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Rising military spending jeopardizes climate targets

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The IPCC's Sixth Assessment Report highlights the reliance on sustainable socio-economic pathways to meet the 1.5 °C or 2 °C targets. However, these scenarios lack a quantitative assessment of the impact of global military spending on CO_2 emissions. Our study shows that events such as the 2001–2011 war on terrorism and the 2022 Russian-Ukrainian war led to an increase in CO_2 emission intensity of 0.04 (95% CI: 0.03–0.05) kg/USD for every 1% escalation in global military expenditure as a percentage of GDP (MILEX ratio). This increase accounts for 27% of the total change in CO_2 emission intensity between 1995 and 2023. In scenarios where the global MILEX ratio exceeds thresholds of 12% (for SSP1-1.9) or 24% (for SSP1-2.6), the 1.5 °C or 2 °C climate goals would become unattainable by the end of the century, highlighting the urgent need for a more peaceful international environment to effectively limit global warming.

The Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) suggests that the 1.5 °C or 2 °C climate targets by the end of the century are attainable under the optimistic Shared Socioeconomic Pathways (SSPs) SSP1-1.9 and SSP1-2.6 scenarios[1], which emphasize sustainable development, rapid decarbonization, and robust international cooperation. The emission inventories utilized in IPCC's temperature rise modeling encompass the production, residential, and transport sectors but do not distinctly categorize the military sector. This sector is heavily reliant on fossil fuels and possesses extensive, complex supply chains[2–5]. Due to the voluntary and inconsistent nature of military fuel use data reporting to the United Nations Framework Convention on Climate Change (UNFCCC)[6], there exists considerable uncertainty in accurately quantifying global military and conflict emissions. As a result, most SSP scenarios have not considered the potential impacts of escalating military spending driven by heightened global tensions or conflicts on temperature projections.

Global geopolitics since 2022 has witnessed considerable complexity and instability, which has been unparalleled since the end of the Cold War. Events such as the Russo–Ukrainian war since 2022 and the Gaza war since 2023 have profound implications on political and security dynamics in Eurasia. These conflicts could intensify climate change vulnerability, hinder climate mitigation efforts, and obstruct multilateral climate action[7–9]. It is vital to address the gap in understanding the interplay between sociopolitical risks and climate change mitigation. Quantifying the impact of escalating global tensions or conflicts on the climate is crucial for formulating effective policy responses and fostering global cooperation in tackling both climate change and geopolitical challenges.

In this study, we utilize historical data and statistical methodologies to investigate the relationship between global military expenditure (MILEX), expressed as a percentage of GDP (hereafter referred to as the MILEX ratio), and CO_2 emission intensity. We employ correlation analysis and linear regression modeling to

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quantify this relationship, complemented by a significance test and uncertainty analysis. Additionally, we scrutinize the composition of war-related emissions and evaluate the impact of unaccounted emissions from wars on the estimation of the MILEX ratio-emission intensity relationship. We further investigate potential mechanisms behind this relationship at both national and sectoral levels. Beyond historical analysis, we explore the implications of rising military spending on achieving climate targets. We leverage the established relationship between the global MILEX ratio and emission intensity, in conjunction with the correlation between annual CO_2 emissions and the annual change in global surface temperature (GST) derived from IPCC AR6 data, to adjust the future GST increase projections in the SSP scenarios, taking into account various levels of global military spending. The research framework is illustrated in Supplementary Fig. 1. Comprehensive descriptions of all data sources, statistical methods, significance tests, and uncertainty analyses are provided in the Methods section.

Results

Quantification of the relationship between the global MILEX ratio and total CO_2 emission intensity

After the end of the Cold War in 1991, the global MILEX ratio saw a notable decrease over the next five years, falling from an average of 4.5% during 1960–1990 to approximately 2.5% by 1995[10]. Post-1995, the global MILEX ratio showed modest fluctuations around 2.3%. The variance in this ratio from 1990 to 1994 (0.19) was considerably larger than that between 1995 and 2023 (0.02), reflecting the distinct characteristics of these eras. This study emphasizes the changes in the MILEX ratio post-1995.

