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

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1 **Militarization of NATO Countries Sparks Climate Change? Investigating** 2 **the Moderating Role of Technological Progress and Financial Development**

3 4 **Abstract**

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

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

Abbreviations

Adj.: Adjusted	IEA: International Energy Agency
ARDL: Autoregressive distributed lag	IMF: International Monetary Fund
ASEAN: Association of Southeast Asian Nations	IPCC: Intergovernmental Panel on Climate Change
BRICS: Brazil, Russia, India, China, South Korea	LM: Lagrange Multiplier
CADF: Cross-sectional augmented Dickey-Fuller	MEX: Military expenditures
CIPS: Cross-sectional Im-Pesaran-Shin	Mt: Metric tons
CS-ARDL: Cross-Sectional ARDL	NATO: North Atlantic Treaty Organization
CSD: Cross-Sectional Dependence	NARDL: Non-linear ARDL
CO₂: Carbon Dioxide	OECD: Organisation for Economic Co-operation and Development
COP26: 2021 UN Climate Change Conference	R&D: Research and development
DH: Durbin-Hausman	SIPRI: Stockholm International Peace Research Institute
EC: Energy consumption.	Std. Dev.: Standard deviation
ECT: Error correction term	TEC: Technological innovation
EKC: Environmental Kuznets curve	USA: United States of America
FD: Financial development	VAR: Vector autoregression model
FMOLS: Fully modified ordinary least squares	
G-7: Group of seven	
GDP: Gross Domestic Product	
GMM: Generalized method of moments	

1

2 **1. Introduction**

3 Global warming is one of the most glaring issues facing the world today. The IPCC (2018)
4 emphasizes that global warming has increased by 1.0°C above the pre-industrial levels. If the
5 current situation continues, the global warming level could reach 1.5°C between 2030 and 2052.
6 Ecological degradation has become a global issue largely due to economic advancements made
7 at the price of the environment. In fact, while the global GDP has grown by more than sevenfold
8 in the last 60 years (World Bank, 2021), global carbon dioxide (CO₂) emissions have
9 quadrupled in the same time (Ritchie et al., 2020). The influences of anthropogenic actions on
10 global climate change and environmental degradation are extensive, as shown by several
11 scientific studies (Ahmed et al., 2018).
12 Researchers concentrate on the environmental effects of factors that maintain or enhance the
13 level of fossil fuel use, as it is possible to implement the main green transformation policy by
14 using fewer fossil fuel. On this basis, the environmental influences of some fossil-intensive
15 factors such as economic growth (Shahbaz et al., 2015a), industrialization (Opoku and Aluko,

1 2021; Shahbaz et al., 2015b), international trade (Pata, 2019; Khan et al., 2021a), foreign direct
2 investment (To et al., 2019; Christoforidis and Katrakilidis, 2021), and population (Yahaya et
3 al., 2020) are intensively examined.

4 There is little research on how to lessen the potential negative consequences of the defense
5 industry, which is one of the most fossil fuel dependent industries and least open to green
6 transformation. The pessimistic view argues that MEX exaggerate environmental degradation
7 through multiple channels, including energy use, production, and technological transformation.
8 According to Bildirici (2017a,b;2018), military strategies of countries lead to a change in their
9 production structure and increase energy use, which leads to environmental pollution. The link
10 with militarization factors and pollution is also rooted in the Treadmill of Destruction Theory
11 (Jorgenson et al., 2012). *The Treadmill of Destruction Theory* claims that the arms race between
12 countries and the spread of militarization due to geopolitical competition not only have
13 economic consequences, but also lead to ecological degradation (Hooks and Smith, 2004).
14 Where geopolitical conflicts encourage arms race and technological developments (Jorgenson
15 et al., 2012), technical tools and equipment, as well as the training of military personnel to adapt
16 to military technology, require high-energy consumption. Besides, the use of advanced high-
17 tech military vehicles such as aircraft, helicopters, and tanks and their large infrastructures
18 cause a large amount of oil consumption (Clark et al., 2010). The improvement of technological
19 and scientific dynamics, especially since the World War (II), directs the countries to have a
20 more capital-intensive military structure that requires high-energy consumption (Bildirici,
21 2017b). Though armaments, military activities, the use of toxic or chemically reactive weapons,
22 soil erosion, and fossil fuel usage all lead to environmental devastation (Clark et al., 2010),
23 there are several other ramifications as well (Bargaoui and Nouri, 2017). Another significant
24 factor that endangers both human life and the environment is nuclear weapons. Nuclear
25 weapons have a substantially more detrimental effect on soil and water than fossil fuel

1 pollution, even if they are not activated (Sanders-Zakre, 2020; Doolittle, 2003). Chemical
2 explosions involving fissile elements such as radioactive materials in nuclear programs, studies,
3 and tests, as well as the approaching of radioactive materials to critical levels, result in ionizing
4 radiation and increased environmental harm (Bolton and Minor, 2021).

