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RESEARCH ARTICLE

Reducing U.S. military spending could lead to substantial decreases in energy consumption

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Abstract

The U.S. military is a significant contributor to the climate crisis and other sustainability concerns. However, there is very limited research on how changes in U.S. military spending directly impact Department of Defense energy consumption and thereby greenhouse gas emissions. Here, we conduct a time series analysis of the relationship between U.S. Department of Defense (DOD) direct energy consumption and U.S. military expenditures from 1975 to 2022, and we test for directional asymmetry in the effect of expenditures on energy consumption. We estimate error correction models, which we ensure are free from residual autocorrelation and structural breaks. We find that a decrease in expenditures has a larger effect on decreasing energy consumption than an increase in expenditures does on increasing consumption. Further analyses reveal that this is due to cuts in DOD energy consumption from facilities and vehicles and equipment, and jet fuel in particular. We also illustrate the potential impacts of different spending decisions on DOD energy consumption and present a forecast from 2023 to 2032 for seven different scenarios. We show that sustained cuts to U.S. military expenditures could result in annual energy savings on par with what the nation of Slovenia or the U.S. state of Delaware consumes annually by 2032.

Introduction

The impact of the world's militaries on energy consumption and the climate crisis is greatly understudied by the scientific community [1–5]. This is surprising and a significant oversight. Military leaders and their institutions consider anthropogenic climate change to be a threat multiplier to geopolitical stability and national security [6–11], and some scholars have suggested that the world's militaries are potentially helpful actors in global climate governance and other sustainability efforts [12].

However, nations with higher military spending are slower to ratify international environmental and climate mitigation agreements, such as the Kyoto Protocol [13,14]. A small body of cross-national research, using statistical analyses, also finds

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that nation-states with relatively greater military spending consume larger amounts of fossil fuels and emit higher levels of carbon pollution [15–22]. While suggestive of climate and energy impacts, these macro-comparative studies do not analyze the effect of military spending on direct measures of militaries' energy consumption or greenhouse gas emissions.

Recent scholarly commentaries [10,23,24] and case studies [1,25] focus on the U.S. military's contribution to the climate crisis, describing its substantial energy use, high-level of anthropogenic emissions, and the fact that it is the largest institutional emitter in the world [25]. According to the U.S. Department of Defense (DOD), their Scope 1 and Scope 2 emissions were over 636 million metric tons of CO_2e (MMT-CO_2e) for the 2010–2019 decade, with a general decline in annual emissions from over 76 million metric tons CO_2e in 2010 to almost 55 million metric tons CO_2e in 2019 [26]. These estimates are incomplete and conservative, as they, at minimum, exclude the DOD's Scope 3 emissions [1]. Nevertheless, they rival the overall emissions of many nations for the same decade [27], and if the U.S. military were its own country, it would be the 47th largest emitter in the world [25]. As important, the U.S. military is the largest and most powerful military in the world, with its annual expenditures being much greater than for any other national military [28].

The environmental effects of the U.S. military, including its energy consumption and climate impacts, are not limited to troop deployments and war [18,22,29–31]. Supported by a significant budget, the U.S. military continually invests in and pursues new technologies in weapons, transportation, and communications systems. While some have closed through the years, the U.S. military has over 900 domestic bases and installations, as well as nearly 800 international bases and smaller military installations (i.e., "lily pads"), staffed by deployed military personnel, throughout the world [3,32–35]. It is estimated that over half of the fuel consumed by national militaries is associated with flying fighter jets [36], and for the United States, as we discuss below, jet fuel accounts for nearly 55% of the average annual total DOD energy consumption over the past half century. These and other forms of fossil-fuel powered military equipment are used for the constant training of personnel in preparation for conflict [18,37]. Overall, the scale of the U.S. military's global infrastructure, including bases, transportation systems to move people, supplies, and weaponry by land, air, and water throughout the world, constant research and development, and never-ending preparations, training, and exercises, all involve the consumption of substantial amounts of fossil fuels [3,23,38].

To advance scientific understanding of the energy and climate impacts of militaries, and the U.S. military in particular, we conduct a time series analysis of the relationship between U.S. DOD direct energy consumption and U.S. military expenditures from 1975 to 2022. A focus on measures of DOD direct energy consumption and U.S. military spending helps resolve limitations of prior cross-national analyses that utilize national-level measures of energy or carbon emissions, and how they are associated with national military spending.

Additionally, another contribution is that we estimate both short-term and long-term effects of military expenditures on energy consumption. The models are estimated for (1) overall DOD energy consumption as well as separately for (2) facilities, (3) vehicles and equipment, (4) jet fuel, (5) all other energy sources, and (6) fossil fuel energy consumption. We also test for directional asymmetry in the effect of expenditures on consumption [39–43]. Directional asymmetry in the effect of military expenditures on DOD energy consumption could have significant implications for climate mitigation and other sustainability concerns, especially if it is found that the effect of a unit decrease in military expenditures on reducing consumption is larger in magnitude than the effect of a unit increase in expenditures on expanding DOD energy consumption [42,44].

Using state-of-the-art time series techniques, we find that a decrease in military expenditures has a larger effect on decreasing DOD energy consumption than an increase in expenditures does on increasing consumption. Further analyses reveal that this is due to cuts in DOD energy consumption from facilities and vehicles and equipment, and jet fuel in particular. We also develop a suite of forecasts to examine how various military spending scenarios may impact DOD energy consumption in the future. Our findings show that sustained cuts to U.S. military expenditures could result in annual energy savings on par with what the nation of Slovenia or the U.S. state of Delaware consumes annually by 2032. These results suggest that cutting U.S. military spending could have significant impacts on DOD energy consumption, and thereby, lead to reductions in greenhouse gas emissions.