The trends in the global MILEX ratio from 1995 to 2023 are linked with regional conflicts and wars, effectively reflecting the degree of global tension during different periods (Fig. 1a). North America contributes the most to the global MILEX during the entire period, as well as to the changes in the global MILEX ratio from 1995 to 2020 (with a coefficient of determination (R^2) of 0.91), compared to other regions (Supplementary Fig. 2). After the United States (U.S.) pursued the war on terrorism following the September 11 attacks, the global MILEX ratio increased by 0.37% in 2011 relative to 2001. This increase was primarily attributed to Operation Enduring Freedom (2001–2014) and the War in Iraq (2003–2011), referred to as Phase II in Fig. 1a. During these conflicts, the MILEX ratio of the U.S. increased by 1.72% in 2011 compared with 2001, whereas Iraq's ratio increased by 1% in 2010 relative to 2004. The 2007–2008 financial crisis, the most severe global economic downturn since the Great Depression, is suspected to have contributed to a marked rise in the global MILEX ratio between 2007 and 2009. Following the Global Financial Crisis, there was a downward trend in the global MILEX ratio (Phase III), which reversed after 2019 (Phase IV). An abrupt surge in the global MILEX ratio occurred in 2020, coinciding with the severe global economic recession caused by the COVID-19 pandemic. From 2021 to 2023, the global MILEX ratio rose by 0.1%, mainly because of increased military expenditures in Eastern Europe resulting from the ongoing Russia-Ukraine war (Fig. 1a and Supplementary Fig. 2).

Throughout the study period, the CO_2 emission intensity displayed a consistent downward trend (Supplementary Fig. 3), primarily driven by technological progress and industrial structure optimization[11,12]. To concentrate on the variations beyond this trend, we analyze the fluctuations after detrending (represented by the blue line in Fig. 1a). The detrended global CO_2 emission intensity shows lagging yet synchronous fluctuations with the global MILEX ratio across the four identified phases (compare the pink and blue lines in Fig. 1a). The three-year weighted average MILEX ratio is depicted in Fig. 1a (red line) due to the strong correlation between the MILEX ratio of the previous two years and the current year, and the CO_2 emission intensity of the current year (Supplementary Table 1).

A significant positive correlation exists between the three-year weighted global MILEX ratio and the detrended CO_2 emission intensity, as evidenced by a Pearson correlation coefficient of 0.83, surpassing the 95% confidence level (Fig. 1b). An increase (or decrease) of 1% in the global MILEX ratio leads to an increase (or decrease) of 0.04 (95% CI: 0.03–0.05) kg/USD in CO_2 emission intensity (see Methods). This change accounts for 27% of the total change in emission intensity