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

18 Opposite to the above causes of ecological degradation from the perspective of militarization,
19 in the energy and environmental literature, technological innovation (TEC) is seen as one of the
20 crucial ways to mitigate pollution through several mechanisms (Villanthenkodath and Mahalik,
21 2022). As we recall the seminal work of Grossman and Krueger's (1991), in the last stage of
22 the EKC hypothesis, the structural change of production type shifting from conventional
23 methods to the technology-intensive process helps reduces CO₂ emissions (Destek and Manga,
24 2021). Besides, TEC helps to improve the potential capacity of renewables (Adebayo et al.,
25 2022). Thus, the policies targeting a clean environment must adopt TEC (Tahir et al., 2021); in

1 this line, investment in R&D becomes the main influential factor in ensuring environmental
2 quality (Sinha et al., 2020).

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

17 Considering the theoretical assertions about the effect of military activities on pollution, this
18 paper aims to explore the influence of militarization on CO₂ emissions for the NATO. Fig. 1
19 shows the CO₂ emissions of the 15 NATO countries examined in the study in 1991 and 2018.
20 With the exception of Turkey, Slovenia, and Portugal, 12 NATO countries have succeeded in
21 reducing their CO₂ emissions. Do TEC and FD play an important role in this success by
22 minimizing the adverse ecological impacts of the military sector? Our study aims to answer this
23 research question.

24 *<Insert Figure 1 here>*

1 We choose the NATO countries for two reasons. First, NATO consists of 30 countries with a
2 significant defense expenditure. For estimated data, NATO defense expenditure of has risen
3 from 910,241 billion dollars in 2014 to 1,050,780 trillion dollars¹ in 2021 (NATO, 2022a).
4 Thus, NATO can substantially affect environmental quality. Second, most countries of NATO
5 have both advanced technologies and developed financial system that may affect the military
6 activities and environmental quality nexus.

7 The scientific contributions of the study to the current literature can be described as follows: i)
8 This study evaluates the environmental effects of MEX of NATO countries for the first time.
9 ii) To account for shock propagation among NATO nations, the study employs panel data
10 approaches that account for CSD. iii) In building empirical models, variables such as financial
11 and technological development, as well as the interaction effects of MEX, are included as
12 independent variables to determine the mitigating factors for the potentially environmentally
13 harmful effects of MEX. iv) The efficacy of MEX and their interactions with technological and
14 FD on CO₂ emissions are analyzed using the CS-ARDL approach. v) The study analyzes the
15 EKC using the approach of Narayan and Narayan (2010) for the first time for NATO countries
16 and avoids potential multicollinearity problems.

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

21 **2. Literature Review**

22 There is an extensive literature analyzing the determinants of CO₂ emissions (Kartal et al.,
23 2023a; Adebayo et al., 2023). The EKC hypothesis has been generally analyzed using quadratic
24 and cubic models. However, Narayan and Narayan (2010) argued that including the square or

¹ It represents constant 2015 prices and exchange rates.

1 cubic of income in the analysis causes a multicollinearity problem, and to avoid this problem,
2 inferences about EKC can be made by comparing the short- and long-term income elasticities.
3 In the few studies that test the EKC using this approach, there is no consensus (Pata and Hizarci,
4 2022). Researchers examining the influence of MEX, FD, and technological development on
5 pollution also reach different findings. None of these studies focus on NATO countries and do
6 not consider the moderating role of FD and technological progress. We attempt to address this
7 gap in the literature.

8 **2.1. Military expenditures and environmental degradation**

9 Although there are numerous empirical studies on the economic, social and political effects of
10 militarization (Gezer, 2022; Knight and Hastey, 2022; Zaman, 2023a), the association between
11 MEX and the environment is not examined in depth. Empirical works mainly concentrate on
12 the link between militarization and income (DeRouen Jr., 1994; Pieroni, 2009; Azam, 2020;
13 Saba and Ngepah, 2020), investment (Smith, 1980; Hou and Chen, 2014; Aziz and Khalid,
14 2019), and debt (Azam and Feng, 2017; Khan et al., 2021b).