Materials and methods

Data

We analyze U.S. DOD energy consumption data by fiscal year from 1975 to 2022, which is obtained from the U.S. Department of Energy's (DOE) comprehensive annual energy data and sustainability performance portal (https://ctsedwweb.ee.doe.gov/Annual/Report/Report.aspx). We investigate total DOD energy consumption, as well as by the individual DOD end use sectors—energy consumption by facilities and vehicle and equipment. The facilities end use sector refers to the energy used in DOD buildings, and the vehicle and equipment end use sector refers to the energy used in vehicles and equipment. The vehicle and equipment end use sector can also be disaggregated by fuel type. We estimate additional models with jet fuel (the largest single category of energy consumption) as an outcome, all other energy sources besides jet fuel as an outcome, and a model with renewable energy sources removed to compare the effect of military spending on total energy consumption. Renewables make up only 0.95% of total DOD energy consumption as of 2022. All energy consumption data is measured in billion BTU, which we convert to trillions for interpretability purposes for our figures.

We examine the impacts of increases and decreases in military spending on DOD energy consumption, which is constructed from U.S. military expenditure data (constant 2021 US$) obtained from the Stockholm International Peace Research Institute's [28] military expenditure database. The summary statistics for these variables are reported in S1 Table.

Methods

WLL-bounds approach

With time series data, estimating long-run relationships (or cumulative effects) are often of interest as effects commonly persist through time. This is especially true when testing for asymmetry because short-run and long-run effects may be different. However, testing for long-run relationships with time series data presents challenges because series exhibiting common trending behavior can produce spurious associations [45].

To address this issue, we use the long-run multiplier bounds approach advanced by Webb, Linn, and Lebo [46], which we refer to as the WLL-bounds approach. The WLL-bounds approach builds off of the popular Pesaran, Shin, and Smith [47] bounds cointegration testing procedure, which we refer to as the PSS-bounds approach. Although the PSS-bounds approach allows for uncertainty in the order of integration of the regressors, it requires that the researcher establish that the dependent variable is integrated of order 1 (contains a unit root). Given the relatively short time series used in this analysis, unit root tests are likely to perform poorly and be plagued by weak power [46,48]. This concern is confirmed by the results from the Dickey-Fuller GLS test and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test reported in S2 Table.

As these test statistics indicate, there are conflicting results regarding the true order of integration of the variables. In additional unreported tests (available upon request), we also found that the results of the unit root tests varied across different lag lengths—a common problem in time series analysis.

The WLL-bounds approach addresses this issue by avoiding pre-testing entirely, and instead, draws inferences from the long-run multiplier (long-run effect) z-statistic according to critical value bounds reported by Webb et al. (46,48), which account for the uncertainty inherent in time series analysis. The first step in this approach is to estimate a generalized error correction model (GECM) that is white noise, which is a model where the first difference of the dependent variable is regressed on the differences of the independent variables and the lags in levels of the dependent variable and independent variables. The second step is to calculate the long-run effect based on these estimates by dividing the negative of the coefficient on the lag of the independent variable by the lag of the dependent variable. The third step is to compare the absolute value of the z-statistic to the bounds provided by Webb et al. (46,48). Using the bounds associated with T = 50, 2 variables, and alpha level = .05, we compare the z-statistics of the long-run effects in our analyses to a lower bound of 1.10 and an upper bound of 3.68. If the z-statistic is greater than 3.68, we can reject the null hypothesis at the.05 alpha level. If the z-statistic is below 1.10, then we cannot reject the null, and if it is in between the two bounds then we are uncertain whether we can reject the null. In other words, the result is considered inconclusive. We conduct the analyses in Stata 18 using the regress command. We compute the standard errors for the long-run effects using the delta method, which is implemented with the *nlcom* command.

Following the standard approach for modeling asymmetry in the time series literature [49], we use the nonlinear autoregressive distributed lag (NARDL) modeling approach to test for potential asymmetry in the effect of military expenditures on DOD energy consumption. This approach models asymmetry by parsing the positive and negative changes of military expenditures into partial sums around a threshold of zero (1):

$$\textit{Military Expenditures}_t^{\textit{Increase}} = \sum_{j=1}^{t} \textit{max}(\Delta \textit{Military Expenditures}_t^{\textit{Increase}}, 0) \tag{1}$$

$$\textit{Military Expenditures}_t^{\textit{Decrease}} = \sum_{j=1}^{t} \textit{min}(\Delta \textit{Military Expenditures}_t^{\textit{Decrease}}, 0)$$

and then modeling the partial sums using an ARDL model that includes *p* lags of the dependent variable and *q* lags of the partial sums (2):

$$\begin{aligned} &\textit{DOD Energy Consumption}_t = c_0 + \sum_{i=1}^{p} \lambda_1 \textit{DOD Energy Consumption}_{t-i} \\ &+ \sum_{i=0}^{q} \beta_i \textit{Military Expenditures}_{t-i}^{\textit{Increase}} + \sum_{i=0}^{q} \beta_i \textit{Military Expenditures}_{t-i}^{\textit{Decrease}} + e_t. \end{aligned} \tag{2}$$

After estimating the model, a Wald test is conducted to determine whether the estimated coefficients for the positive and negative changes are equivalent [42,49,50]. The effects are asymmetric if the null hypothesis of symmetry is rejected.

