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1 November 2020

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First version, November 1, 2020

Abstract: We evaluate the relationships between renewable energy consumption, net energy imports, military expenditures, arms exports, gross domestic product, and carbon dioxide emissions by using annual data about the USA during the period 1980-2016. The autoregressive distributed lag approach and the vector error correction model are used. Long-run unidirectional causalities are running from all considered variables to net energy imports and arms exports. We show that arms exports have a positive long-run effect on both renewable energy consumption and on net energy imports. Military expenditures have a positive long-term effect on renewable energy consumption, but they have a negative long-term effect on net energy imports. We recommend that the United States should prefer to export sophisticated weapons to its allies rather than intervene directly and militarily in the event it should secure its supply of imported fossil fuels; we also recommend increasing the R&D budget of the US Department of Defense allocated to innovations in renewable energies.

Keywords: Renewable energy; net energy imports; arms exports; military expenditures; autoregressive distributed lag; USA.
JEL classifications: C32; H56; O51; Q42.

1. Introduction

Several analytical papers have studied the relationship between energy and arms conflicts in the world, and particularly in the Middle East region. However, few articles have conducted an empirical analysis of this issue. Some of these studies have evaluated the impact of military spending on pollution, and to the best of our knowledge, only Bove et al. (2018) have evaluated the impact of net energy imports (NEI) on arms exports (AE). Finally, the question of the contribution of the military sector to improving that of renewable energies has been highlighted by a few analytical studies (Samaras et al., 2019) but has never been addressed empirically. This is one of the main contributions of our study. The main objective of this research is to evaluate the relationships between military expenditures (ME), military exports, net energy imports, and renewable energy (RE) consumption. Our data are about the USA, which is considered as the world number one in terms of military expenditures and exports. Also, the USA is one of the main importers of fossil energy, and one of the main producers and consumers of renewable energy.

The issue of the relationship between energy security and arms exports has been very well addressed and explained by Bove (2018) and Bove et al. (2018). Net energy importer countries export arms to net energy exporter countries to assure their security and stability because any disruption in the provision of fossil fuels has dramatic impacts on their economy. This dependency could be seen as bilateral between an importer of oil and an importer of arms, or even as regional or global because the disruption in oil provision in one important exporting country has a direct impact on international oil prices. There is a lack of empirical studies about this interesting question, and our study tries to fill this gap.

The other question we will tackle is the relationship between military expenditures and energy security. Did countries like the USA increase their military expenditures for energy security purposes? Or is it better to export arms rather than directly intervening militarily? We will try to give a response to this interesting question. We note that papers treating the relationship between energy consumption and military expenditures have mainly evaluated the impact of ME on carbon dioxide (CO_2) emissions. While some papers found that ME increase carbon emissions in the long-run (Jorgenson et al., 2010; Bildirici, 2017a; 2017b; 2017c), other papers found a mixed effect depending on the database chosen for military expenditures (Solarin et al., 2018). Clark et al. (2010) found that military expenditures increase energy consumption. Bildirici (2016) found bidirectional causality between defense expenditures, energy consumption, and economic growth in China.

Lastly, and importantly, does the military sector can contribute to improving renewable energy production and use? Samaras et al. (2019) pointed out that the interaction between military and non-military energy issues has not been sufficiently and explicitly dealing with in the literature. It is well known that research and development (R&D) in the defense sector has impacted technological change in several economic sectors like civil aviation or aerospace (jet engines, radar, satellite communication, etc.). Samaras et al. (2019) claim that we are now on the cusp of an eventual similar energy technology transfer because of economic reasons as well as more direct military concerns. Indeed, the department of defense is the largest US department user of energy with a 77% share of the entire federal government energy consumption (Greenley, 2019). Besides, innovation in energy and in particular in renewable energy could considerably reduce the heavy military energy bill and increase the autonomy of troops on battlefields concerning the supply of energy, in particular fossil energy. For example, the technology of home-mini-grids-installation has been improved as an alternative fuel for major weapons systems. These authors suggest to those concerned by civilian energy to take the innovations emanating from the military sector seriously and to take advantage of technological externalities in both directions.