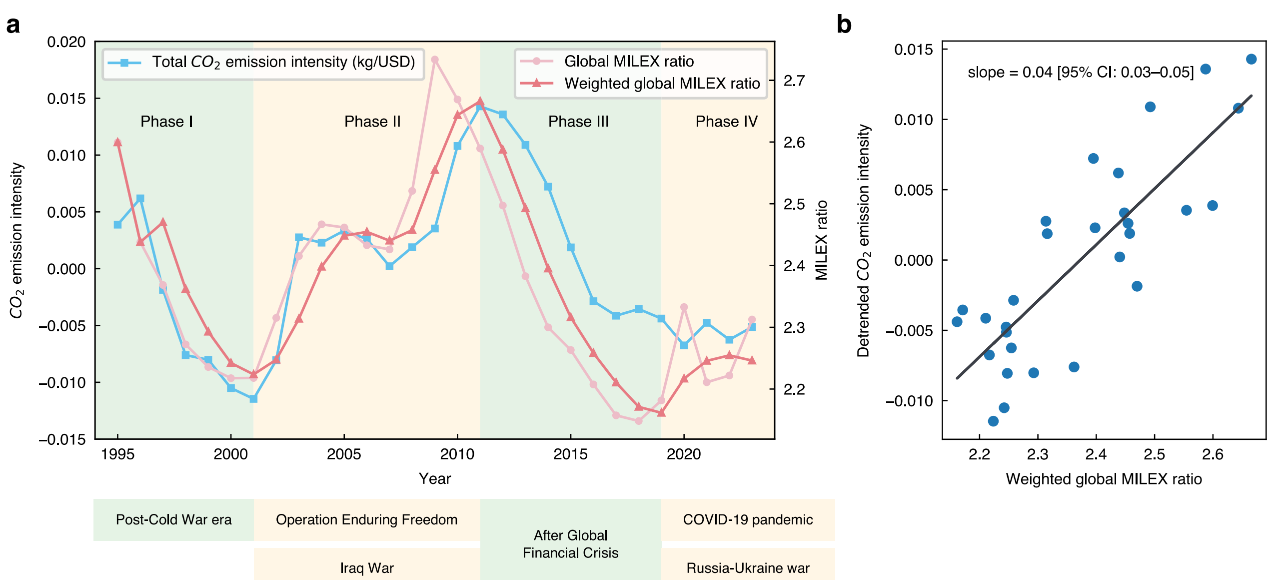

Fig. 1 | The relationship between global military expenditure ratio and global CO_2 emission intensity. a Time series of detrended global CO_2 emission per unit of GDP (emission intensity; kg/USD in constant 2017 of purchasing power parity; represented by the blue line), global military expenditure as a percentage of GDP (MILEX ratio; pink line), and three-year weighted average global MILEX ratio (red line) from 1995 to 2023. The global MILEX ratios for 1995 and 1996 are not weighted. The study period is divided into four phases, showcasing a relatively peaceful phase (highlighted with a light-green background) and a phase of frequent regional wars (marked with a light-orange background). The boxes below display the major events or wars of each phase. **b** Scatter plot of the weighted MILEX ratio and detrended CO_2 emission intensity from 1995 to 2023, along with the fitted line (black line) for the two variables with a slope of 0.04 (95% confidence interval: 0.03–0.05).

from 1995 to 2023. Despite the overall reduction in global CO_2 intensity due to technological advancements (Supplementary Fig. 3), the escalation of global military spending is anticipated to impede this reduction trend. The influence of the global MILEX ratio on emission intensity underscores the detrimental impact of heightened global conflicts on climate change mitigation efforts.

The global CO_2 emission intensity is significantly influenced by the global MILEX ratio, primarily due to its effect on total CO_2 emissions (Supplementary Fig. 4a, b). The growth rate of global GDP is mainly affected by financial crises rather than wars or conflicts during 1995 and 2023 (Supplementary Fig. 5). Four principal sources of CO_2 emissions are associated with warfare: i. operational emissions from military bases and operations; ii. the military industry, which includes the production of vehicles, weapons, and equipment; iii. post-conflict reconstruction; and iv. the destruction of carbon reservoirs[4,13]. However, current accounting methods for war-related emissions typically only consider sources i and ii, often neglecting the others. The Scientists for Global Responsibility estimated that the total military carbon footprint accounts for approximately 5.5% (CI: 3.3%–7%) of global emissions, including operational emissions (source i) and upstream emissions from the supply chain (source ii)[3]. Despite efforts by some military entities and defense contractors to reduce carbon emissions, the military sector's environmental transition remains highly challenging. The lack of viable alternative fuels for military transportation and equipment hinders substantial emission reductions[14].

The Stockholm International Peace Research Institute statistics for military expenditures[15] used in this study include inputs to military operations, military industry, and partially post-conflict reconstruction (Supplementary Table 2), indicating that the statistical relationship between the global MILEX ratio and CO_2 emission intensity accounts for the effects of these emission sources. Previous research suggests that emissions from post-war reconstruction are relatively small compared to those from military bases, operations, and industry[2,3,13,16]. This is primarily due to the limited number of large-scale regional wars over the past 30 years. Additionally, most reconstruction-related emissions are already accounted for in national emission inventories under broader categories such as construction and industry[17]. Therefore, we do not separately consider emissions from post-conflict reconstruction when quantifying the relationship between the MILEX ratio and CO_2 emission intensity. However, this source could considerably affect the CO_2 emission accounting in large-scale wars, as the construction sector is more carbon-intensive than other civilian sectors[7]. For instance, the expected emissions from rebuilding civil infrastructure due to the Russia-Ukraine war in 2022 were estimated to be around 50 million tons, accounting for half of all war-related emissions for that conflict[7].

Carbon emissions resulting from the destruction of carbon reservoirs (source iv) are not directly related to GDP and are therefore excluded from global emission accounting. Supplementary Table 3 illustrates the CO_2 emissions arising from the combustion of carbon-containing materials during wars. To assess the possible effect of emissions from source iv, we incorporate estimates from Supplementary Table 3 into the analysis of the relationship between emission intensity and MILEX ratio. Assuming additional emissions of 320 million tons of CO_2 annually from 2001 to 2011 and 32 million tons of CO_2 from 2022 to 2023, the CO_2 emission intensity increases by 0.042 kg/USD (95% CI: 0.030–0.054) for each 1% increase in the MILEX ratio—representing a 5% increase from the original estimate of 0.04 kg/USD. Notably, 20th-century conflicts produced higher carbon emissions from destroyed carbon reservoirs than recent wars. For instance, the 1991 Gulf War resulted in approximately 320 million tons of CO_2 emissions[13], whereas the 2022 Russia-Ukraine war has led to an estimated 17.7 million tons of CO_2 equivalent[7].

