advances, or FD in other countries, which are significant in terms of global military investment, may also affect NATO countries' environmental indicators. Hence, future research can use the novel cross-panel data approaches as suggested by Zaman (2023b).

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