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Asymmetric Effects of the Defense Burden on Environmental Degradation: Evidence from NATO Countries

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Abstract: Rapid industrialization tends to occur at the expense of natural resources. Thus, countries are inclined to control natural resources for their development objectives, which may create conflicts when countries allocate scarce resources to national defense. As a major military block, NATO poses a potential threat to environmental degradation, as it comprises large industrialized arms manufacturers and military spenders. Therefore, the aim of this study is to investigate the asymmetric effects of the defense burden on environmental degradation, which has rarely been studied in the empirical literature. Panel ARDL and NARDL methodologies were used to analyze the period 1965–2018 for the 15 oldest members of NATO. The findings of the panel ARDL analysis do not indicate any significant effect of the defense burden (ME) on carbon dioxide emissions (CO_2) in the long term. On the other hand, panel NARDL analysis indicates that the effect of the defense burden on carbon emissions is asymmetric; a 1% negative change in ME leads to a 0.08% drop in CO_2 emissions in the long term. In line with these findings, the results of panel causality tests verify the validity of the treadmill of destruction theory.

Keywords: environmental degradation; defense burden; panel ARDL; panel NARDL; panel causality

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1. Introduction

Carbon emissions are the result of the use of fossil fuels to generate the energy required for production. They lead to the greenhouse effect, causing radiation that would be returned to space to remain in the atmosphere. Increasing carbon emissions since the industrial revolution, together with other greenhouse gases such as methane (CH4), (HFCs), and sulfur hexafluoride (SF6), have been the main cause of hydrofluorocarbons climate change and environmental crises. Considering that climate change occurs with the interaction of three important parameters—economy, energy, and environment—the best way to prevent climate change and to minimize its negative effects is to reduce anthropogenic greenhouse gas emissions [1].

To mitigate the adverse impacts of greenhouse gas emissions, global initiatives have been undertaken by industrialized countries such as the Montreal Protocol, the United Nations Framework Convention on Climate Change (UNCC), the Kyoto Protocol, the European Union (EU) Green Deal, and the Paris Agreement. The Montreal Protocol, which required 196 countries to stop the production of substances that damage the ozone layer, is considered to have been the most successful multilateral agreement on the environment [2]. The Kyoto Protocol, signed within the framework of the UNCC, foresees developed countries reducing their gas emissions by 5% compared to levels in 1990, and to reduce their emission values for an average of five years [3]. The Paris Agreement is the only globally legally binding monitoring agreement and, unlike the Kyoto Protocol, it lays a burden for not only developed countries, but the rest of the world as well. The effect of the Paris Agreement was immediately apparent in Europe. It stipulates conserving the universal mean temperature to 2 °C above pre-industrial standards to restrain climate change [4]. With the EU Green Deal, EU countries aim to reduce carbon emissions by 55% by 2030 and to transform the European economy in order to become a "carbon-free continent" by 2050 [5]. Similarly, China is seeking to reach its highest carbon emission by 2030 and to achieve carbon neutrality by 2060 [6]. As calculated by the Intergovernmental Panel on Climate Change, 76% of the gases causing climate change are CO_2, 16% are methane and 6.2% are nitrous oxide gases; therefore, respectively [7]. Therefore, as an essential element of greenhouse effect, analyzing the effects of the defense burden and energy use on CO_2 emissions would contribute to the literature on climate change.

The effects of climate change and the desire to leave a more livable world to future generations have led to the idea that countries cannot exist only with economic growth, but also must be involved in a multi-faceted transformation process [8]. Calculations that global material use will increase from 89 gigatons to 167 gigatons between 2017 and 2060 and that gas emissions causing global warming will increase accordingly have caused a change in perspectives on the concept of sustainability. Brutland's motto of "producing more with less" has evolved into a different growth concept with the internalization of externalities; in this way, responsibility is placed on countries that growth in use of resources and production be realized without harming the environment. Thus, having first been introduced in 1987 in the report of the World Commission on Environment and Development titled "Our Common Future", sustainability has been defined by the Global Sustainability Development Report (2019) and become a more grounded concept [9].

To achieve development objectives, countries aim to achieve greater industrialization. With the unprecedented pace of industrialization in recent decades, pressures on natural resources have emerged that are being widely discussed by environmental scientists and policy makers. In order to control natural resources, countries tend to spend on their military operations. Those military operations bear potential risks to the environment due to their excessive depletion of natural resources. Furthermore, those environmental risks do not necessarily emerge in warfare. For instance, construction of military bases might occur at the expense of the destruction of forest areas, gasoline consumption may result in air pollution due to the deployment of military personnel by vehicles, and ammunition and personnel waste are associated with environmental pollution. These are some potential cases of militarization resulting in environment degradation. According to the Stockholm International Peace and Research Institute (SIPRI), worldwide military expenditures have reached their greatest historical level and accounted for 2.4% of the world's GDP in 2020. The top fifteen military spenders accounted for 81% of global military spending, at USD 1603 billion, in 2020. The leading country in military spending is the United States of America (USA) at USD 778 billion, followed by China, India, the Russian Federation, and the United Kingdom (UK) [10].

In 1949, after World War II, the North Atlantic Treaty Organization (NATO) was established to ensure the territorial integrity of member states and solve political and military disputes between them. In addition to its general mission regarding the security issues of member states, NATO has also taken various actions to address sustainability issues since the end of 1960s. In this respect, the earliest attempt was the 1969 establishment of the Committee on the Challenges of Modern Society (CCMS), which was designed to initiate and support studies and fellowships to deal with all forms of pollution and disposal of hazardous wastes. Nonetheless, essential actions have been accelerated by the turn of the new millennium, with the rapidly growing interest in climate change and environmental concerns, as demonstrated by UN initiatives. In 2006, CCMS evolved as the Science for Peace and Security Plan to execute initiatives dealing with environmental security challenges. Among the most notable initiatives was the introduction of the Smart Energy Initiative, which calls for energy efficiency and innovative technologies to maintain the operations of the alliance. In addition, the concept of "Green Defense Framework" was ratified by the member states at the Wales Summit in 2014 [11]. In 2021, militarization and the environmental crisis were an "important issue" within the framework of the Climate Change and Security Action Plan [12]. In addition, this situation is also considered in Brussels Submit of NATO in 2021. In the final declaration of the Submit, heads of states and governments committed to reduce greenhouse emissions to zero by 2050 [13]. However, the current position of NATO regarding environmental issues is mainly built upon awareness, information sharing, education and training activities of troops, and helping member states in the light of their own regulations and measures.