15 However, as discussed theoretically, MEX is one of the crucial factors affecting climate change
16 in various ways (Jorgenson and Clark, 2009; Bildirici, 2017a, 2017b; Ullah et al., 2021).
17 Recently, scholars have attempted to explore these relationships for different countries/country
18 groups by using different empirical strategies. For example, Jorgenson and Clark (2009) used
19 data from 1975 to 2000 for a panel of 53 countries and documented that there is a positive
20 association between militarization and ecological footprint. Jorgenson et al. (2010) examined a
21 similar relationship among the 72 countries from 1970 to 2000 and concluded that per soldier
22 MEX increase environmental degradation. In another analysis, Bildirici (2017a) discovered a
23 unidirectional causality from MEX to CO₂ emissions for G-7 countries over 1985-2015.
24 Bildirici (2018) also found similar findings of environmental degradation measured by the
25 greenhouse gases emissions for same country group and period.

1 Solarin et al. (2018) revealed the mixed effects of militarization on the pollution depends on
2 estimators with the data spanning the period 1960 and 2015 for the USA. Zandi et al. (2019)
3 highlighted that MEX and corruption increased pollution in ASEAN nations from 1995 to 2017.
4 Bradford and Stoner (2017) noted that the link between MEX and CO₂ emissions varies
5 depending on the development wealth of nations. According to the estimation findings
6 conducted by Edmond and Boker (2019) for Africa with the VAR and GMM methods, MEX
7 exaggerate ecological degradation measured by CO₂ emissions, nitrous oxide, and methane gas.
8 Gokmenoglu et al. (2020) studied for Turkey from 1960 through 2014 by employing FMOLS.
9 According to their estimation outcomes, MEX lead to a decline in environmental quality. Using
10 CS-ARDL, Chang et al. (2023) reported that MEX have an increasing effect on CO₂ emissions
11 for 15 countries. In contrast, Ullah et al. (2021) used NARDL technique for Pakistan and India
12 from 1985 to 2018, highlighted that MEX reduce CO₂ emissions, and verified the asymmetric
13 relationships between the two variables. Konuk et al. (2023) also concluded that MEX mitigate
14 ecological degradation in G7 countries. To sum up, the first sub-research question that emerged
15 as a result of this review is as follows: How does the militarization of NATO countries affect
16 their environmental quality?

17 **2.2. Financial development and the environment**

18 The effect of FD on environmental degradation is controversial. However, two opposing views
19 can be identified in the literature. The pessimistic view of the arguments expresses that access
20 to financial sources stimulate environmental degradation because it creates an opportunity to
21 obtain the cheapest credits for consumers. Therefore, most affordable financial sources increase
22 consumption and cause intense pressure on the environment. Similarly, environmental
23 degradation increases as firms build new activities and use more inputs by access to financial
24 resources (Sadorsky, 2010). However, optimistic approaches suggest that environmental

1 pollution decreases with FD because it encourages technology investments that increase energy
2 efficiency (Abbasi and Riaz, 2016).

3 The findings of studies examining the impact of FD on the environment vary. Shahbaz et al.
4 (2013) analyzed the influence of FD on pollution for South Africa and concluded that FD
5 improves environmental quality. Similarly, Tamazian et al. (2009) inspected the effect of
6 economic growth and FD on ecological degradation in BRIC countries between 1992 and 2004
7 and found out that FD mitigates pollution. Al-Mulali et al. (2015) used FMOLS estimator for
8 18 countries, verified the presence of the EKC, and concluded that FD improves environmental
9 quality. The empirical analysis conducted by Saidi and Mbarek (2017) indicated that FD is
10 negatively associated with CO₂ emissions for 19 developing countries. Zaidi et al. (2019)
11 concluded that globalization and FD reduce CO₂ emissions in APEC countries during 1990-
12 2016.

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

17 Another strand of literature addressing the effects of FD highlights environmentally damaging
18 behavior. Esmailpour-Moghadam and Dehbashi (2018) documented that FD accelerates
19 pollution, while technological investments mitigating environmental damage in Iran from 1970
20 to 2011. Pata (2018a, 2018b) used the widely known ARDL approach and showed that FD
21 increases CO₂ emissions in Turkey. Shahbaz et al. (2020) found that both FD and income led
22 to an increase in pollution for the United Arab Emirates from 1975q1 to 2014q4, but the
23 association between FD and CO₂ emissions provides two different structures as a U- and
24 inverted-N shaped. Likewise, Destek and Manga (2021) reported that FD have a positive impact
25 on CO₂ emissions and ecological footprint in the case of Big Emerging Countries during the