We reparametrize the ARDL model into the algebraically equivalent GECM that regresses the first difference of the dependent variable on its own lags in levels, and the first differences and lag levels of the independent variables. Given the limited temporal scope of this study (48 years) and the potential issues that arise from overfitting [51], we estimate a GECM (1,1) for all the models except for facility energy consumption and non-jet fuel (all other) energy consumption (3):

$$\begin{aligned} &\Delta \textit{DOD Energy Consumption}_t = c_0 + \theta_1 \textit{DOD Energy Consumption}_{t-1} \\ &+ \beta_1 \Delta \textit{Military Expenditures}_t^{\textit{Increase}} + \beta_2 \Delta \textit{Military Expenditures}_t^{\textit{Decrease}} \\ &+ \beta_3 \textit{Military Expenditures}_{t-1}^{\textit{Increase}} + \beta_4 \textit{Military Expenditures}_{t-1}^{\textit{Decrease}} + e_t. \end{aligned} \tag{3}$$

For facility energy consumption, we include the lagged first difference of a decrease in military expenditures (4):

$$\begin{aligned}\Delta \textit{DOD Facility Energy Consumption}_t &= c_0 + \theta_1 \textit{DOD Facility Energy Consumption}_{t-1}\\ &+\beta_1 \Delta \textit{Military Expenditures}_t^{Increase} + \beta_2 \Delta \textit{Military Expenditures}_t^{Decrease}\\ &+\beta_3 \textit{Military Expenditures}_{t-1}^{Increase} + \beta_4 \textit{Military Expenditures}_{t-1}^{Decrease}\\ &+\beta_5 \Delta \textit{Military Expenditures}_{t-1}^{Decrease} + e_t.\end{aligned} \tag{4}$$

For non-jet fuel (all other) energy consumption, we include two lags of the first difference of each variable (5):

$$\begin{aligned}\Delta \textit{DOD All Other Energy Consumption}_t &= c_0 + \theta_1 \textit{DOD All Other Energy Consumption}_{t-1}\\ &+\beta_1 \Delta \textit{Military Expenditures}_t^{Increase} + \beta_2 \Delta \textit{Military Expenditures}_t^{Decrease}\\ &+\beta_3 \textit{Military Expenditures}_{t-1}^{Increase} + \beta_4 \textit{Military Expenditures}_{t-1}^{Decrease}\\ &+\beta_5 \Delta \textit{DOD All Other Energy Consumption}_{t-1} + \beta_6 \Delta \textit{DOD All Other Energy Consumption}_{t-2}\\ &+\beta_7 \Delta \textit{Military Expenditures}_{t-1}^{Increase} + \beta_8 \Delta \textit{Military Expenditures}_{t-2}^{Increase}\\ &+\beta_9 \Delta \textit{Military Expenditures}_{t-1}^{Decrease} + \beta_{10} \Delta \textit{Military Expenditures}_{t-2}^{Decrease} + e_t.\end{aligned} \tag{5}$$

These models are chosen because they are free of residual autocorrelation and structural breaks. In other words, these models produce white noise residuals, which suggests that they are capturing the underlying data generating process. We confirmed that the model residuals are not autocorrelated using the Breusch-Godfrey and Durbin's alternative tests for serial correlation (*estat bgodfrey* and *estat durbina* in Stata 18) and that there are no structural breaks according to the cumulative sum test for parameter stability (*estat sbcusum* in Stata 18). Because there are no structural breaks, the estimates we report are stable over time. These results are reported in S3 and S4 Tables.

Forecasting

To examine how various military spending scenarios may impact DOD energy consumption in the future, we use the forecast package in Stata 18. This program works by generating dynamic forecasts by repeatedly solving the model using 100 stochastic simulations to obtain point estimates and uncertainty around that estimate. Uncertainty in the estimate is added by taking random draws from a multivariate distribution where the mean is the estimated slope coefficient, and uncertainty in the error term is estimated by adding a random error term based on the root RMSE (root mean square error) from the model. We use a time horizon of 10 years to minimize uncertainty compared to more distant futures. In total, we develop seven scenarios. Six scenarios represent the 10th percentile, median, and 90th percentile percentage changes for increases and decreases in military spending based on historical spending data going back to 1975 and each is compared to a change in military spending based on its historical median, which is also represented as its own scenario. Military spending is assumed to change at the given scenario rate for each year. The use of seven different scenarios allows us to capture the impacts of a range of possible spending futures and quantify how they may impact DOD energy consumption.

Results

Fig 1 illustrates time series from 1975 to 2022 for U.S. military expenditures and total DOD direct energy consumption, as well as separately for DOD facilities and for DOD vehicles and equipment. Military expenditures, overall, increased from $463,536 million (constant 2021 US$) in 1975 to $811,591 million in 2022. The increase was not linear, as expenditures increased in the early 1980s during Ronald Reagan's presidency, peaking in 1986 at $730,694 million, then they declined to $484,915 million by 1999. This was followed by another and more sustained increase, given U.S. military involvement in Afghanistan and Iraq, peaking in 2010 at $917,092 million followed by a decline through 2017, with a value of $714,959 million in the latter. Military expenditures then began increasing again through 2022 except for a slight decrease in 2021.