Mechanism behind the relationship between global MILEX ratio and CO_2 emission intensity

Most military activities are characterized by high carbon intensity[4,17–20]. Using the United States as an example, we compare the emission intensity of various military categories with national total emission intensity (Supplementary Fig. 6). The military industry (source ii) shows markedly higher emission intensity than the U.S. total (red vs. orange markers), while military bases and operations (source i; blue markers) are less emission-intensive. The combined military emission intensity (sources i and ii) exceeds the national total emission intensity (green markers vs. orange markers), indicating that military activities are generally more emission-intensive than civilian sectors. The emission intensity for the U.S. military industry is estimated based on two alternative methods described by Crawford[21], both showing nearly double the U.S. total emission intensity during 2018–2019. Notably, European arms companies typically demonstrate lower emission intensities than their U.S. counterparts (evident in the different shapes of pink markers), as also discussed by Lin et al.[14].

A country's military expenditures, expressed as a percentage of GDP, indicate the degree of military activities and act as an effective indicator of military-related emissions for most North Atlantic Treaty Organization (NATO) members, particularly the United States. This relationship is evidenced by a strong correlation between U.S. MILEX ratios[15] and emissions from the U.S. Department of Defense (DOD) from 1975 to 2020[21] (dark blue dots in Supplementary Figs. 7 and 8), with a Pearson correlation coefficient of 0.89 that passes the 95% confidence level. Similarly, other European NATO members, notably Germany, France, and Spain, exhibit a clear positive correlation between their military-related emissions (including sources i and ii) and MILEX ratios from 2021 to 2023 (Supplementary Fig. 7).

The influence of MILEX ratios on CO_2 emissions extends beyond the countries directly involved in conflicts. Between 1995 and 2019, North America—particularly the United States—was the dominant driver of changes in the global MILEX ratio (Supplementary Fig. 2), while East Asia, especially China, contributed the most to global CO_2 emission changes (Supplementary Fig. 9). This pattern is linked to the substantial increase in U.S. military-related imports from China during the 2001–2011 war on terrorism (Supplementary Fig. 10). More recently, from 2021 to 2023, Eastern Europe has been the primary contributor to the rise in global MILEX ratio due to the Russo–Ukrainian war. However, despite these shifts, global emission intensity has remained relatively stable since 2020. During this period, detrended carbon emissions have increased in Western, Eastern, and Central Europe while declining sharply in East Asia. These findings highlight the necessity of adopting a global perspective when assessing the environmental impact of military activities.

Impacts of global military spending on future GST projections

The IPCC Sixth Assessment Report assessed GST projections across five SSP scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5), which integrate different socioeconomic development pathways (SSP1-SSP5) with projected radiative forcing levels (1.9 to 8.5 W/m^2) by 2100[1]. Utilizing the established relationship between the global MILEX ratio and CO_2 emission intensity (Fig. 1b), we project the potential effects of varying global military spending on emission pathways across the five baseline SSP scenarios, as depicted in Fig. 2. The baseline SSPs do not specifically outline the global MILEX ratio. Hence, we hypothesize that the ratio from 2014 represents those for the years 2015–2099 in each baseline SSP (approximately 2.3%). We developed a series of sensitivity scenarios based on historical shifts in MILEX ratios, particularly those observed during World War II and the Cold War[10,22]. These scenarios, based on each baseline SSP, contemplate variations in the global MILEX ratio ranging from −2% to 30% (incrementing in 1% steps) annually from 2024 to 2099. The selected results for scenarios with −2%, 5%, and 10% deviations in the MILEX ratio compared to the baselines are presented in Fig. 2. Recognizing that economic