1 1995-2016 period. Ahmad et al. (2022) showed that FD fosters environmental degradation, but
2 it can increase environmental quality over the 1984-2017 period for 18 developing countries.
3 In addition to these positive associations between FD and environmental degradation, Ahmad
4 et al. (2020) for 90 countries, Tahir et al. (2021) for South Asian countries, Rjoub et al. (2021)
5 for Turkey, Shen et al. (2021) for China, and Kartal et al. (2023b) for the United States revealed
6 the same results.
7 Moreover, some studies explore no substantial relationship between FD and pollution. For
8 instance, the analysis conducted by the study of Charfeddine and Kahia (2019) found a weak
9 link between FD and ecological quality in 24 countries. In Lithuania, neither the EKC nor FD
10 and CO₂ emissions link existed during 1989-2018, according to Rahman et al. (2020). Similarly,
11 Rasiah et al. (2018) for five ASEAN countries and Seetanah et al. (2019) for 12 countries
12 reported that there is no link between FD and environmental degradation. Based on these
13 studies, the second sub-research question is: What are the direct and indirect influences of FD
14 on ecological quality?

15 **2.3. Technology and environmental quality**

16 In the literature, another component of the ecological quality is the technology. Although there
17 exist mixed results in the relationship between technology and pollution, there is an extensive
18 consensus about the green impact of technology on environmental degradation. Ali et al. (2016)
19 noted that technological developments led to a decline in CO₂ emissions in Malaysia from 1985
20 to 2012. The study by Adebayo et al. (2021) showed that TEC mitigates CO₂ emissions in South
21 Korea. Adebayo et al. (2022) found out that a positive shock of TEC is negatively related to
22 CO₂ emissions in Sweden between 1980 and 2018.
23 The empirical findings of the study assessed by Rafique et al. (2020) with data of BRICS
24 countries for the period 1990-2017 indicated that TEC reduces environmental degradation.
25 Xinmin et al. (2020) analyzed the association between income, trade openness, CO₂ emissions,

1 technology innovation, and adoption in China. According to the marginal effect, trade openness
2 and technology innovation decrease CO₂ emissions. Chien et al. (2021) showed TEC negatively
3 affect CO₂ emissions in Pakistan between 1980 and 2018. Destek and Manga (2021) found that
4 nexus between TEC has non-significance link with ecological footprint, whereas TEC
5 negatively influences CO₂ emissions in 10 countries from 1995 to 2016. Erdogan (2021) found
6 that TEC has a mitigating effect on pollution in the building sector for BRICS countries between
7 1992 and 2018. Utilizing data from 1992 to 2016, Hussain and Dogan (2021) illustrated that
8 environmental technologies improve ecological quality for BRICS. Aqib and Zaman (2023)
9 confirmed that technological improvement reduces CO₂ emissions in Pakistan. Sharif et al.
10 (2023) confirmed the pollution-reducing effect of technological progress for Nordic countries.
11 Contrary to prevalent opinion, Adebayo and Kirikkaleli (2021) presented evidence that TECs
12 in Japan lead to environmental degradation. A similar finding is highlighted by Fan and Hossain
13 (2018) for China and India. Dauda et al. (2019) reported that technological development has
14 the influence of increasing CO₂ emissions for 18 countries from 1990 to 2016. In the time-series
15 examination of CO₂ emissions, Villanthenkodath and Mahalik (2022) also found that TEC
16 increase environmental destruction in India. Khan (2023) also validated the emission increasing
17 effect of technological innovations for Pakistan. Finally, the third sub-research question is: How
18 does the technological development of NATO countries affect their environmental indicators?
19 In a three-part, extensive literature review, it appears that there is no consensus among
20 researchers on the ecological impacts of MEX, FD, and TEC. The key findings from the
21 literature are shown in Fig. 2.

22

23

<Insert Figure II here>

24

1 Fig. 2 summarizes the findings of studies in the literature. Seven of 10 studies find that MEX
2 have an increasing effect on CO₂ emissions. In terms of FD, 13 out of 24 studies show that FD
3 plays an environmental role. Technological progress provides environmental benefits in 10 out
4 of 16 studies. As can be seen from the literature, the main results indicate that MEX worsens
5 environmental quality, while FD and TEC play a helpful role in CO₂ reduction, although the
6 studies contain different results.