We have chosen to study the USA case because of several reasons. First, the USA has the biggest defense budget in the world and is the first world exporter of arms. Indeed, according to Tian et al. (2020), world military expenditures have been estimated to $1917 billion in 2019, and the top five biggest spenders were the United States ($732 billion), China ($261 billion), India ($71.1 billion), Russia ($65.1 billion), and Saudi Arabia ($61.9 billion). These five countries accounted together for 62% of global military spending.

International transfers of major arms have grown continuously in volume since 2003 (Wezeman et al., 2019) and have increased by 23% between 2004–2008 and 2014–18. The top five biggest exporters in 2014–18 were the United States, Russia, France, Germany, and China, accounting together for 75% of the global volume of arms exports. In 2014-18, US exports accounted for 36% of global exports. US arms exports have realized an increase of 29% between 2009–13 and 2014–18, while arms imports by the Middle East states have increased by 87%. Between 2014 and 2018, the destination of US arms exports in Saudi Arabia (22%), Australia (7.7%), and the United Arab Emirates (6.7%). For most golf countries, the USA was the main supplier of arms. US arms imports as a percentage of total arms imports represent 68% for Saudi Arabia, 64% for the United Arab Emirates, 47% for Iraq, 65% for Qatar, and 87% for Kuwait.

Second, according to the Energy Information Administration (2020), the USA is the largest producer of oil (including crude oil, all other petroleum liquids, and biofuels) in the world in 2019 with 19.51 million barrels per day representing 19% of the world's total share. The five biggest oil producer countries of the Gulf region are Saudi Arabia, Iraq, United Arab Emirates, Iran, and Kuwait with an oil production per day as a share of the total world equal to 12%, 5%, 4%, 3%, and 3%, respectively, representing a total share of 27% for these five countries together. In 2017, the USA is the largest consumer of oil with 19.96 million barrels per day representing 20% of the world's total share. The USA is one of the biggest exporter and importer of petroleum and other liquids in the world. Almost 20% of US oil imports come from the OPEC (Organization of the Petroleum Exporting Countries) countries in the Persian Gulf (Nerurkar, 2011). Estimates showed that a sustained $10 increase in the barrel price of oil could reduce U.S. economic growth by 0.2%. This may be true even in a scenario where the U.S produced as much oil as it consumed because international oil prices increase would raise the costs of oil for U.S households and businesses and cause economic disruptions.

The USA has decided on several incentives for renewable energy and energy efficiency to reduce their fossil fuel consumption and greenhouse gas emissions. These decisions brought worth considering results as the share of renewable energy in the energy mix has notably increased. In this respect, the consumption of biofuels and other non-hydroelectric renewable energy sources has more than doubled from 2000 to 2018, and a continuous increase is expected until 2050 (Energy Information Administration, 2020). For the 2018 year, the USA has an energy mix including petroleum, natural gas, coal, renewable energy, and nuclear electric power with the proportions of 36%, 31%, 13%, 11%, and 8%, respectively. Electricity generation has a proportion of 17% coming from renewable energy and this latter is comprised of renewable biomass (45%), hydroelectric (25%), wind (21%), solar (6%), and geothermal (2%).

To our knowledge, there is no empirical research estimating the long-term impact of military spending or arms exports on renewable energy consumption or net energy imports. Moreover, the causal relationships between renewable energy consumption, net energy imports, military spending, and arms exports have never been evaluated. We aim to fill this gap in this study. For this purpose, we use annual data about the USA during the period 1980-2016. Our variables of interest are renewable energy consumption, net energy imports, arms exports, military expenditures, carbon dioxide emissions, and gross domestic product (GDP). Long-term elasticities will be estimated through the autoregressive distributed lag (ARDL) approach, the long-term cointegration between all considered variables is checked through the Johansen and

Juselius (1990) cointegration test, and the short and long-term causalities are established using the vector error correction model (VECM) approach.