On the other hand, studies of defense economics have mainly addressed the macroeconomic effects of militarization, either theoretically or empirically, despite the presence of recent growing interest in environmental concerns. This article aims to empirically analyze the relationship between militarization and environmental degradation in terms of the treadmill of destruction theory, both symmetrically and asymmetrically, for the 15 oldest NATO countries over the period 1965–2018. The treadmill of destruction theory suggests that countries with more labor-intensive and cutting-edge technologies demand more natural resources. There are two basic motivations worth highlighting for this study. The first motivation is directly related to the purpose of this study. This paper aims to fill gaps in the literature in various aspects. First of all, it is a preliminary attempt to empirically address the asymmetric effects of militarization on environmental degradation, giving special focus to NATO. In other words, it differs from all studies in the literature, as it deals with the relationship between defense expenditures and the environmental degradation for NATO member countries from an asymmetrical point of view, which allows the observation of both sudden changes in military expenditures on environmental degradation and asymmetric long-term cointegration. In fact, NATO deserves special attention, since it accounted for 55% of global military expenditure in 2020 [10]. It should also be noted that six countries (the list of the countries by expenditure level is as follows: United States of America (USA), United Kingdom (UK), Germany, France, Italy, and Canada) of the top fifteen military spenders are members of NATO. Furthermore, four member states of NATO (the USA, Germany, Canada, and Turkey) were among the top fifteen CO_2-emitting countries in the world in 2020 [14]. Since NATO, which has focused on many security issues since the Cold War period, has recently focused on environmental degradation as creating a possible global security problem, this study, as among a few militarization and environmental studies, focuses on the subject in regard to NATO. In addition, our empirical investigation is limited to fifteen member states of NATO. Most of the countries in the sample are regarded as the founders of the alliance. Accordingly, these 15 countries are the top military spenders and top carbon emitters. Although NATO is an alliance between the member states, some members have engaged in arms races with each other. Greece and Turkey are members that have a significant defense burden due to historical and ongoing geopolitical conflicts with each other.

The second motivation for this paper lies on the methodology used throughout, which is relatively a novel approach and thought to fill a gap in the empirical literature. Except for Ullah et al. [15], the majority of empirical studies have examined the effect of militarization on environmental degradation in a linear context. Our study aims to detect asymmetric effects for a relatively broader group of countries that are considered as contenders in terms of arms races and are top emitters globally. To the best of our knowledge, this goal has not been specifically addressed in the empirical literature thus far. This study also aims to contribute a new dimension to the literature by integrating the effects of changes in the defense burden into a long-term relationship within the scope of the treadmill of destruction theory. Within the context of time-series analysis, an autoregressive distributed lag (ARDL) approach to cointegration presents some advantages. First of all, ARDL generates efficient results with small sample sizes. Secondly, the variables can be integrated by different orders. Finally, the inclusion of an error correction model integrates short-term dynamics into the long-term equilibrium model [16]. In addition to these advantages, NARDL methodology allows for examining the asymmetric interplay by decoupling the variables into positive and negative components when generating the effects of changes. The selection of the sample period is mainly dictated by the availability of data on carbon dioxide emissions and primary energy use, which were gathered from British Petroleum's (BP) Statistical Review Database. It should also be noted that the sample period was selected to be long as possible in order to efficiently analyze the time-series characteristics of the data with respect to the availability of data for those countries.

In line with the aforementioned arguments, the layout of the present paper is as follows. The Section 2 presents the theoretical arguments on the nexus of militarization and the environment. The Section 3 is devoted to a literature review, in which we present theoretical and empirical studies, giving special focus to militarization and the environment. In the Section 4, we present our model and empirical strategies, and discuss the data issues. In accordance with the modeling and our empirical strategy, we present the findings of our estimations in the Section 5. Finally, in the Section 7, we terminate our paper with concluding remarks and policy recommendations.

2. Theoretical Arguments

This study is driven by the impulse to understand how energy use in defense production is harmful to the environment by determining the links between environmental degradation, defense expenditures, and energy consumption. Countries are bound by climate change-related reports and agreements, and the awareness of citizens of carbon emissions and environmental pollution has forced countries to be more environmentally-friendly in energy production and use. Although there has been a decrease in energy production and consumption due to the COVID-19 pandemic over the last three years, the CO_2 concentration in our atmosphere has increased from 280 to 415 ppm over the last thirty years, and CO_2 emissions due to energy consumption increased by 4.8% in 2021 [14].