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

15 **3. Data and methodology**

16 **3.1. Data**

17 The study applies annual data for 15 NATO member countries for the period 1991-2018. Based
18 on these data, CO₂ emissions is regressed with per capita gross domestic product (GDP),
19 military expenditures (MEX), per capita energy consumption (EC), technology (TEC), and
20 financial development (FD). The sources, units of measurement, and definitions of the data are
21 listed in Table 1.

22 *<Insert Table I here>*

23

1 For testing the impact of MEX on CO₂ emissions concurrently with technological development
2 and FD, the study analyzes both TEC*MEX and FD*MEX interaction terms. The modeling
3 performed on this basis is shown in Eq. (1).

$$\begin{aligned} 4 \quad \ln CO_{2,it} = & \alpha_0 + \alpha_1 \ln GDP_{it} + \alpha_2 \ln MEX_{it} + \alpha_3 \ln EC_{it} + \alpha_4 \ln TEC_{it} + \alpha_5 \ln FD_{it} \\ 5 \quad & + \alpha_6 \ln TEC * MEX_{it} + \alpha_7 \ln FD * MEX_{it} + e_t \end{aligned} \quad (1)$$

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

16 **3.2. Methodology**

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

24 *<Insert Figure III here>*

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

7 **3.2.1. CADF unit root test**

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

$$10 \quad \Delta \text{GDP}_{it} = \delta_i + \beta_i \text{GDP}_{it-1} + \alpha_i \overline{\text{GDP}}_{t-1} + \sum_{j=0}^p \varphi_{ij} \Delta \overline{\text{GDP}}_{it-1} + \sum_{j=0}^p \varphi_{ij} \text{GDP}_{it-1} + e_{it} \quad (2)$$

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

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

$$18 \quad \text{CIPS} = N^{-1} \sum_{i=1}^n t_i(N,T) \quad (3)$$

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

$$21 \quad H_0: \beta_i = 0 \text{ for all } i, \quad H_1: \begin{cases} \beta_i < 0, & i = 1, 2, 3, \dots, N_1 \\ \beta_i = 0, & i = N_1 + 1, \dots, N \end{cases}$$

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

1 3.2.2. Durbin- Hausman cointegration test

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

$$8 \quad DH_{panel} = \hat{s}_n(\varphi_1 - \varphi_2)^2 \sum_{i=1}^N \sum_{t=2}^T \hat{e}_{i(t-1)}^2; DH_{group} = \sum_{i=1}^N \hat{s}_i(\varphi_{1i} - \varphi_{2i})^2 \sum_{t=2}^T \hat{e}_{i(t-1)}^2 \quad (4)$$

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

12 3.2.3. Cross-sectionally augmented ARDL

13 The CS-ARDL is an extended version of Pesaran et al. (1999) using the pooled mean group
14 estimator and has a structure that includes a cross sectional mean, a long-term parameter, and a
15 short-term parameter with an error correction coefficient for each variable. The CS-ARDL
16 developed by Chudik et al. (2013) and Chudik and Pesaran (2015) accounts for CSD and
17 heterogeneity phenomena by including dynamic common correlated effects in the analysis. This
18 approach is also effective against potential problems such as serial correlations and endogeneity
19 (Zeqiraj et al., 2020). To eliminate the influence of unobserved common factors in the CS-
20 ARDL estimation, the individual regressions are augmented with cross-sectional averages
21 (Chudik, 2016). In the CS-ARDL approach, the estimated coefficients based on the mean group
22 are also unbiased in the cases where $N \rightarrow \infty$ and $T \rightarrow \infty$. In Eq. (5), the CS-ARDL estimator
23 first calculates the short-run elasticities and then uses these coefficients to derive the long-run
24 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 (CO₂ 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 elasticities 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):

$$\begin{aligned} \Delta Y_{i,t} = & \beta_i + \phi_i (Y_{i,t-1} - \omega_i X_{i,t-1}) + \mu_{ji}^* \sum_{j=1}^{ay-1} \Delta Y_{i,t-j} + \alpha_{ji}^* \sum_{j=0}^{bx} \Delta X_{i,t-j} + \gamma_i \sum_{j=1}^c \overline{Y_{i,t-j}} \\ & + v_i \sum_{j=0}^d \overline{X_{i,t-j}} + \rho_i \sum_{j=1}^{c-1} \overline{Y_{i,t-j}} + \sigma_i \sum_{j=0}^{d-1} \overline{X_{i,t-j}} e_{i,t} \end{aligned} \quad (7)$$

where $\phi_i = -(1 - \sum_{j=1}^{ay} \mu_{ij})$ 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, μ_{ji}^* and α_{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, CO₂ 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

1 characterized as the effect of a shock that may occur in energy, finance, technology, military,
2 and various sectors in one nation and affect other nations. In this case, traditional panel tests
3 that do not consider heterogeneity and CSD can lead to biased results.