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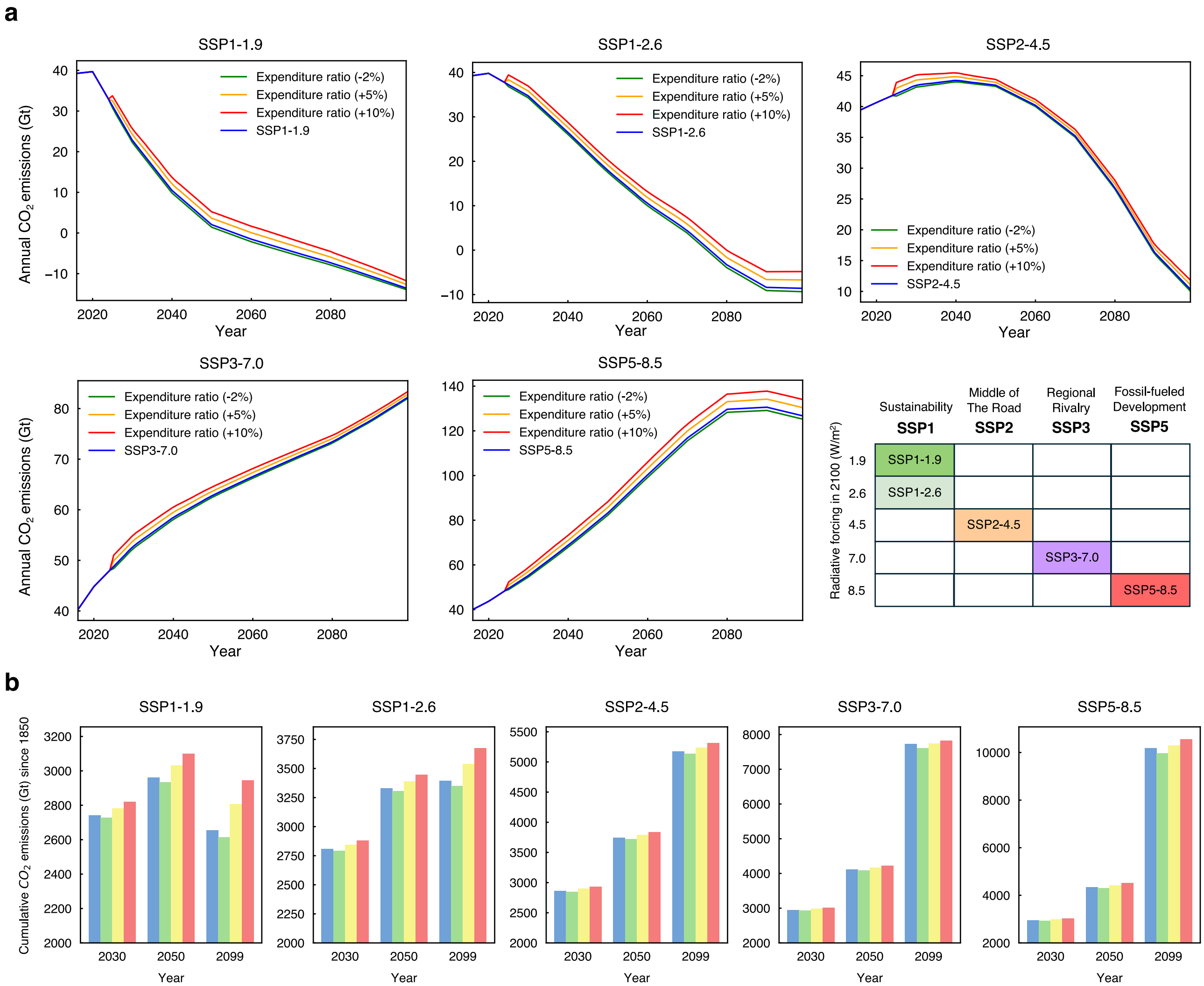

Fig. 2 | Global CO_2 emissions in the five baseline shared socioeconomic pathways (SSPs) and the sensitivity scenarios with various global military spending. **a** Annual CO_2 emissions from 2015 to 2099 under baseline SSP scenarios (blue lines) and sensitivity scenarios when global military expenditure as a percentage of GDP (MILEX ratio) decreases by 2% (green lines) or increases by 5% (orange lines) or 10% (red lines) compared with the baseline. We assume equal variations in the global MILEX ratio of each year in the sensitivity experiment relative to the baseline. **b** Cumulative CO_2 emissions since 1850 in 2030, 2050, and 2099, under the baseline SSP scenarios (blue bars) and sensitivity scenarios, when the global MILEX ratio decreases by 2% (green bars) or increases by 5% (yellow bars) or 10% (red lines) compared with the baseline. The five baseline scenarios integrate the SSP (SSP1–SSP5) and the projected radiative forcing levels by 2100 (1.9–8.5 W/m²), representing possible future socioeconomic and climate pathways.

development is influenced by a complex array of factors and that GDP is not necessarily affected by fluctuations in global military spending (Supplementary Fig. 4 and Supplementary Fig. 5), we assume that the GDP trajectories in these sensitivity scenarios align with those of their respective baseline SSPs. Increases (or decreases) in the MILEX ratio correspondingly increase (or reduce) annual CO_2 emissions relative to the baseline (Fig. 2a). The impact of variations in the MILEX ratio on cumulative CO_2 emissions is more evident in SSP1-1.9 and SSP1-2.6 compared to higher emission pathways (Fig. 2b).