The unprecedented pace of rapid industrialization since the Industrial Revolution has led countries to endeavor to dominate energy resources. In this context, the 20th century has witnessed power struggles in the international security system to ensure energy supplies. Jorgenson [17] links this fact with the concept of "military coercive power", which has two main strands. The first strand mainly addresses the ability and desire of countries to allocate budgetary resources to militarization. Even though the share of the public budget used military expenses tends to increase in wartime, during peacetime, countries may upgrade defense systems and military structures. The augmentation of these systems and structures not only requires more budgetary allocations, but also require more energy resources [18]. For instance, the US Department of Defense (Pentagon) is the world's largest consumer of petroleum-based energy, and its overall emissions of waste, fossil fuels, and other greenhouse gases are more than the sum of Sweden, Denmark, and Portugal [19]. According to the European Defense Agency, the defense institutions of the EU member states make significant use of energy within the Union and are seeking sustainable energy models, as the majority of those countries are overwhelmingly net importers [20]. Despite the introduction of cutting-edge technologies in the arms industry, the demand for energy is continuously growing. Although sustainable renewable energy models are being widely discussed in all countries, especially in the UN and NATO, there is no way for countries to realize these models in the short term except for their own military bases and personnel. According to the United Nations Environment Program, a military mission within the UN structure usually takes between six months and a year, while it takes up to five years to cover the costs of relatively expensive renewable energy elements [21]. Thus, short-term analyses do not work efficiently for planning energy and military elements. In addition, Jorgenson argues that another strand of military coerciveness stems from the level of military technology, which is captured by military spending per soldier [17]. Higher military spending per soldier is an indication of military technology, which is associated with research and development activities and procurement of military defense products despite the larger ecological footprint [17,22–24].

Indeed, militarization is among the most important anthropogenic factors causing environmental degradation [25] due to the destruction of forest areas to construct military bases, the adverse impacts on ecosystems associated with military demonstrations, and ammunition and personnel waste, along with pollution stemming from the deployment and shipment of military personnel and assets. These examples illustrate the sociology-based "treadmill of destruction" theory and great portion of the studies in this field draw attention to the high-intensity and causal relationship between militarization and environmental degradation, e.g., [26–32]. According to this theory, the dynamics of militarization in themselves can harm nature, and countries that want to become stronger damage the environment in many different ways by spending more on their militaries and defense [27]. Larger bases and production areas also require more natural resources, causing more damage to ecosystems [29]. In the struggle to be stronger, there is no need to harm the environment. An asymmetric study on warfare conducted on 126 countries between 2000 and 2010 predicted that extensive carbon emissions and environmental degradation is associated with higher militarization [32]. The destruction caused by militarization can occur not only through war, personnel, and armaments, but also through economic effects caused by production, international trade, and/or institutions; see [31,33]. The economic effects, especially those triggered by war, form depending on capital-intensive technology and cause multiple and joint negative effects on the environment, such as diminution of natural resources, augmentation of waste, and the release of toxic substances [26]. While the direct environmental effects of militarization such as bombing and destruction manifest themselves in the short term, effects such as the reduction in forests, pollution of soil and water, decreases in production, and waves of migration manifest themselves in the long term. Since climate change is a long-term phenomenon, its relationship with militarization should be evaluated in the long term.

3. Relevant Literature

Even though there is an extensive body of literature in the area of defense economics addressing the economic effects of military expenditure, studies that examine the effects of military expenditure on environmental sustainability are relatively scarce, despite recently growing interest. In this context, we present the findings of some prominent empirical studies that focus on the nexus of militarization and environmental sustainability. However, the findings of these empirical studies vary due their selection of methodology, sample period, and units. Accordingly, the bulk of these studies were inspired by earlier pioneering attempts [17,27–29,34,35] that argued for the impact of militarization on environmental and sociological grounds.

Earlier empirical efforts aimed to reveal the impacts of militarization on environmental degradation within the context of political economy by accounting for sociological aspects as well. In this context, Jorgenson [17], Jorgenson and Clark [34], and Jorgenson et al. [35] argued for the role of militarization in expanding the ecological footprints of nations within the context of the treadmill of production and the treadmill of destruction theories. Jorgenson [17] analyzed the effects of international power on the ecological footprint of nations by dividing international power into economic power, coerciveness, and dependence on exports. The results of standard cross-sectional regressions revealed that military technological power and dependence on exports have detrimental effects on a nation's ecological footprint, whereas capital intensity has both direct and indirect effects driven by military power, urban population, domestic income inequality, and secondary education. Jorgenson and Clark [34] analyzed the effect of militarization on ecological footprint by incorporating the panel data set of 53 developed and less-developed countries over the period 1975–2000. Utilizing a random-effects estimator, the results indicate that the per capita ecological footprint of a nation is highly dependent on per capita GDP and military expenditure per soldier. Hence, these findings firmly confirm the treadmill of production and treadmill of destruction theories. Likewise, Jorgenson et al. [35] examined whether the treadmill of destruction theory was valid for 72 countries between 1970 and 2000. The conventional panel data estimates (fixed effects estimator) suggest that militarization has directly positive effects on environmental degradation. By incorporating an annual panel dataset covering 68 countries over the period 1970–2000, Clark et al. [36] validated the treadmill of destruction theory and detected a positive interplay between defense expenditures and energy consumption. They also identified the link between militarization, energy use, and environmental damage from the fuel consumption of military elements. In line with our arguments in this present study, Reis et al. [37] adopted a different method, touching on the relationship between militarization and carbon footprint. Based on systematic literature review and case study researches, the authors find that European Union defense industry plays a crucial role on circular economy.

Some studies examine this relationship in terms of individual countries by employing various time-series methods. To this end, in a relatively earlier attempt, Reuveny et al. [38] drew attention to the destructive effects of militarization and energy use in the USA between 1980 and 2000. Their findings tended to support the treadmill of destruction theory, so that deforestation was associated with increases in conflicts and mass production. For the USA, Bildirici [39] analyzed the effects of militarization on carbon dioxide emissions by employing a bounds test approach to cointegration over the period 1960–2013. The findings showed that, together with economic growth and disposal of energy, militarization has an intensifying effect on CO_2 emissions. In addition, the findings of causality tests verified the presence of unidirectional causality from CO_2 emissions to militarization, as well as bidirectional causality. By employing the same methodologies, Bildirici [40] derived similar findings for the USA economy between 1984 and 2015. Solarin et al. [41] discussed the role of energy consumption and military expenditures on CO_2 emissions for the USA and highlighted the crucial role of militarization in environmental degradation. Ahmed et al. [42] uncovered a long-term interplay between energy consumption, military expenditure, and environmental degradation in Pakistan between 1971 and 2016 by employing novel cointegration tests and bootstrap causality tests. In addition to militarization, Gokmenoglu et al. [43] also investigated the role of financial development on environmental degradation and ecological footprint in Turkey, which is among the leading military spenders in NATO. Incorporating annual data spanning from 1960 to 2014, they employed the FMOLS estimator to find the magnitude and direction of the long-term coefficients. Overall, the findings support the treadmill of destruction theory for Turkey.