Total DOD energy consumption decreased from 1360.24 trillion BTU in 1975 to 622.48 trillion BTU in 2022. The pattern of decrease for total energy consumption is largely driven by the nearly identical pattern of reduced vehicle and equipment

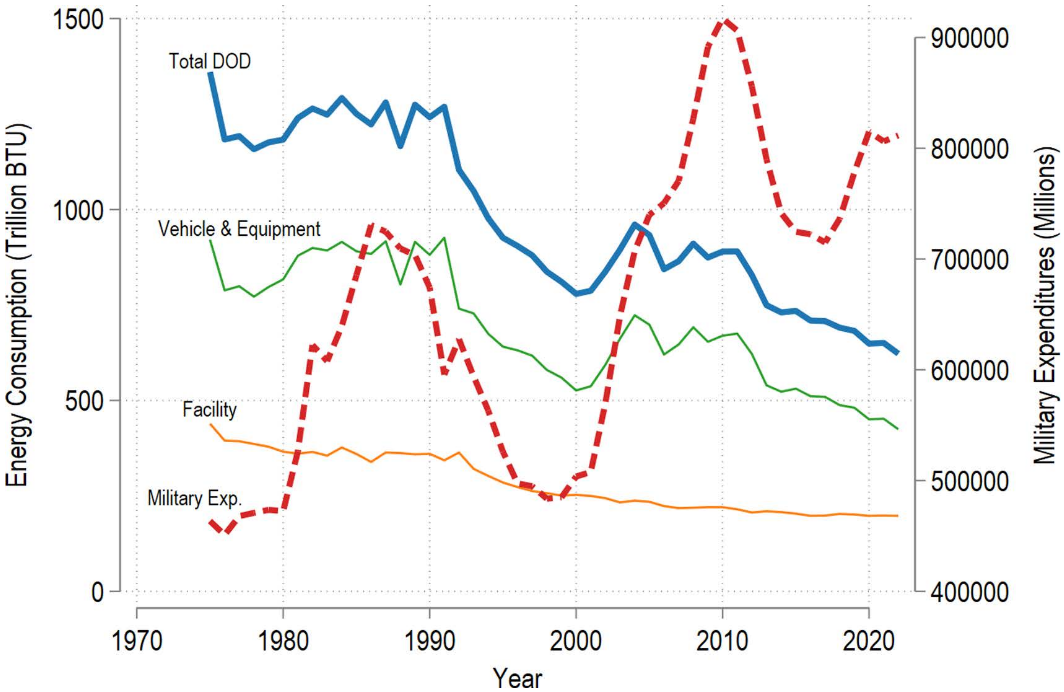

Fig 1. Time series of military expenditures and DOD energy consumption.

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energy consumption from 921.01 trillion BTU in 1975 to 424.53 trillion BTU in 2022. Facility energy consumption, roughly a third of total DOD energy consumption, also decreased from 439.23 trillion BTU in 1975 to 197.95 trillion BTU in 2022. These decreases likely reflect, to some extent, both increasing fuel efficiencies in the U.S. military's ground, air, and sea transportation vehicles and systems, and the closure of facilities (e.g., military bases and installations) throughout the world [1].

Table 1 provides summarized results for the analysis of the effect of military expenditures on total DOD energy consumption and also disaggregated into facility consumption and vehicle and equipment consumption, while the full information for each estimated model is found in S3 Table. An error correction model is estimated for each energy consumption measure, which we ensure is free from residual autocorrelation and structural breaks.

For total DOD energy consumption, the short-run effect of an increase in military expenditures is associated with an increase in energy consumption, whereas the short-run effect for a decrease in military expenditures is not statistically significant. The result of the Wald test indicates that the effects are symmetric.

For the long-run effects, the z-statistic for *Military Expenditures*^{Decrease} is above the upper bound critical value (3.68) at the.05 significance level, which indicates that a long-run relationship exists. The z-statistic on *Military Expenditures*^{Increase} is between the lower (1.10) and upper bound (3.68), meaning that it is inconclusive whether there is a long-run effect. The long-run effects are asymmetric, as the effect of a decrease in military expenditures has a significantly larger impact on decreasing energy consumption than an increase in expenditures does in increasing energy consumption. More specifically, a 1% increase in military expenditures has a positive effect on total DOD energy consumption (coefficient = .111, 95% confidence interval = -.020 —.241), whereas a 1% decrease in military expenditures is associated with a .981% (95% confidence interval = .782 — 1.180) decrease in total DOD energy consumption.

The results separated by energy consumption category show that changes in total DOD energy consumption are driven by changes in facility consumption and vehicle and equipment consumption. An increase in military expenditures is not associated with changes in facility energy consumption in the short- or long-run, but a 1% decrease in military

Table 1. Results for the asymmetric relationship between military expenditures and DOD energy consumption.

	Total DOD ECM (1)	Facility ECM (2)	Vehicle & Equipment ECM (3)
Short-Run Effects			
ΔMilitary Expenditures^{Increase}	.421* (.160)	-.031 (.118)	.648* (.235)
ΔMilitary Expenditures^{Decrease}	.008 (.243)	.611* (.188)	-.098 (.349)
Long-Run Effects			
Military Expenditures^{Increase}	.111# (.067)	-.014 (.109)	.212# (.097)
Military Expenditures^{Decrease}	.981* (.101)	.900* (.159)	1.090* (.146)
Short-Run Asymmetry?	No	Yes	No
Long-Run Asymmetry?	Yes	Yes	Yes

Note:

*$p < .05$ (two-tailed). Standard errors are in parentheses. The standard errors for the long-run effects are calculated using the delta method. For the long-run effects,

*indicates the z-statistic is greater than 3.68 (reject null at.05 alpha level), and

#indicates the z-statistic is in between 1.10 and 3.68 (uncertain whether to reject null at.05 alpha level). ECM = error-correction model.