Given the near-linear relationship between the GST increase since 1850–1900 and cumulative CO_2 emissions[1], variations in the global MILEX ratio could influence GST changes by affecting CO_2 emissions. We estimate the GST changes under different levels of global military spending, using the relationship between annual changes in GST increase relative to 1850–1900 (°C) and annual CO_2 emissions (Fig. 3 and Supplementary Fig. 11; see Methods). SSP1-1.9 and SSP1-2.6 represent the “Green Road” scenarios, aligning with socioeconomic pathways aimed at achieving the 2015 Paris Agreement target of limiting global warming to well below 2 °C (preferably 1.5 °C) above pre-industrial levels. In the baseline scenario SSP1-1.9, GST is projected to exceed 1.5 °C around 2035 but is expected to return below 1.5 °C after 2070. However, an increase in the global MILEX ratio prolongs the time required to reduce GST increase below 1.5 °C following the initial overshoot. For example, a 5% rise in MILEX ratio compared with the SSP1-1.9 baseline would delay achieving the 1.5 °C climate target by an additional 13 years, resulting in a 0.05 °C increase in GST at the end of this century (refer to Supplementary Table 4). If the global MILEX ratio increases beyond 12%, it becomes unfeasible to meet the 1.5 °C climate target (after the overshoot) by the end of the century, with GST increase potentially rising by over 0.12 °C by 2099 compared with the baseline. Conversely, in scenarios where global MILEX ratio decreases by 2% compared to the SSP1-1.9 baseline, humanity could potentially reach the goal of restricting the GST increase below 1.5 °C three years ahead of the original schedule.

SSP1-2.6 shares the same socioeconomic framework as SSP1-1.9 but exhibits higher radiative forcing values owing to the different mitigation strategies. In this scenario, if the global MILEX ratio increases by less than 24%, the rise in GST can still be confined to under

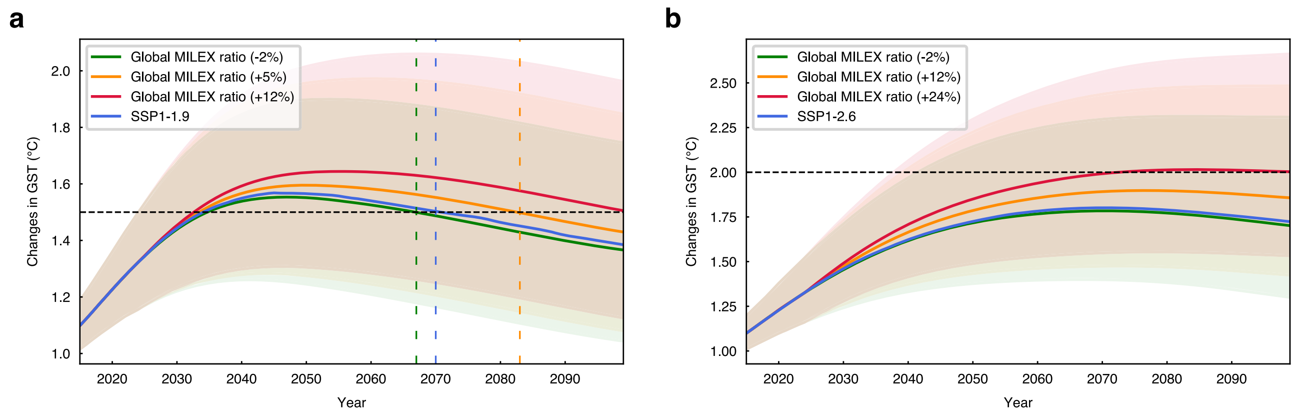

Fig. 3 | Projections of global surface temperature (GST) increase in baseline SSPs and sensitivity scenarios with varied global military spending. a Projected changes in GST relative to the 1850–1900 mean under the SSP1-1.9 baseline (blue line), as well as sensitivity scenarios with varying global military expenditure as a percentage of GDP (MILEX ratio): −2% (green line), +5% (orange line), and +12% (red line) compared to baseline. **b** Similar projections for SSP1-2.6 baseline (blue) and sensitivity scenarios with varying global MILEX ratios: −2% (green line), +12% (orange line), and +24% (red line) compared to baseline. The shaded areas represent 95% confidence intervals for each scenario.

2 °C during this century. Notably, the temperature overshoot associated with a 24% increase in the expenditure ratio is negligible. However, if the global MILEX ratio increases beyond 24%, the 2 °C climate target would become unattainable by the end of this century, resulting in a GST increase exceeding 0.28 °C by 2099 compared with the baseline SSP1-2.6. In medium- or high-emission scenarios such as SSP2-4.5, SSP3-7.0, and SSP5-8.5, the impact of changes in MILEX ratio on GST increase projections is comparatively less pronounced than in SSP1-1.9 and SSP1-2.6 scenarios (Supplementary Fig. 12 and Supplementary Table 4). In scenarios with already high emissions, variations in military spending have a more muted effect on future GST trends.