Ullah et al. [15] investigated the asymmetric effects of militarization on economic development and environmental degradation for Pakistan and India, which are competing in arms and industrialization, and have extensive disputes over the Kashmir issue. By employing the NARDL model for the period 1985–2018, the authors uncovered the presence of an asymmetric relationship between militarization and environmental degradation for both countries. In this case, a 1% decrease in militarization tended to alleviate carbon emissions by 0.225% in Pakistan, whereas carbon emissions tended to diminish by 0.337% in India for the same decrease. Using a novel empirical approach, Wang et al. [44] scrutinized the influence of militarization on crude oil dependency and CO_2 emissions for 11 crude oil net importing countries between 1990 and 2019. The results of Fourier ARDL (FARDL) methodology underlined that, as the largest crude oil consumers, only China and India exhibit a cointegration relationship between crude oil dependence, CO_2 emissions, and militarization. Strikingly, among the developed countries, only Italy displayed a cointegration relationship between dependency on crude oil, CO_2 emissions, and militarization due to its geography, energy shortage, and high crude oil dependency. For the rest of the sample, Wang et al. [44] found no cointegration relationships. Finally, in a recent paper, Erdogan et al. [45] examined the effect of militarization on environmental sustainability for Mediterranean countries over the period 1965–2019. By conducting global vector autoregression (VAR) analysis, the authors confirmed the validity of the treadmill of destruction theory. Accordingly, an unanticipated positive change in global military expenditure tends to increase carbon emissions.

It should also be noted that there has been recent growing interest among scholars in conducting empirical analyses due to recent advances in panel data analysis. In this context, Ben Afia and Harbi [46] investigated the impacts of militarization on air pollution for 121 countries, covering the period between 1980 and 2011. By conducting instrumental variables analysis, the authors found that militarization had positive direct and indirect effects on per capita emissions for all countries. Bildirici [47] analyzed the interconnectedness of CO_2 emissions and militarization for the G7 countries by incorporating annual panel data over the period 1985–2015. In order to reveal the long-term relationship between CO_2 emissions, militarization, GDP per capita, and energy consumption, panel autoregressive distributed lag (ARDL) methodology was utilized. The findings demonstrate the long-term interplay between the aforementioned variables.

Furthermore, the findings of panel causality tests confirmed the existence of unidirectional causalities running from militarization and energy consumption to CO_2 emissions. Bradford and Stoner [48] aimed to determine the energy use and environmental effects of militarization by using CO_2 emission levels, per capita national income, city population, and military expenditures in a panel data analysis for 62 countries between 1975 and 2014, and 162 countries between 1960 and 2014. Working with a fairly large and comprehensive dataset, the authors found that countries with high military expenditures also have high carbon emissions, and that militarization has harmful environmental consequences. In a similar vein, Ben Afia and Harbi [49] examined the direct and indirect effects of militarization through the income channel for 120 countries, spanning from 1980 to 2015. Their findings suggest that military outlays tend to have positive direct and indirect effects on per capita emissions overall. Using a generalized method of moments (GMM) and structural VAR (SVAR) model, Domguia and Poumie [50] scrutinized the relationship between CO_2 and methane gases and defense expenditures for 54 African countries between 1980 and 2016. The findings exhibited the presence of positive interplay between environmental damage, militarization, and energy use. Zandi et al. [51] conducted fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) analysis for six Asian countries between 1995 and 2017, uncovering a positive and strong relationship between military expenditures, energy use, and CO_2 emissions. Finally, for South Asian countries between 1984 and 2019, Qayyum et al. [52] demonstrated the devastating effects of defense expenditures and energy use on the environment by using panel ARDL and causality tests. Dudzevičūtė et al. [53] employed Spearman correlation as well as ALM for Baltic countries, and found a positive relationship between military expenditure and energy use. However, all the studies mentioned in this section excluded the asymmetric relationships when evaluating direct effects. The development of nonlinear methods has provided a remarkable opportunity to reveal networks of relations, such as the damage to the environment from sudden military expenditures, or environmental sustainability during arms races. Therefore, this study aims to make a contribution to this field using the NARDL method.

4. Data Issues, Model Structure, and Estimation Strategy

4.1. Data Issues

This study utilizes the balanced panel data of fifteen member states of NATO (See Table A1 in the appendix for the list of the countries in the sample), spanning the period 1965–2018. The lack of available data for the new member states that joined the alliance in the late 1990s and early 2000s forced us to limit our empirical analysis to older member states of the alliance. We incorporated the annual balanced panel data for carbon dioxide emissions (CO_2), the defense burden in the percentage of military expenditure to GDP ratio (ME), and primary energy use (EN). We collected the data for the defense burden from the World Development Indicators (WDI) database of the World Bank [54], whereas the data for carbon dioxide emissions (kilotons) and primary energy use (kg of oil equivalent per capita) were compiled from the Statistical Review of World Energy database of British

Petroleum (BP) [55]. Empirical analysis was carried out using GAUSS 10 and Stata 16 software. Table 1 presents the definitions and data sources of the variables.

Table 1. List of variables and data sources.

Variables	Abbreviation	Source
Carbon dioxide emissions (kilotons) **	CO_2	BP, Statistical Review of World Energy
Primary energy use (kg of oil equivalent per capita)	EN	BP, Statistical Review of World Energy
Defense burden (military expenditure to GDP ratio, %)	ME	World Bank, WDI

Note: ** dependent variable.