The remainder of our paper is composed of Section 2 dealing with literature review, Section 3, which is about data, econometric analysis, and results' discussion, and Section 4 contains a conclusion with policy recommendations.

2. Review of the literature

While several analytical papers are dealing with the relationship between energy and arms conflicts, there are few empirical papers about this interesting subject. Bove et al. (2018) use data about 149 countries and gravity models to understand how oil dependency impacts weapons' trade between countries. They show that the degree of dependence on oil supply from a given country has an impact on the volume of arms transfers to that country. However, even when there is no direct bilateral exchange of oil-for-weapons, global oil dependence justifies the export of arms to oil-rich countries. Net energy imports and the military burden (% of GDP) have a positive impact on arms exports.

Papers dealing with the relationships between energy consumption and military expenditures have mainly estimated the impact of these latter on carbon dioxide emissions. Some papers found that ME increase carbon emissions in the long-run. Jorgenson et al. (2010) use cross-national panel analyses and show that both the number of soldiers and military technological sophistication have significant and negative effects on the environment. They explain their results by the expansion of militarism that led to the development of high-tech weapons and vehicles big consumers of fossil fuels and large emitters of carbon dioxide. Bildirici (2017a) uses several econometric tools to investigate the causal relationships between per capita CO_2 emissions, per capita GDP, defense expenditures, and ethanol consumption for the USA case by considering data covering the period 1984 to 2015. They find bidirectional causality between defense expenditures and ethanol consumption, and a unidirectional causality running from defense expenditures to carbon emissions. While defense expenditures increase carbon emissions in the long-run, ethanol consumption reduces it.

Bildirici (2017b) investigates the relationships among defense expenditures, carbon emissions, per capita GDP, and energy consumption by applying panel methods to G7 countries (Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States). Bidirectional causalities between the three variables defense expenditures, energy consumption, and economic growth have been found. There is a unidirectional causality running from defense expenditures to carbon emissions. In the long-run, defense expenditures, energy consumption, and economic growth increase CO_2 emissions. Bildirici (2017c) uses data about the USA during the period 1960–2013 and examines the causal relationships between CO_2 emissions, defense expenditures, per capita GDP, and energy consumption. There is a bidirectional causality between defense expenditures and economic growth. In the long-run, defense expenditures, energy consumption, and economic growth contribute to global warming.

Other papers found a mixed effect concerning the impact of military expenditures on the environment. Solarin et al. (2018) evaluate the impact of military expenditures on CO_2 emissions in the USA during the years 1960–2015. Two measures of military expenditure are used, and several time series models are estimated. They find that military expenditures have a mixed impact on carbon emissions depending on the database used. While per capita energy and non-renewable energy consumption increase per capita carbon emissions in the long-run, per capita renewable energy consumption reduces it.

Clark et al. (2010) analyze an unbalanced cross-national panel data set comprised of 68 countries. Their estimate of fixed effects panel models highlights that both high-tech militarization, measured as military expenditures per soldier, and military personnel, measured as the number of soldiers, increase total energy consumption. Bildirici (2016) use time-series data about China and found bidirectional causalities between defense expenditures, energy consumption, and economic growth. In the long-run, economic growth and military expenditures increase energy consumption in China.

The literature about energy (non-renewable and renewable) consumption is very rich. We can cite Ang (2007), Belloumi (2009), Ozturk and Acaravci (2010), Apergis and Payne (2011), Sadorsky (2012), Al-Mulali et al. (2014), Shahbaz et al. (2014), Inglesi-Lotz and Dogan (2018), Ben Jebli et al. (2020), and Nathaniel and Khan (2020). Wurlod and Noailly (2018) consider 17 OECD (Organisation for Economic Co-operation and Development) countries and 14 industrial sectors and show that, in most sectors, green innovation has reduced energy intensity, this reduction being more pronounced during recent years. Cheng et al. (2019) compute panel regressions with data about the BRIICS countries (Brazil, Russian Federation, India, Indonesia, China, South Africa). They find that renewable energy reduces CO_2 emissions with the highest effect being attained at the 95th quantile. Since environmental patents are shown increasing carbon emissions importantly at the 95th quantile, they advise BRIICS countries to support new environmental patents creations, while speeding up their dissemination.