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expenditures decreases facility energy consumption by .611% (95% confidence interval = .230 —.993) in the short-run and .900% in the long-run (95% confidence interval = .588 — 1.211). In comparison, a 1% increase in military expenditures increases vehicle and equipment energy consumption by .648% (95% confidence interval = .172 — 1.124) in the short-run and has an inconclusive long-run effect according to the bounds test (coefficient = .212%, 95% confidence interval = .021 —.402). A 1% decrease in military expenditures decreases vehicle and equipment energy consumption by 1.090% (95% confidence interval = .804 — 1.377) in the long-run, but it has no effect in the short-run.

We also examine whether changes in jet fuel are largely driving these findings, as jet fuel makes up 54.6% of average annual total DOD energy consumption from 1975-2022. The summarized results are reported in Table 2 (see S4 Table for the full results). According to the regression analysis and cross-model Wald tests (reported in S5 Table), the long-run effect of an increase in spending and the long-run effect of a decrease in spending are significantly larger in magnitude for jet fuel compared to all other energy consumption sources. However, the long-run effects for *Military Expenditures*^{Increase} are inconclusive in both models, while in contrast, the long-run effect of a decrease in military expenditures is conclusive at the.05 alpha level in both models. The long-run effect of a decrease in military expenditures on jet fuel is 1.165 (95% confidence interval = .876 — 1.454) compared to .604 (95% confidence interval = .378 —.830) for all other energy consumption sources. The key results for the analyses in Tables 1 and 2 are combined and summarized with coefficient plots for short-run effects in Fig 2 and long-run effects in Fig 3. The inconclusive results are shaded in gray in Fig 3.

These findings indicate that the main results are largely, but not entirely, driven by changes in jet fuel consumption. They also suggest that increases in military expenditures increase jet fuel consumption in the long-run but might actually decrease the energy consumption of other sources, but this latter finding is inconclusive. One potential reason is that increases in military expenditures are disproportionately allocated to funding aviation and might crowd out other activities. However, Model 7 in S4 Table provides inconclusive evidence for this explanation by regressing the percentage of all energy consumption from jet fuel on military expenditures. Increases in military expenditures increase the percentage of energy consumption from jet fuel and decreases in military expenditure decrease the percentage, but both effects are between the critical bounds. These inconclusive findings warrant greater investigation beyond the scope of the present analysis.

Table 2. Results for the asymmetric relationship between military expenditures and DOD energy consumption.

	Jet Fuel ECM (5)	**All Other ECM (6)**
Short-Run Effects		
ΔMilitary Expenditures^{Increase}	.573* (.252)	.214 (.183)
ΔMilitary Expenditures^{Decrease}	-.392 (.401)	.361 (.277)
Long-Run Effects		
Military Expenditures^{Increase}	.244# (.096)	-.145# (.076)
Military Expenditures^{Decrease}	1.165* (.147)	.604* (.115)
Short-Run Asymmetry?	No	No
Long-Run Asymmetry?	Yes	Yes

Note:

*$p < .05$ (two-tailed). Standard errors are in parentheses. The standard errors for the long-run effects are calculated using the delta method. For the long-run effects,

*indicates the z-statistic is greater than 3.68 (reject null at.05 alpha level), and

#indicates the z-statistic is in between 1.10 and 3.68 (uncertain whether to reject null at.05 alpha level).

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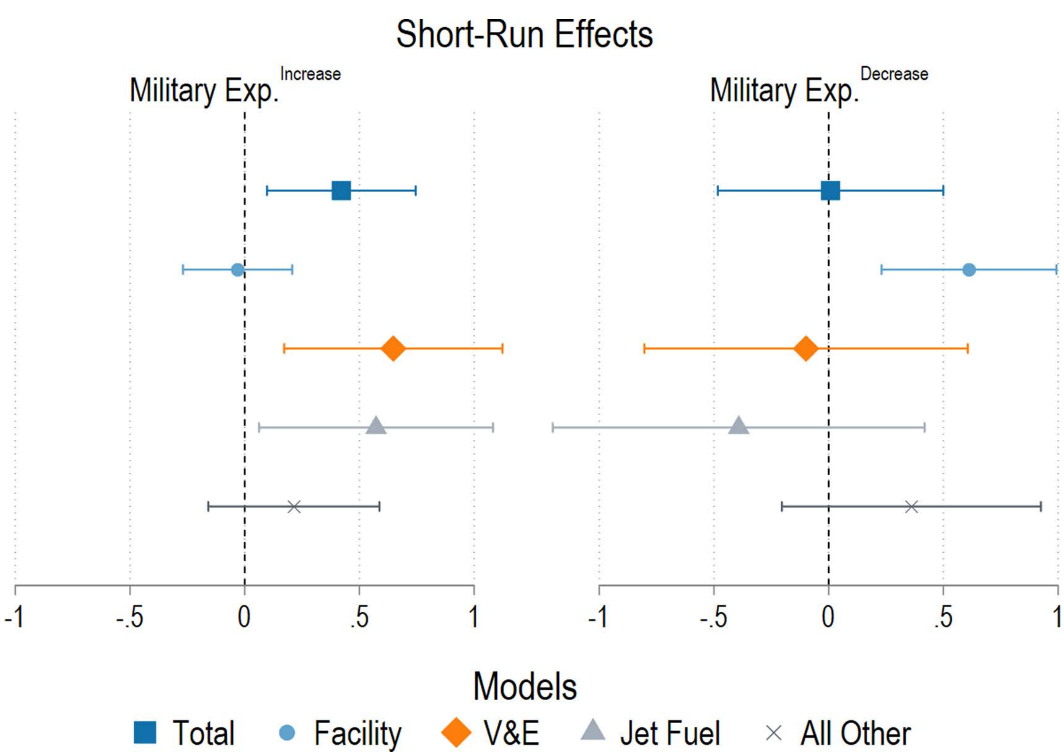

Fig 2. Coefficient plot of short-run effects. Note: V&E = vehicle & equipment energy consumption. Estimated slope coefficients with their 95% confidence interval are presented. A positive coefficient for Military Exp.^{Decrease} indicates a decrease in energy consumption, and a negative coefficient indicates an increase in energy consumption.