Table 2 displays descriptive statistics. The standard deviation for CO_2 and EN are relatively higher due to larger differences between maximum and minimum values. The minimum values for CO_2, ME, and EN were observed in Luxembourg, while the maximum values for these variables by far were observed in the USA. It should also be noted that the variables were converted into natural logarithmic form to reduce the likelihood of skewness in the original data set in order to obtain more reliable statistical results.

Table 2. Descriptive statistics.

Variable	Observation	Mean	Standard Deviation	Minimum	Maximum
CO_2	810	576.020	1210.372	8.025	5892.213
ME	810	2.576	1.383	0.420	9.417
EN	810	9.775	19.830	0.104	96.967

4.2. Model Structure and Estimation Strategy

In line with the aforementioned empirical studies that deal with the treadmill of destruction theory, we construct our baseline model in implicit functional form as follows:

$$CO_2 = f\,(ME,\ EN) \tag{1}$$

where CO_2 is carbon dioxide emissions, which are the proxy for the environmental degradation. The right-hand-side variable ME represents the defense burden, which is measured as the ratio of military expenditures to GDP, while EN is the proxy for primary energy use. Accordingly, the baseline specification is constructed in the following equation:

$$CO_{2it} = \beta_0 + \beta_1 ME_{it} + \beta_2 EN_{it} + u_{it} \tag{2}$$

where the indices i and t denote cross-sectional units and time periods, respectively. β_0 is the drift parameter, while β_1 and β_2 are the parameters to be estimated. u_{it} denotes the conventional idiosyncratic disturbance term, which follows the i. i. d. process. In line with the theoretical arguments that support the treadmill of destruction theory, we postulate that the defense burden (ME_{it}) and energy use (EN_{it}) are positively associated with carbon dioxide emissions (CO_{2it}). In other words, the hypothesis could be postulated as in the following:

- H_0: ME_{it} and EN_{it} positively and asymmetrically influence CO_{2it}.
- H_1: ME_{it} and EN_{it} do not have significant and asymmetric influence on CO_{2it}.

In this respect, we will estimate the relationship given in Equation (2) using linear and nonlinear panel ARDL methods. In this empirical investigation, we specifically focus on the symmetric and asymmetric effects of the defense burden on environmental degradation. By adding the positive and negative partial sums of the defense burden to the linear ARDL model, we can detect the potential effects on carbon emissions of changes in the defense burden. By performing long-term analysis in the ARDL model, the variables can be integrated at different orders. As pioneered by Shin et al. [56], asymmetric relationships among the variables can be examined within the scope of the ARDL model, which was introduced by Pesaran et al. [57]. Thus, we assume the presence of symmetric effects using the following error correction model:

$$
\begin{aligned}
\Delta CO_{2it} &= \alpha_i + \gamma_{1i} CO_{2i,t-1} + \gamma_{2i} ME_{i,t-1} + \gamma_{3i} EN_{i,t-1} + \sum_{j=1}^{k} \delta_{1ij} \Delta CO_{2it-j} + \sum_{j=0}^{k} \delta_{2ij} \Delta ME_{it-j} \\
&+ \sum_{j=1}^{k} \delta_{3ij} \Delta EN_{it-j} + \pi_{1i} \overline{\Delta CO}_{2t} + \pi_{2i} \overline{CO}_{2t-1} + \pi_{3i} \overline{ME}_{t-1} + \pi_{4i} \overline{EN}_{t-1} + \pi_{5i} \overline{\Delta ME}_{t} \\
&+ \pi_{6i} \overline{\Delta EN}_{t} + \sum_{\lambda=2}^{p} \pi_{7i\lambda} \overline{\Delta CO}_{2t-\lambda} + \sum_{\lambda=1}^{p} \pi_{8i\lambda} \overline{\Delta ME}_{t-\lambda} + \sum_{\lambda=1}^{p} \pi_{9i\lambda} \overline{\Delta EN}_{t-\lambda} + u_{it}
\end{aligned} \tag{3}
$$

As argued by Ullah et al. [14], the main advantage of this setup emanates from the combination of the short-term and long-term effects into single equation [15]. In accordance with Eberhardt and Presbitero [58], the short-term effects are captured by the term Δ, which denotes the first differences of the relevant variable, whereas the bar notation denotes the cross-sectional means of relevant variables in Equation (3). The long-term dynamics are captured by the normalization of the estimates of γ_{2i} and γ_{3i} on γ_{1i}. Following Eberhardt and Presbitero [58] and Ullah et al. [15], to determine whether the defense burden has asymmetric effects on CO_2 emissions, we decoupled the defense burden into positive and negative partial sums using the following equations:

$$ME_{it}^{+} = \sum_{j=1}^{t} \Delta ME_{ij}^{+} = \sum_{j=1}^{t} \max(\Delta ME_{ij}, 0) \tag{4}$$

$$ME_{it}^{-} = \sum_{j=1}^{t} \Delta ME_{ij}^{-} = \sum_{j=1}^{t} \min(\Delta ME_{ij}, 0) \tag{5}$$

where ME_{it}^{+} represents the positive partial sums of the defense burden and ME_{it}^{-} represents the negative partial sums of the defense burden. In this respect, by using Equations (4) and (5), an asymmetric error correction representation of Equation (3) is given as follows:

$$
\begin{aligned}
\Delta CO_{2it} &= \alpha_i + \omega_{1i} CO_{2i,t-1} + \omega_{2i} ME_{i,t-1}^{+} + \omega_{3i} ME_{i,t-1}^{-} + \omega_{4i} EN_{i,t-1} \\
&+ \sum_{j=1}^{k} \gamma_{1ij} \Delta CO_{2it-j} + \sum_{j=0}^{k} \gamma_{2ij} \Delta ME_{it-j}^{+} + \sum_{j=0}^{k} \gamma_{3ij} \Delta ME_{it-j}^{-} + \sum_{j=1}^{k} \gamma_{4ij} \Delta EN_{it-j} + \tau_{1i} \overline{\Delta CO}_{2t} + \tau_{2i} \overline{CO}_{2t-1} \\
&+ \tau_{3i} \overline{ME^{+}}_{t-1} + \tau_{4i} \overline{ME^{-}}_{t-1} + \tau_{5i} \overline{EN}_{t-1} + \tau_{6i} \overline{\Delta ME^{+}}_{t} \\
&+ \tau_{7i} \overline{\Delta ME_{t}^{-}} + \tau_{8i} \overline{\Delta EN}_{t} + \sum_{\lambda=2}^{p} \tau_{9i\lambda} \overline{\Delta CO}_{2t-\lambda} + \sum_{\lambda=1}^{p} \tau_{10i\lambda} \overline{\Delta ME_{t-\lambda}^{+}} + \sum_{\lambda=1}^{p} \tau_{11i\lambda} \overline{\Delta ME_{t-\lambda}^{-}} + \sum_{\lambda=1}^{p} \tau_{12i\lambda} \overline{\Delta lnEN}_{t-\lambda} + u_{it}
\end{aligned} \tag{6}
$$

where ω_{2i}, ω_{3i}, and ω_{4i} denote the long-term coefficients, the positive and negative partial sums of the defense burden, and energy use, respectively. In a similar vein, γ_{2ij}, γ_{3ij}, and γ_{4ij} denote the short-term coefficients, the positive and negative partial sums of the defense burden, and energy use, respectively. The existence of the long-term relationship is dependent only if ω_1 has a negative value. In order to determine whether asymmetric effects of the defense burden on environmental degradation exist, we test the null hypothesis $\omega_{2i} = \omega_{3i}$. Rejection of the null hypothesis indicates that the effects of the defense burden on environmental degradation tend to be asymmetric in the long term. Likewise, rejection of the null hypothesis $\gamma_{2ij} = \gamma_{3ij}$ indicates the presence of asymmetric effects of the defense burden on environmental degradation in the short term. For heterogeneous dynamic panel data models, Chudick and Pesaran [59] proposed the dynamic common correlated effects estimator (DCCE), through which we estimated the error correction models shown in Equations (3) and (6). The major superiority of the DCCE estimator lies in the fact that it generates efficient estimates not only in the presence of cross-sectional dependency (CD) and endogeneity, but also in the presence of heterogeneity among the slope coefficients. Furthermore, the consistency of the DCCE estimator stems from the inclusion of the lags of the cross-sectional means of each variable [60].

For investigation of the causal interplay between the variables, both symmetrically and asymmetrically, we employed the panel causality test developed by Dumitrescu and Hurlin [61], in which the CD and heterogeneity of the coefficients for each unit are also considered. The following equation represents the general form of the panel causality test.

$$Y_{it} = \alpha_i + \sum_{k=1}^{K} \gamma_i^{(k)} Y_{it-k} + \sum_{k=1}^{K} \beta_i^{(k)} X_{it-k} + \varepsilon_{it} \quad (7)$$

Along with the estimation of causality between the variables both symmetrically and asymmetrically, the next session will be mainly devoted to the estimation of our NARDL model, represented by Equation (6).

5. Estimation Results

Through the aforementioned baseline specifications, our empirical analysis consists of four steps. We commence the empirical treatment by checking for slope homogeneity and CD; the relevant results are displayed in Table 3, where the upper part shows the results of homogeneity tests and the lower part shows the results of CD tests. As developed by Pesaran and Yamagata [62], the homogeneity tests firmly indicate the presence of heterogeneity by rejecting the null hypothesis of the homogeneity of the slope coefficients at a 1% significance level. In order to clarify whether cross-correlations among the variables exist, we performed CD and CD_{LM} tests, as introduced by Pesaran [63]. The results of CD tests clearly revealed the existence of cross-correlations among the variables by rejecting the null hypothesis of CD independency at a 1% significance level.

Table 3. Slope homogeneity and CD tests.

A-Homogeneity Tests	
$\widetilde{\Delta}$ Test	$\widetilde{\Delta}_{adj}$ Test
50.936 (0.000) ***	52.934 (0.000) ***
B-CD Tests	
CD Test	CD_{LM} Test
66.020 (0.000) ***	297.546 (0.000) ***

Notes: significance codes: *** $p < 0.01$. Source: authors' estimations based on World Bank and British Petroleum (BP) data.

Before proceeding to the symmetric and asymmetric panel ARDL analysis, we performed unit root tests to account for heterogeneity and CD, as pioneered by Pesaran [64]. Table 4 reports the results of the CADF and CIPS tests. The results firmly attest that the series are integrated at different orders. The series of CO_2 and ME become stationary by first differencing, whereas the series of EN is stationary at level, i.e., I (0). Thus, as argued by Pesaran et al. [57], it is feasible to utilize ARDL methodology in linear and nonlinear structures.

Table 5 provides the results of panel ARDL and panel NARDL estimates. The coefficient of the error correction term (EC) is negative in each estimate, indicating that there is a cointegration relationship between carbon dioxide emissions and other variables. According to the short-term symmetric panel ARDL estimation results, ΔEN and ΔME are positively associated with CO_2. However, in the long term, there is no significant interplay between the defense burden and CO_2 emissions, whereas primary energy use has a positive effect on CO_2 emissions. A 1% increase in EN exacerbates CO_2 emissions by 0.361. The right panel of Table 4 exhibits the estimation results of the panel NARDL model, in which we decoupled ME into positive and negative components to capture the effects of changes on carbon dioxide emissions. We also performed Wald tests so that the coefficients of ME^+ and ME^- were identical to each other to determine the presence of an asymmetric relationship between the defense burden and CO_2 emissions. The long-term Wald test statistic (WLR) confirms the asymmetry in the defense burden by rejecting the null hypothesis, in which the coefficients of ME^+ and ME^- are identical. In this respect, the short-term estimation results demonstrate that positive changes in the defense burden (ΔME^+) do not have a significant effect on carbon dioxide emissions. According to WSR, there is no asymmetric relation in the short term. However, negative changes in the defense burden tend to diminish carbon dioxide emissions. Hence, a 1% fall in ΔME^- leads to a decrease in CO_2 by 0.06%. In line with the symmetric ARDL analysis, the results of the NARDL model verify the distorting effect of rising energy use on environmental quality. A 1% increase in ΔEN tends to increase CO_2 by 0.962%. In a similar vein, the long-term asymmetric analysis confirmed the validity the ameliorative effects of a decreasing defense burden on environmental quality. Accordingly, a 1% fall in ME tends to alleviate CO_2 by 0.08%. On the other hand, the estimation results points out the positive effect of energy use on CO_2 emissions. In this respect, 1% rise in EN causes CO_2 to increase by 0.486%.