Discussion

This research reveals a statistically significant positive correlation between the global MILEX ratio and the detrended global CO_2 emission intensity from 1995 to 2023. Specifically, a 1% increase in the global MILEX ratio corresponds to a change of 0.04 kg/USD (95% CI: 0.03–0.05) in global CO_2 emission intensity. The country-level analysis reveals that military activities, especially within the military industries, are typically more carbon-intensive than civilian sectors. For example, the emission intensity of the U.S. military industry was estimated to be nearly twice the national average during the period of 2018–2019. An increase in a country's MILEX ratio generally correlates with an expansion of military-related activities, resulting in higher carbon emissions. This trend is further amplified on a global scale through international trade and military supply chains.

The finding addresses a critical knowledge gap in understanding how rising military spending prompted by geopolitical tensions influences climate change mitigation efforts. Escalating global tensions with a MILEX ratio exceeding 12% or 24% would critically jeopardize our ability to prevent the climate system from reaching dangerous greenhouse gas concentration levels, even under the most optimistic scenarios of SSP1-1.9 and SSP1-2.6, respectively.

This study focuses on emissions directly linked to military bases, operations, and supply chains. While the impacts of post-conflict reconstruction and the destruction of carbon reservoirs on CO_2 emission intensity are negligible during our study period (1995–2023), they could be more pronounced in the event of a large-scale war. Future research will require extensive data collection and analysis to explore whether the widespread adoption of renewable energy, green military technologies, and shifting global trade patterns could weaken the link between military expenditures and carbon emissions—or whether heightened global tensions could indirectly hinder climate action and reinforce this relationship.

Our findings indicate that escalating global military spending threatens climate goals, underscoring the need for peace and technological advancements to combat climate change. Achieving the 1.5 °C or 2 °C climate targets and mitigating the risk of extreme temperatures require a stable international environment and strong international cooperation. To integrate military emissions into international climate frameworks, we suggest mandatory military emissions reporting under the UNFCCC framework and advancing the green transition of the military sector through targeted policies. These measures could include incorporating military emissions in Nationally Determined Contributions, establishing independent verification mechanisms, and promoting multilateral agreements to reduce the military sector's carbon footprint.

Methods

Data sources

This study requires the integration of data and methodologies from diverse sources and scientific disciplines. We utilize global MILEX from the Stockholm International Peace Research Institute[15] and global GDP[23] from 1995 to 2023 to obtain the global MILEX as a percentage of GDP. Global CO_2 emission intensity (kg/USD) during 1995 and 2023 is computed by dividing historic anthropogenic CO_2 emissions (from fossil fuels and industry, excluding land-use change)[24,25] by global GDP[26] (USD in constant 2017 of PPP). The carbon emission intensities of various military categories for the United States are estimated using multiple data sources. The emission intensity of operational activities from 1995 to 2020 is computed by dividing the U.S. DOD emissions[21] by the national defense outlays for operation, maintenance, and military construction[27]. The military industry's emission intensity in 2019 is estimated using military-industrial emissions provided by Crawford[21] and the national defense outlays for procurement[27]. To calculate the overall U.S. military emission intensity, we use the military-related carbon footprint data from Lin et al.[14] and corresponding defense outlays. Additionally, the military carbon footprints for European NATO members from 2021 to 2023 are computed based on the formula provided by Lin et al.[14]. Due to inconsistencies and incompleteness in the reporting of military fuel use data, the national military emissions data used in this study are limited to specific countries and years. Regarding the future projections, annual anthropogenic CO_2 emissions for five SSP scenarios during 2015–2100 are derived from data in Figures SPM.4 and SPM.10 (v20210809) in IPCC AR6[1,28,29]. GST changes since 1850–1900 for five SSPs during 2015–2099 are obtained from data in Figure SPM.8 (v20210809) in

IPCC AR6[1,30]. Global GDP projections (USD in constant 2010 of PPP) for the five SSPs are provided by Jiang et al.[31].

Quantification of the relationship between MILEX ratio and CO_2 emission intensity

We use the historic data from 1995 to 2023 to quantify the relationship between CO_2 emission intensity and global MILEX ratio. The use of CO_2 intensity (CO_2 emissions per unit of GDP) removes to some extent the impact of the increase in global total emissions associated with general economic growth. Considering that technological advancements are anticipated to substantially boost carbon emission efficiency, changes in CO_2 emission intensity over time mirror efforts to enhance energy efficiency and mitigate climate change. Therefore, the CO_2 emission intensity time series is linearly detrended before analysis to reduce the impact of technological progress. Acknowledging the potential non-contemporaneous effects of the global MILEX ratio on CO_2 emission intensity, we compute their lagged Pearson correlation coefficients (Supplementary Table 1). This analysis reveals that the MILEX ratio of the current year significantly influences CO_2 emission intensity for the current and subsequent two years. Consequently, we use the ratios of correlation coefficients with lags of 0, 1, and 2 years as weights for the current and preceding two years to calculate the three-year weighted averages of the global MILEX ratio. These three-year weighted average ratios serve as explanatory variables, and the detrended CO_2 intensity as the dependent variable, in constructing our linear regression model (Fig. 1b and Eq. (1)).