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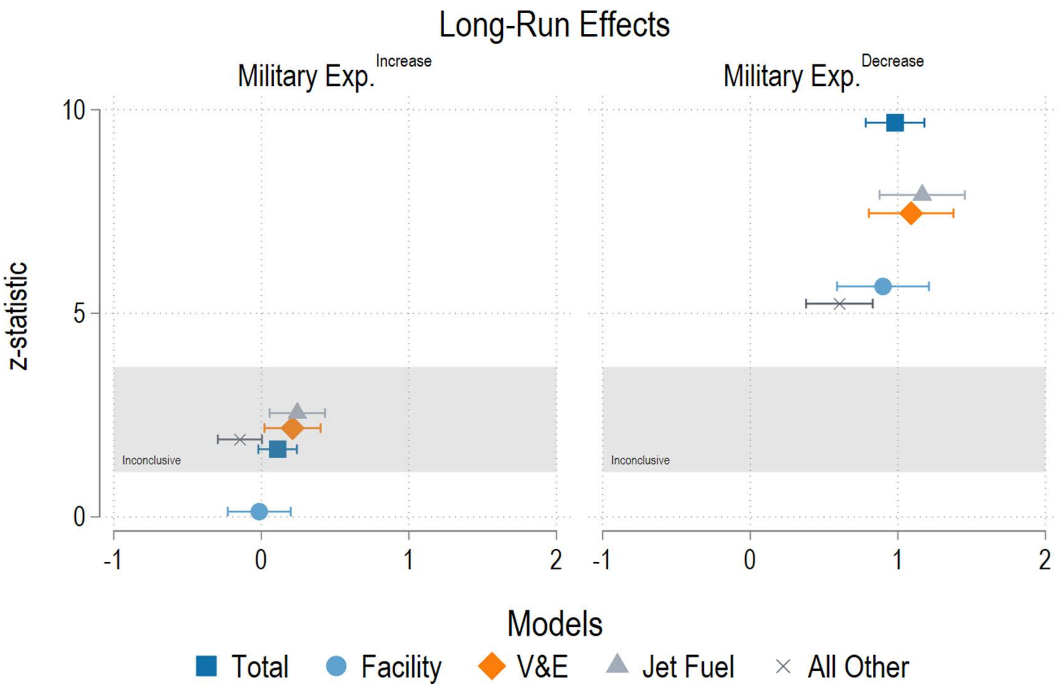

Fig 3. Coefficient plot of long-run effects. Note: V&E = vehicle & equipment energy consumption. Estimated slope coefficients with their 95% confidence interval are presented. Inconclusive region corresponds to z-statistics in between 1.10 and 3.68. A positive coefficient for Military Exp.^{Decrease} indicates a decrease in energy consumption, and a negative coefficient indicates an increase in energy consumption.

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We also compare the effect of military spending on total energy consumption with renewable energy removed. As expected, given that renewable energy is just a tiny fraction of overall DOD energy consumption (see Materials and Methods), the effects are mostly statistically equivalent. The one exception is the long-run effect for an increase in military spending on total energy consumption, which is statistically larger when renewables are included. However, the coefficients are very similar in magnitude (all energy consumption coefficient = .111, fossil fuel energy consumption coefficient = .104). The full results are reported in S4 and S5 Tables.

Comparing future military spending scenarios

To illustrate the potential impacts of different spending decisions on energy consumption, we present a forecast from 2023 to 2032 for seven different scenarios (see Table 3). We restrict the forecast to a decade to minimize uncertainty compared to more distant futures. The first three scenarios correspond to increases in U.S. military spending, whereas scenarios four through six correspond to decreases in U.S. military spending. These six scenarios represent the 10th percentile, median, and 90th percentile percentage changes for increases and decreases in military spending based on historical spending data going back to 1975. Military spending is assumed to change at the given scenario rate for each year from 2023 to 2032. In Fig 4 below, we compare each of the first six scenarios to a seventh scenario that represents a change in military spending based on its historical median (0.57%).

The results of the forecasts suggest that U.S. military spending decisions could have a substantial impact on DOD energy consumption. If spending follows its historical median change, energy consumption will increase from 642.51 trillion BTU (95% CI = 588.49 — 701.49) in 2023 to 666.92 trillion BTU (95% CI = 597.06 — 744.95) in 2032. Changes in energy consumption are magnified as the increase/decrease in spending increases in absolute terms and over time. For example, if military spending increases annually at its 90th percentile (12.28%) then energy consumption will increase from

Table 3. Seven forecast scenarios.