Table 4. Panel unit root tests.

	CADF Test			CIPS Test		
	I (0)	**I (1)**	**Decision**	**I (0)**	**I (1)**	**Decision**
CO_2	−2.498 (0.238)	−5.563 (0.000) ***	I (1)	−2.609	−6.312 ***	I (1)
ME	−2.401 (0.392)	−4.887 (0.000) ***	I (1)	−2.659	−6.163 ***	I (1)
EN	−2.738 (0.037) **	−4.879 (0.000) ***	I (0)	−2.854 **	−6.268 ***	I (0)

Note: significance codes: *** $p < 0.01$ and ** $p < 0.05$. Critical values at 1%, 5%, and 10% significance levels for both tests are −2.93, −2.76, and −2.66, respectively. Source: authors' estimations based on World Bank and British Petroleum (BP) data.

Table 5. Panel ARDL and panel NARDL results.

Dependent Variable: CO_2				
Variable	**ARDL**		**NARDL**	
	Coefficient	***p*-Value**	**Coefficient**	***p*-Value**
Short term				
ΔME^+			0.0888	0.207
ΔME^+ (−1)			0.0590	0.343
ΔME^-			0.0413	0.258
ΔME^- (−1)			0.0601	0.090 *
ΔEN	0.9217	0.000 ***	0.9622	0.000 ***
ΔEN (−1)	−0.0491	0.567		
ΔME	0.0481	0.065 *		
ΔME (−1)	0.0322	0.258		
Long term				
ME^+			0.0197	0.647
ME^-			−0.0876	0.001 ***
EN	0.3617	0.000 ***	0.4867	0.000 ***
ME	−0.0355	0.125		
Diagnostic tests				
EC (−1)	−0.3746	0.000 ***	−0.4854	0.000 ***
Kao cointegration test	−3.8003	0.001 ***	−4.1560	0.000 ***
WLR			11.34	0.0009 ***
WSR			0.30	0.5859

Note: significance codes: *** $p < 0.01$ and * $p < 0.1$. WLR indicates long-term asymmetry test. WSR indicates short-term asymmetry test. Source: authors' estimations based on World Bank and British Petroleum (BP) data.

We finish the empirical analysis by investigating the causal interplay among the variables. The left panel of Table 6 shows the results of the symmetric causality tests, whereas the right panel shows the results of the asymmetric causality tests. The results of the symmetric causality tests demonstrate that unidirectional causality exists from ME to CO_2 and EN to CO_2, clearly rejecting the null hypotheses at 10% and 5% significance levels, respectively. To address the asymmetric effects of the defense burden, we examine the causal relationships between the positive and negative components of ME and each variable. In line with the results of the panel NARDL analysis, unidirectional causality is present from ME^{-} to CO_2. To this end, the null hypothesis of ME^{-} does not cause CO_2 is rejected at a 10% significance level. Finally, it should also be noted that there is no evidence of causality from CO_2 and EN to positive or negative changes in ME.

Table 6. Symmetric and asymmetric panel causality tests.

Symmetric Causality				Asymmetric Causality			
Direction	**W_{bar}-Stat.**	**Z_{bar}-Stat.**	**Prob.**	**Direction**	**W_{bar}-Stat.**	**Z_{bar}-Stat.**	**Prob.**
ME → CO_2	3.408	6.596	0.063 ***	ME^{+} → CO_2	2.893	5.186	0.148
EN → CO_2	3.967	8.126	0.020 **	ME^{-} → CO_2	3.715	7.435	0.067 ***
CO_2 → ME	2.411	3.866	0.167	CO_2 → ME^{+}	1.565	1.548	0.547
CO_2 → EN	1.729	1.996	0.512	CO_2 → ME^{-}	1.429	1.177	0.471
ME → EN	1.204	0.559	0.823	ME^{+} → EN	1.092	0.252	0.924
EN → ME	2.140	3.122	0.350	ME^{-} → EN	1.497	1.361	0.652
				EN → ME^{+}	1.413	1.131	0.724
				EN → ME^{-}	0.894	−0.287	0.896

Note: significance codes: *** $p < 0.01$ and ** $p < 0.05$. Source: authors' calculations based on World Bank and British Petroleum (BP) data.

6. Discussion

Overall, our findings tend to support the findings of other empirical studies that address this issue for a panel of countries over various time spans [34,35,45–47,50–52]. Furthermore, our findings are in conformity with empirical studies validating the treadmill of destruction theory in the context of individual countries [15,39–41,43]. Thus, in line with the majority of the empirical literature, our findings reveal the validity of the so-called "treadmill of destruction" theory. Aligning with principle of the theory that countries with more labor-intensive and cutting-edge technologies demand more natural resources, our findings show that reductions in military outlays tend to diminish pressure on the environment. Since its establishment, NATO has taken various actions to mitigate pressure on the environment and natural resources due to the potential threat of climate change. The earliest example of this was the establishment of CCMS to initiate and support studies and fellowships to deal with all forms of pollution and the disposal of hazardous waste. These essential actions have been accelerated by the turn of the new millennium, with rapidly growing interest in the climate change and environmental concerns and the initiatives of the UN.