Several other papers about energy have been devoted to the USA case (Payne, 2009; Bowden and Payne, 2009; Soytas et al., 2007; Menyah and Wolde-Rufael, 2010; Dogan and Turkekul, 2016). Dogan and Ozturk (2017) use annual data about the USA and show that while non-renewable energy consumption increases CO_2 emissions renewable energy consumption reduces carbon emissions. Shahbaz et al. (2017) show that the relationship between economic growth and carbon emissions is inverted-U shaped and even N-shaped in the case of data about the USA. Besides, biomass energy consumption, exports, imports, and trade openness reduce carbon emissions. Bidirectional Granger causality between CO_2 emissions and biomass energy consumption, and a unidirectional causality running from economic growth to CO_2 emissions are also detected. Ben Youssef (2020) evaluates the impact of foreign R&D spillovers on pollution and renewable energy consumption by using data bout the USA. Short-run unidirectional causalities are running from NEI to non-resident patents (NRP), renewable energy, carbon emissions, and fossil energy. NRP reduce carbon emissions in the long-run, while resident patents (RP) increase it. RP and NRP are shown to boost economic growth and renewable energy consumption.

According to the literature review, there is no empirical research estimating the long-run impact of military expenditures or arms exports on renewable energy consumption or net energy imports. Also, the causal relationships between military spending, arms exports, net energy imports, and renewable energy have never been evaluated. Notice that, to the best of our knowledge, Bove et al. (2018) is the only paper studying the relationships between military spending, arms exports, and NEI, and has more precisely evaluated the impact of net energy imports and military burden on arms exports. Solarin et al. (2018) have estimated the long-run impact of military expenditures and renewable energy consumption on carbon emissions.

3) Data and econometric analysis

31. Data and stationary tests

Our annual collected data about the United States range from 1980 to 2016 and include the variables: *i)* gross domestic product (GDP, y) in constant 2010 US $; *ii)* imports and exports of petroleum and other liquids are in 1000 barrels per day (Mb/d), and net energy imports (NEI, nei) are equal to imports minus exports; *iii)* renewable electricity (RE, re) net generation is measured in billion kilowatt-hours (kwh); *iv)* carbon dioxide emissions (CO_2, e), in million metric tons (MM Tons), comprise emissions coming from the consumption of petroleum, natural gas, coal, and natural gas flaring; *v)* arms transfers or exports (AE, ae) consist of the supply of military weapons through sales, aid, gifts as well as those made through manufacturing licenses; data are in Trend Indicator Values (TIVs) expressed in millions of US dollars (US$ m.) at constant 1990 prices; *vi)* military expenditures (ME, me) are in constant 2018 US millions dollars (US$ m.).

Data about renewable energy, net energy imports, and carbon emissions have been obtained from the US Energy Information Administration (2020), and those about GDP have been obtained from the World Bank (2020). Data on arms exports and military expenditures have been obtained from the Stockholm International Peace Research Institute (SIPRI, 2020). We were constrained by data availability without any possibility to use monthly or quarterly data. Our econometric computations are done with Eviews 10 software after natural logarithmic transformation.

For stationary purposes, we use two unit root tests: augmented Dickey and Fuller (ADF, 1979) and Phillips and Perron (PP, 1988). The three cases of intercept, intercept and trend, and no intercept and trend are evaluated for both tests, and the same conclusions are obtained. Table 1 gives the case of intercept and trend and shows that all our variables are no stationary at level. However, their first differences are stationary, meaning that our considered variables are integrated of order one.