Increase in Military Spending		
Low (10th percentile)	Median	High (90th percentile)
0.63%	4.71%	12.28%
Decrease in Military Spending		
Low (10th percentile)	Median	High (90th percentile)
-0.52%	-2.31%	-6.59%
Median Historical Change		
	0.57%	

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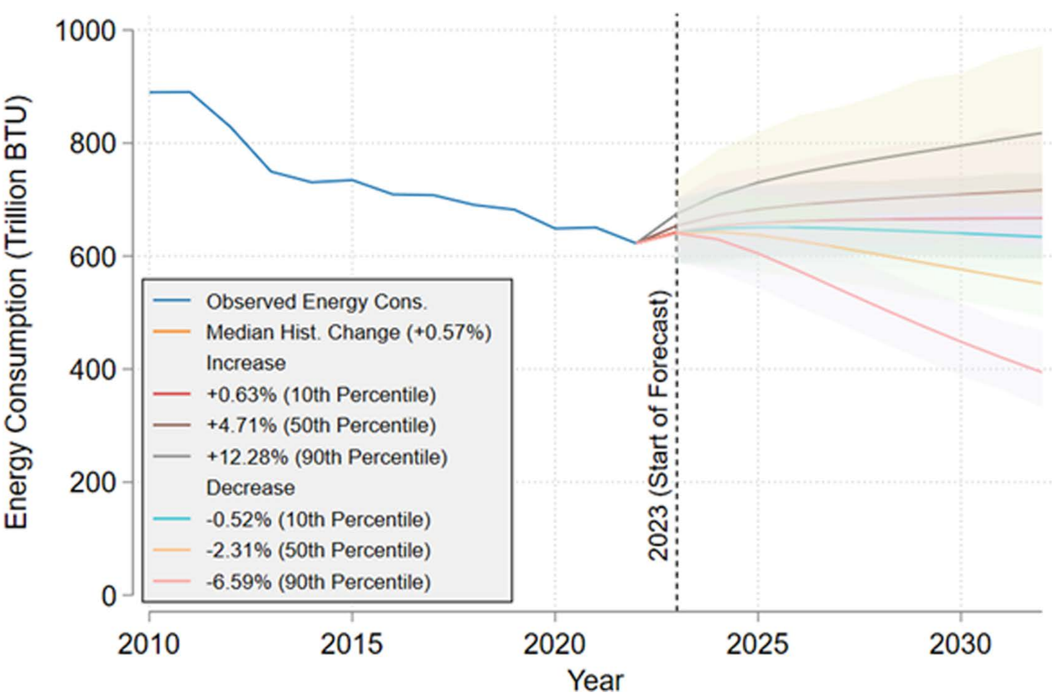

Fig 4. Forecast for each scenario, 2023-2032.

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675.01 trillion BTU (95% CI = 619.89 — 735.04) in 2023 to 817.84 trillion BTU (95% CI = 688.14 — 971.97) in 2032. In contrast, an increase at the 10th percentile (0.63%) increases energy consumption from 642.67 trillion BTU (95% CI = 592.33 — 697.29) in 2023 to 667.61 trillion BTU (95% CI = 595.30 — 748.71) in 2032.

Decreases in U.S. military expenditures have an even larger impact on DOD energy consumption. A continual annual decrease at the 10th percentile (-0.52%) results in a decrease in energy consumption from 640.94 trillion BTU (95% CI = 587.39 — 699.38) in 2023 to 634.00 trillion BTU (95% CI = 571.68 — 703.12) in 2032. A decrease at the 90th percentile (-6.59%) decreases energy consumption from 640.62 trillion BTU (95% CI = 589.09 — 696.66) in 2023 to 394.32 trillion BTU (95% CI = 332.39 — 467.77) in 2032.

Comparing changes in military energy consumption to historical median change along with country comparisons

Just how large are these changes in U.S. DOD energy consumption? Table 4 compares these consumption changes to the historical median change for the year 2032 and provides country comparisons based on 2022 data from the EIA's

Table 4. Annual Difference in Energy Consumption Relative to Historical Median Change by 2032.

Percentile	Energy Consumption Difference by 2032 (Trillion BTU)	Country/Territory/U.S. State Comparison
Increase		
10th	.698	Falkland Islands
50th	49.877	The Bahamas
90th	150.921	El Salvador/District of Columbia
Decrease		
10th	-32.915	Togo
50th	-115.767	Estonia/Vermont
90th	-272.601	Slovenia/Delaware

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International Energy Statistics (https://www.eia.gov/international/data/world), as well as U.S. state (and the District of Columbia) comparisons where applicable. By 2032, relatively small increases in military spending (the 10th percentile) result in an increase in U.S. DOD energy consumption roughly equivalent to what the Falkland Islands consume on an annual basis. At the 50th percentile, the increase in energy consumption is approximately what The Bahamas consumes annually. In a more extreme case, a large, consistent increase in military spending (the 90th percentile) results in an increase in energy consumption to approximately what El Salvador and the District of Columbia consume annually.

Decreases at the 10th, 50th, and 90th percentiles produce even larger energy consumption differences relative to the historical median change. At the 10th percentile decrease, savings in energy consumption are on par with Togo's annual energy consumption, and at the 50th percentile, the difference is similar to Estonia and Vermont's annual consumption. At the 90th percentile, the difference is approximately what Slovenia and Delaware consume annually, and Slovenia is 95th in the world in national annual energy consumption.

Discussion

This study is one of the first to examine the impact of increases and decreases in U.S. military spending on DOD energy consumption. A focus on the U.S. military addresses the limitations of prior cross-national analyses that utilize national-level measures of energy or carbon emissions, and how they are associated with national military spending. We find that a decrease in military expenditures has a larger effect on decreasing DOD energy consumption than an increase in expenditures does on increasing consumption.