In 2006, CCMS introduced the Science for Peace and Security Plan to execute initiatives dealing with environmental security challenges. Among the most notable examples of this is the Smart Energy Initiative, which promoted energy efficiency and innovative technologies to maintain the operations of the alliance. In addition, the "Green Defense Framework" was ratified by the member states at the Wales Summit in 2014. Since all members of the alliance are involved in both the United Nations Framework Convention on Climate Change and the Paris Agreement, the member states are eager to achieve the target of limiting global warming to 2 or 1.5 degrees Celsius above pre-industrial levels [11,12]. Thus, within NATO, there is a growing tendency to implement innovative and eco-friendly technologies to reduce carbon dioxide and other greenhouse gas emissions through the individual efforts of member states. The majority of members tend to replace obsolete technology with eco-innovative technologies, and tend to reduce the military outlays for the purchase of emissions-producing arms products. Another factor that potentially supports our findings is the restrictions and regulations on carbon emissions within member countries. The countries in the sample are considered to be either high income or upper-middle income. Furthermore, the majority of the sample consists of EU members, for whom regulations on carbon and other greenhouse emissions are relatively strict for producers and suppliers compared to the rest of the world. Therefore, arms producers are also influenced by regulations that potentially compel the use of eco-innovative technologies.

7. Conclusions

Climate change is a major challenge for the global economy. Rapid industrialization has caused the exploitation and disposal of natural resources to grow at an unprecedented pace compared to the early industrialization period. The flagrant waste of resources is a major potential risk for sustainable development. However, focusing only on sustainable development would not be an appropriate approach either, since peace and security for countries is also essential. In this respect, it becomes inevitable that countries to allocate some of their resources to the defense sector. Furthermore, tensions between and within countries drive them to arms races, resulting in the allocation of scarce resources to inefficient areas. This situation is known as the famous phenomenon of "butter versus guns" in the field of defense economics. The arms races and increase in military outlays mean no only the transfer of scarce resources to the arms industry, but also increases in energy consumption and the use of natural resources for the production and use of defense products. While the direct environmental effects of militarization such as bombing and destruction manifest themselves in the short term, effects such as the reduction in forests, pollution of soil and water, decreases in production, and waves of migration manifest themselves in the long term. Thus, the association between militarization and environmental degradation should be assessed in the long term.

In light of this information, this particular study deals the asymmetric effects of the defense burden on environmental degradation for fifteen countries within NATO, which is a major power in the global context in terms human resources, logistics, and technology. In line with the majority of empirical studies in the literature, our findings support the treadmill of destruction theory. Accordingly, a negative change in the defense burden has a retarding effect on carbon dioxide emissions in the long term. Furthermore, a unidirectional causal relationship exists between negative changes in the defense burden and carbon dioxide emissions.

The treadmill of destruction theory is tested by novel methods and confirmed asymmetrically; this creates the opportunity to better comprehension the link between militarization, environment, and sustainable development. Although it is widely accepted that countries with more labor-intensive and advanced technologies demand more natural resources, the findings for the countries investigated within the scope of this study show that as military expenditure decreases, pressure on the environment also decreases. Allocating significant budgetary resources to defense expenditure in extraordinary times as wars, coups, or natural catastrophe increases air pollution, as well as environmental waste. These findings draw attention to the high level of defense expenditure in the long-term and reveal that resources become scarcer as a result of shifting existing productive resources to inefficient fields such as defense. This resource transfer process both reduces efficiency and creates problems in terms of sustainability.

In connection with these findings, studies carried on the nexus of environment and militarization in the last ten years has been partially successful. It could be argued that initiatives aimed at reducing carbon emissions and other greenhouse emissions have been effective in recent decades. Furthermore, most of NATO countries are parties to vital agreements on environmental sustainability and the reduction in the adverse impacts of climate change and greenhouse gas emissions. Thus, they are also regarded as pioneers in these terrains. The fact that some of the countries included in the sample are important arms producers and exporters at the global scale might affect not only production technology, but also the military outlays that are made over old conventional arms products. Nevertheless, the existence of standards regarding the environment and energy consumption in the EU member states of NATO might potentially affect this situation.

The subject discussed in our study helps shed light on current practices and to develop policy recommendations for defense expenditure within the framework of a sustainable development model in the future. Ensuring the usage of environmentally-friendly policies on defense technologies that avoid the consumption of fossil fuels may have a mitigating effect on environmental pollution. Through these policies, foreign dependency can also be decreased, paving the way for countries to be more active and effective politically. Awareness that increased defense expenditure in extraordinary times can increase air pollution and environmental waste can also aid in effective planning before these situations occur. Furthermore, the implementation of green growth policies can reduce the possible negative impacts of economic growth in terms of environmental pollution. NATO's future agenda includes ensuring the security and territorial integrity of member states, as well as taking action against climate change. It is inevitable that, using obsolete and less-sensitive technologies to environment, make defense activities gradually less effective. Therefore, using non-innovative and environmentally-friendly technologies also put pressure on scarce natural resources that are at risk of depletion. Thus, investments in renewable energy resources should also be given priority in how NATO members allocate resources for common defense. Actions taken within the "Green Defense Framework" developed at the Wales Summit in 2014 can also contribute to the creation of new employment opportunities and alleviate the concerns of countries regarding their economic growth while ensuring sustainability. In addition, while these actions are carried out, NATO should focus attention on minimizing conflicts of interest among members, enacting joint decision-making mechanisms, and developing relations in a peaceful framework.

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Appendix A

Table A1. List of countries.

List of Countries *	Date of Membership
Belgium	1949
Canada	1949
Denmark	1949
France	1949
Germany	1955
Greece	1952
Italy	1949
Luxembourg	1949
Netherlands	1949
Norway	1949
Portugal	1949
Spain	1982
Turkey	1952
United Kingdom	1949
United States of America	1949

Note: * countries are shown in alphabetical order.

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