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

6 The results of the LM and CD_{LM} tests of Breusch and Pagan (1980), LM_{adj} test of Pesaran et al.
7 (2008), and weak CD test of Pesaran (2015) indicate that the null hypothesis of no CSD is
8 rejected for all series. In this case, there is a pass-through between shocks between countries.
9 In addition, the p-values of the Δ and Δ_{adj} tests of Pesaran and Yamagata (2008) indicate that
10 the slope coefficient is heterogeneous. Therefore, the study uses second-generation panel unit
11 root and cointegration tests that consider CSD and heterogeneity.

12 *<Insert Table III here>*

13
14 Table 4 presents the results of the panel CADF and CIPS unit root tests. The CADF test statistics
15 illustrate that FD and FD*MEX are stationary at the level. The other six series contain a unit
16 root. These series become stationary at their first difference. The results of the CIPS reveal that
17 MEX, FD, and FD*MEX are stationary. CO₂, GDP, EC, TEC, and TEC *MEX contain a unit
18 root. In other words, MEX, FD, and FD*MEX are found to be stationary at level, while the
19 other series are stationary at first difference. Therefore, the study uses the DH cointegration test
20 and CS-ARDL estimator, which allows for different orders of integration ((I(0) & I(1)) and
21 considers the CSD.

22 *<Insert Table IV here>*

23

1 After investigating the stationarity of the variables, the study tests the long-run associations
2 with the DH cointegration test and presents the outcomes in Table 5. The statistics and
3 probability values of the panel and group test prove that the null hypothesis is rejected at the
4 1% significance level.

5 *<Insert Table V here>*
6

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

10 *<Insert Figure IV here>*
11

12 In the final stage, the study estimates elasticities using the CS-ARDL method. The CS-ARDL
13 approach provides the short- and long-term coefficients and the short- and long-term cross-
14 sectional means of each variable together (Usman et al., 2022). This approach estimates the
15 long-term coefficients by means of individual short-term coefficients obtained by least squares
16 estimation (Chudik et al., 2013). The CS-ARDL approach, which is based on the ARDL of
17 Pesaran et al. (2001), decomposes the short- and medium-term coefficients using multiplier
18 matrices. Table 6 report the outcomes of the CS-ARDL estimator. Since the logarithmic values
19 of the variables are considered, the coefficients express elasticities of CO₂ emissions with
20 respect to the independent variables. A 1% augment in the technology level stimulates CO₂ by
21 1.2% and 0.6% in the short and long term, respectively. The underlying reason for this could
22 be the increase in production and consumption of polluting products in the member nations of
23 NATO when the technology level increases. This finding supports the results of Fan and
24 Hossain (2018), Adebayo and Kirikkaleli (2021), and Villanthenkodath and Mahalik (2022).

1 Adebayo and Kirikkaleli (2021) reported that TECs increase CO₂ emissions in Japan, which
2 could be due to the country's failure to increase investment in green technologies. Similarly,
3 Villanthenkodath and Mahalik (2022) stated that in the process of India's economic
4 development, less importance is given to eco- friendly innovations and therefore technological
5 development emits pollution. Since NATO countries do not primarily transfer their
6 technological developments into green investments, technological advancement may lead to a
7 rise in pollution.

8 A 1 % rise in per capita income increases CO₂ emissions by 0.5 percent in the short term and
9 0.2 percent in the long term. This finding indicates that in the assessed country group, wealth-
10 generating activities are conducted in a manner that harms the environment. However, since
11 long-term GDP coefficients are smaller than short-term coefficients, the EKC hypothesis is
12 valid. This finding confirms previous research of Shittu et al. (2021) and Pata and Hizarci
13 (2022). In addition, the results imply that a 1 percent increase in EC raises emissions by 0.6%
14 and 0.3% in the short and long term, respectively. This is the foreseeable conclusion for NATO
15 countries whose energy portfolios are still dominated by fossil fuels. Our findings are
16 compatible with studies of Usman et al. (2019), Khan et al. (2021a), and Sheraz et al. (2021).

17 There are indications that FD benefits the environment. A 1% augment in the FD mitigates CO₂
18 emissions by 1.1% in the short term and 0.5% in the long term. The emission-reduction effect
19 of FD suggests that the financial sector works successfully in supporting green transformation
20 and gives funding assistance for the necessary researches required to produce environmentally
21 friendly technology. In contrast to Pata (2018a, 2018b), Shahbaz et al. (2020), Ahmad et al.
22 (2022), the eco- friendliness of FD supports the results of Tamazian et al. (2009), Al-Mulali et
23 al. (2015), and Zaidi et al. (2019).