The asymmetrical long-run effect of military spending on DOD energy consumption, largely due to the observed asymmetry in the effect of spending on consumption tied to facilities, vehicles and equipment, and jet fuel in particular, suggests that modestly shrinking the U.S. military might contribute meaningfully to reduced fossil-fuel consumption and climate mitigation efforts. Spending cuts could place increased pressure on the military to reduce the movement of machinery, goods, and military personnel, in terms of scale, distance, and frequency, both domestically and abroad, while also being mandated to invest a greater proportion of funds in more efficient air, land, and sea vehicles, as well as equipment that uses renewable forms of energy. A simultaneous push to retire older inefficient vehicles and equipment could likely occur, increasing the overall benefits. It is likely that such future spending cuts would lead to the closure of additional military bases, installations, and other adjacent facilities, which could further propel the reduction in the use of military air, land, and sea vehicles and equipment, and prioritizing the retirement of relatively older fossil-fueled machinery. A reduction in the military budget could help create opportunities to increase U.S. public funds for decarbonization, climate adaptation, and other sustainability efforts.

Our findings are in contrast to macro-comparative studies that find "expansion-leaning asymmetry" [39], such as cross-national research on carbon emissions and economic growth, where the estimated effect of per unit increase of

GDP on increasing carbon emissions during economic expansion is greater than the estimated effect of per unit decrease of GDP on decreasing emissions during economic contraction [43]. An explanation offered for such findings focuses on infrastructural momentum, where carbon-intensive infrastructure produced during economic expansions continue to be in service and generate carbon emissions during subsequent periods of economic contraction [43]. Comparative research on U.S. states finds expansion-leaning asymmetry as well, in the context of fossil fuel dependency and the carbon intensity of well-being [52].

Instead, our findings are consistent with prior research focusing on a singular case, such as analyses of the U.S. economy that suggest “contraction-leaning asymmetry” [39], where the estimated effect of per unit decrease of GDP on decreasing national-level carbon emissions during economic contraction is greater than the estimated effect of per unit increase of GDP on increasing emissions during economic expansion [53,54]. Contraction-leaning asymmetry has also been found for industrial sector energy consumption and aggregate GDP for the United States, as well as for the U.S. residential and commercial sectors [54]. Explanations for these prior results focus on behavioral shifts and operational changes, such as reducing miles driven and retiring production equipment with lower energy efficiency [53,54], which are consistent with our tentative explanations for the results of this study.

It is worth noting that cutting U.S. defense spending will likely be difficult as both major political parties in the United States have often maintained or increased defense spending. However, cutting defense spending has garnered support among politicians in recent years. U.S. Senators Edward Markey and Bernie Sanders called for a 10% cut in military spending in 2020 to invest in jobs, health care, and education [55], and Defense Secretary Pete Hegseth recently called for a 8% cut over each of the next five years [56]. Nevertheless, there is also additional international pressure for nations of the North Atlantic Treaty Organization (NATO) to keep defense expenditures at 2% of a country’s gross domestic product [57]. With President Trump in office for a second term, it remains to be seen what will transpire under his leadership. Trump has mentioned potentially withdrawing from NATO, but he is prohibited from doing so by Congress [58]. If Trump was able to withdraw the United States from NATO, it is possible that this would place pressure on other nations to increase their military budgets, which among other things, would increase their energy consumption and related carbon emissions. What is possible, given our results, is that if reducing defense spending did gain traction, especially within the United States, this could have spillover effects regarding the defense spending decisions of other nations, including those in NATO, which could lead to reduced energy consumption and emissions elsewhere.

Like all research, this study has limitations, which should be addressed in future analyses, data permitting. Our discussion of how decreases in military spending might lead to nontrivial long-term reductions in consumption, while consistent with the arguments of others, is largely speculative. Future research needs to dive deeper into identifying and understanding the underlying mechanisms that shape the observed asymmetrical effects of military spending on DOD energy consumption, especially for jet fuel, facility, and vehicles and equipment more broadly. Given the implications for climate mitigation and other sustainability concerns, a clearer and deeper understudying of them is critical. The analyses are also limited in nuance, as we are currently unable to separate energy consumption into narrower categories for time series large enough for analogous modeling and investigation, such as by particular types of aircraft and other vehicles, equipment, facilities, or by military branch. Similarly, we are unable to decompose the military spending data into different categories. While the analyses span multiple decades, the temporal scope is limited due to data availability, and it is unclear if the results are generalizable beyond the United States. Ideally, and data permitting, future research should conduct similar analyses for other large national militaries, including China, Germany, Russia, and the United Kingdom. Lastly, although our forecasts represent a range of spending decisions based on historical changes, it is unlikely that future scenarios will exactly follow our forecasts as spending changes will differ year-to-year. However, the forecasts provide a general sense of how energy consumption could change depending on the path that legislators take.

In conclusion, this study significantly advances our understanding of how military spending impacts energy consumption by focusing specifically on the U.S. military, which is the largest institutional polluter in the world. Our finding that a decrease in military expenditures has a larger effect on decreasing energy consumption than an increase in expenditures does on increasing consumption suggests that cutting military spending could have significant implications for climate change mitigation. As we show in our forecasts, sustained cuts to U.S. military expenditures could result in annual energy savings on par with what Slovenia or the U.S. state of Delaware consumes annually by 2032.

Supporting information

S1 Table. Summary statistics.
(DOCX)

S2 Table. Unit root tests.
(DOCX)

S3 Table. NARDL results for three main categories of energy consumption.
(DOCX)

S4 Table. NARDL results for jet fuel consumption, all other energy consumption, fossil fuel consumption, and jet fuel (% Energy Consumption).
(DOCX)

S5 Table. Cross-model hypotheses tests for NARDL results.
(DOCX)

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