$$Y_i = m \times X_i^* + \varepsilon \; i = 1, 2, \cdots, N \tag{1}$$

$$X_i^* = \sum_{k=0}^{2} r_k X_{i-k}$$

where Y_i denotes detrended CO_2 emission intensity (kg/USD) for year i. N is the total number of years. m denotes the slope coefficient, and ε denotes the residual. X_i^* indicates the three-year weighted average global MILEX ratio. r_k denotes the weight for the global MILEX ratio in the current year ($k = 0$) or the previous two years ($k = 1$ or 2). X_{i-k} represents the global MILEX ratio for the year $i - \text{k}$.

Significance analysis

We utilize Student's t-test to assess the statistical significance of the correlation coefficient between the time series of detrended global CO_2 emission intensity and the weighted global MILEX ratio from 1995 to 2023. The underlying assumption is that both variables approximate a normal distribution. The effective sample size for N years of data is calculated using Eq. (2)[32], accounting for their temporal correlation. The 95% confidence interval (CI) of the regression coefficient (m) is determined using Eq. (3).

$$N_e \approx N \frac{1 - r_1 r_2}{1 + r_1 r_2} \tag{2}$$

$$\text{CI} = m \pm t_{\frac{\partial}{2}, n-2} \times \sqrt{\frac{\text{MSE}}{\sum (X_i^* - \bar{X})^2}} \tag{3}$$

$$\text{MSE} = \frac{\sum_{i=0}^{N} (Y_i - \hat{Y}_i)^2}{N - 2}$$

where N_e can be regarded as the effective sample size of the N years of data. N denotes the sample size. r_1 and r_2 indicates the lag-one autocorrelation of detrended CO_2 emission intensity and global MILEX ratio, respectively. CI represents the confidence interval of the regression coefficient m with $\partial = 0.05$. $\bar{X}$ denotes the average of X_i^*. MSE represents the mean−squared error between the estimated $\hat{Y}_i$ and the actual Y_i.

Quantification of the relationship between CO_2 emissions and GST changes

The IPCC AR6 determines a near-linear relationship between cumulative CO_2 emissions and the increase in GST, as the transient climate response (TCRE) to cumulative CO_2 emissions remains constant. This relationship holds true during periods of net positive global CO_2 emissions; however, there is limited evidence for the quantitative application of TCRE to estimate temperature evolution under conditions of net negative CO_2 emissions[29]. Both the SSP1-1.9 and SSP1-2.6 scenarios anticipate net negative annual CO_2 emissions after 2050, rendering the linear relationship inapplicable. Consequently, we estimate the evolution of GST changes by constructing a relationship between annual CO_2 emissions and the annual change in GST increase using polynomial fitting for the five SSPs (Supplementary Fig. 11).

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

Global and national military expenditures are available at https://milex.sipri.org/sipri. Historical global GDP is provided at https://data.worldbank.org/indicator/NY.GDP.MKTP.KD. Global GDP projections across the five SSP scenarios are provided at https://doi.org/10.57760/sciencedb.01683. Annual anthropogenic CO_2 emissions used for calculating CO_2 emission intensity are available at https://ourworldindata.org/co2-dataset-sources. The GST rise since 1850–1900 and annual anthropogenic CO_2 emissions across the five SSP scenarios, used for estimating the relationship between CO_2 emissions and GST increase, can be found at https://ipcc-browser.ipcc-data.org/.

Code availability

All code used to process data and generate the figures in this study is publicly available on Zenodo (https://zenodo.org/records/12787585).

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Author contributions

W.D. conceived and supervised the research. W.D. and Q.R. designed the study and wrote the first version of the manuscript. Q.R. conducted the research and prepared graphs. F.L. contributed to analyzing the relationship between global MILEX ratio and CO_2 emission intensity. F.L., J.C., and W.Y. participated in the review and editing of the manuscript. R.D., J.Y., K.W., X.W., D.Z., C.L., and W.L. contributed investigation, data collection and visualization. D.C. contributed to the framing of the study and revision process. All co-authors interpreted the results.

Competing interests

The authors declare no competing interests

Additional information

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