24 Consistent with the overall objective of the study, it is discovered that the coefficient
25 representing the effect of MEX on the emission level is, as anticipated, positive. The primary

1 explanation for this result is because the defense industry is one of the industries that consumes
2 the most fossil fuels. The conclusion that MEX trigger pollution is compatible with Clark
3 (2009), Edmond and Boker (2019), and Gokmenoglu et al. (2020).

4 Table 6 also presents the interaction effects of FD and technological advancement with MEX.

5 It is intriguing to note that when the parameters of the interaction variables are examined, the

6 direct impacts of the variables (FD and TEC) are inverted. First, the negative value of the

7 TEC*MEX interaction variable implies that MEX may lower CO₂ emissions in NATO

8 countries as a result of technological advancement. In another sense, defense investments

9 contribute to environmental quality in countries with relatively high technology levels. This is

10 due to the fact that the defense industry is the most technologically intensive industry in any

11 country. It is well-known that no matter how much money is spent on technological R&D in

12 the defense industry, the outputs of these investments spill over to other industries via the

13 technological spillover effect. If this diffusion leads to green innovation initiatives,

14 environmental quality may benefit. In contrast, the FD*MEX interaction term has a positive

15 effect. This finding indicates that, if the financial sector develops in NATO countries, MEX

16 may have adverse environmental repercussions. In other words, MEX in NATO nations with

17 more robust finance sectors are detrimental to the environment. The primary reason for this

18 situation is that defense industry companies, which in recent years have begun to reduce public

19 dominance in the defense industry by acquiring funds from financial markets, prioritize military

20 superiority production over energy-efficient production in the production of military

21 equipment. In short, while the moderating influence of technology progress is relevant for

22 NATO members, FD does not mitigate the adverse environmental impact of MEX.

23 *<Insert Table VI here>*

24

1 Fig. 5 visually summarizes the CS-ARDL results, which show that MEX, EC, technological
2 development, and the orientation of the financial sector toward MEX cause environmental
3 pressure. On the contrary, overall FD and technological development in the military sector
4 contribute to the ecological quality. Similarly, an increase in income reduces CO₂ emissions in
5 the long-run because the EKC hypothesis is valid in NATO countries. Due to a lower long-run
6 income elasticity than in the short-run, the increasing effect of income on CO₂ emissions is less
7 in the long-run, which reduces environmental degradation. Moreover, the TEC*MEX
8 interaction term can reduce CO₂ emissions, while FD*MEX causes an increase in
9 environmental pressure. For this reason, NATO countries should take advantage of
10 technological development to reduce the harmful environmental effects of militarization and
11 not use FD as a policy tool that can limit the environmental damage of MEX.

12 *<Insert Figure V here>*

13
14 Finally, the study performs Dumitrescu and Hurlin (2012) causality test to check the robustness
15 and reliability of the findings. Following Agozie et al. (2022), Chen et al. (2022), and Hassan
16 et al. (2022), the causal links between CO₂ emissions and the interaction terms are also tested;
17 the findings are shown in Table 7.

18 *<Insert Table VII here>*

19
20 Table 7 shows that that there is a unidirectional causality relationship from MEX and FD*MEX
21 to CO₂ emissions and bidirectional causality links for all other analyses. In other words, the
22 increase in environmental degradation does not affect MEX and the interaction of FD and MEX,
23 while the increase in CO₂ has an impact on macroeconomic indicators such as GDP, energy
24 consumption, technological development and FD. Moreover, the fact that GDP, MEX, EC,

1 TEC, FD and interaction terms have causal associations with CO₂ emissions verify the findings
2 of the CS-ARDL test. Based on these results, NATO countries should consider the financial
3 and technological aspects of MEX in their environmental policies.

4 **5. Conclusion and policy recommendation**

5 **5.1. Conclusion**

6 In 2021, members of NATO adopted a Climate Change and Security Action Plan to address
7 climate change at the military and policy levels (NATO, 2022b). At the COP26, NATO allies
8 also committed to supporting net-zero emissions targets in military emissions reductions and
9 defense planning. Given the current environmental efforts of NATO countries, this study aims
10 to analyze the moderating role of technological progress and FD in the impact of MEX on
11 environmental degradation under the EKC hypothesis. The findings can be summarized as
12 follows: (i) The long-run elasticities of GDP are less than the short-run ones, indicating the
13 validity of the EKC. (ii) EC, MEX, and technological development increase pollution. (iii) FD
14 plays a role in reducing CO₂ emissions. (iv) Technological development has a role to moderate
15 the harmful environmental effects of MEX, while FD has no such effect in the military sector.

16 **5.2. Policy inferences**

17 The findings of this study provide crucial policy recommendations for NATO countries to
18 address climate change and reduce CO₂. The validity of the EKC shows that income growth in
19 NATO countries can help minimize environmental problems. For this reason, NATO countries
20 should align their economic expansion with environmental growth models by taking advantage
21 of techniques and composition effects and by putting their economic resources into
22 implementing environmental policies that promote clean energy types, environmentally
23 conscious education programs, and energy efficiency activities. Energy consumption negatively
24 influences environmental conditions in NATO countries. NATO aims to enhance energy
25 efficiency and the utilization of renewable energy in its operations (Bocse, 2020). NATO seeks

1 to reduce environmental pressure by integrating smart grids that use renewable resources into
2 military platforms, thereby reducing the use of conventional fossil fuels (NATO, 2022b). In
3 addition, NATO has established The Specialist Team on Energy Efficiency and Environmental
4 Protection to increase energy efficiency and provide solutions. Together with all these
5 appropriate steps, the findings of our study emphasize the necessity of reducing the weight of
6 polluting fossil fuels in energy use in NATO countries with environmental policies such as
7 monitoring energy use in military camps, carbon tax, and renewable energy incentives.

8 Militarization of countries from NATO increases environmental degradation. High MEX are
9 closely related to various environmental and sociocultural problems such as air pollution, access
10 to electricity and drinking water, infant mortality, and low life expectancy (Elgin et al., 2022).
11 NATO has high MEX and military equipment, weapons, and construction increase demand for
12 fossil fuels. Even without war, military transportation activities lead to an expansion of CO₂
13 emissions from fossil fuel use. For this reason, NATO countries must use cleaner energy
14 sources and production technologies in military activities to combat climate change. Above all,
15 the use of clean technologies should be encouraged in military activities. For example, using
16 well-equipped unmanned aerial vehicles can reduce the need for military personnel and energy
17 sources that consume large amounts of energy.

18 Technological innovations in NATO countries negatively affect environmental quality as a
19 whole. This could be due to the fact that NATO countries do not adequately transform their
20 technological progress into clean and green investments. NATO countries should invest in
21 green technologies to meet their CO₂ emission reduction targets. A review of the moderating
22 effect shows that technological development helps to moderate the harmful effects of
23 militarization on the environment. NATO's Science and Technology Organization promotes
24 scientific research activities related to environmental issues (NATO, 2022b). Technological
25 developments in the military field should be supported by governments to create a more

1 sustainable ecosystem. To this end, governments and companies can increase the share of clean
2 energy technologies and green innovation capabilities in R&D expenditures. To this end,
3 governments of NATO countries should provide tax incentives and low-cost funding
4 opportunities for scientific research to develop technological improvements. In addition,
5 coordination between the public and private sectors should be strengthened with a view to
6 establishing a common technology policy. In addition, NATO countries can encourage
7 scientific research funding for technological advances that favor the use of green fuels in the
8 military sector.

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

23 **5.3. Limitations and future directions**

24 In light of the findings and policy recommendations, we discussed the influence of various
25 factors on CO₂ emission reduction policies in NATO. Future works can analyze the impact of

1 other factors such as education, urbanization, geopolitical risk, democratization, and nuclear
2 energy on environmental degradation in NATO countries. In addition, further researchers can
3 focus on broader environmental indicators in NATO countries, such as ecological footprint and
4 load factor, to provide a comprehensive environmental assessment.

5 Although this study makes an crucial contribution to the field, it has some limitations. First,
6 only the CO₂ indicator is employed as the basis for considering the environmental implications
7 of MEX. Indicators such as a larger ecological footprint or load capacity factor can be used in
8 addition to CO₂ emissions as a basis to examine the link more consistently. Second, the study
9 only examines how MEX affect NATO countries' environments. However, it is well known
10 that there has been significant MEX in recent years, particularly by China and Russia. This
11 study can therefore be expanded with examples of nations that allow for comparison. MEX,
12 technological advances, or FD in other countries, which are significant in terms of global
13 military investment, may also affect NATO countries' environmental indicators. Hence, future
14 research can use the novel cross-panel data approaches as suggested by Zaman (2023b).

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