Table 1. Stationary tests

Variables	ADF stat				P-P stat			
	Level	k	1st diff	k	Level	k	1st diff	k
re	-2.284	0	-6.085[a]	0	-2.284	0	-6.692[a]	6
nei	-0.614	0	-4.012[b]	3	-1.240	3	-4.146[b]	3
ae	-2.981	1	-4.594[a]	1	-2.082	4	-5.133[a]	25
me	-1.958	1	-3.313[c]	0	-1.918	4	-3.222[c]	2
e	-0.315	0	-6.150[a]	1	-0.283	2	-5.476[a]	2
y	-1.197	1	-4.343[a]	0	-0.789	3	-4.136[b]	7

We give only the intercept and trend case. Augmented Dickey-Fuller and Phillips-Perron tests are denoted by ADF and P-P, respectively. In the case of the ADF test, k is the optimal lag length selected by the Schwarz information criterion (SIC), with a maximum lag of 4. In the case of the PP test, k is the Newey-West Bandwidth using Bartlett Kernel.
Statistical levels of significance at 1%, 5%, and 10% are denoted by [a], [b], and [c], respectively.

3.2. Long-run cointegration and elasticities

Our main independent variables in this study are arms exports and military expenditures. We will try to evaluate their long-run impact on renewable energy consumption and on net energy imports. For this purpose, the following two models will be estimated:

$$re_t = c_1 + \alpha_1 nei_t + \alpha_2 ae_t + \alpha_3 me_t + \alpha_4 e_t + \varepsilon_{1t} \quad (1)$$

$$nei_t = c_2 + \beta_1 re_t + \beta_2 ae_t + \beta_3 me_t + \beta_4 y_t + \varepsilon_{2t} \quad (2)$$

Where c_i denote the constant terms; α_i *and* β_i denote the long-run elasticity of the endogenous variable with respect to the corresponding exogenous variable; ε_{it} represent the residual terms.

We use the autoregressive distributed lag approach proposed by Pesaran and Pesaran (1997), Pesaran and Smith (1998), and Pesaran et al. (2001) to assess the long-run cointegration between variables and to evaluate long-run elasticities. This ARDL method is preferred to other cointegration techniques because it avoids endogeneity problems and can lead to good estimates even with small samples. When Y_t is the endogenous variable and $X_{it}, i = 1, \dots k$ are the exogenous variables, the ARDL equation may have the following expression:

$$\begin{aligned}\Delta Y_t &= c + \sum_{i=1}^{q_0} \gamma_{0i} \Delta Y_{t-i} + \sum_{i=0}^{q_1} \gamma_{1i} \Delta X_{1,t-i} + \sum_{i=0}^{q_2} \gamma_{2i} \Delta X_{2,t-i} + \dots + \sum_{i=0}^{q_k} \gamma_{ki} \Delta X_{k,t-i} + \\ &\lambda_0 Y_{t-1} + \lambda_1 X_{1,t-1} + \lambda_2 X_{2,t-1} + \dots + \lambda_k X_{k,t-1} + \varepsilon_t\end{aligned} \tag{3}$$

Where the first differences, the residual terms, and the numbers of lags are denoted, respectively, by Δ, ε_t, and $q_j, j = 0,1,2,..k$. The estimated coefficients are denoted by $c, \gamma_{ji}, \lambda_j$. The Akaike information criterion (AIC) could be used to fix the optimal number of lags. Pesaran et al. (2001) propose to compare the estimated Fisher-statistics (F) of the Wald test to two critical values: there is no cointegration between variables when it is weaker than the lower value I(0), and there is cointegration when it is higher than the upper value I(1). However, this test is inconclusive when the Fisher statistics is comprised between I(0) and I(1). The tests for normality, heteroskedasticity, and serial correlation of residues are then computed to assure the robustness of our results. In Table 2, we give the results of our cointegration analysis. It is shown that there is long-run cointegration between the considered variables, for each considered equation.

Table 2. ARDL bounds for cointegration

Estimated model	Optimal lag length	F-statistics	Normality test	LM-test	BPG-test	Conclusion
F_1(re/nei,ae,me,e)	1,5,4,2,5	4.737[b]	0.865	0.160	0.449	Cointegration
F_2(nei/re,ae,me,y)	4,0,1,4,0	11.850[a]	0.743	0.157	0.561	Cointegration

The F(.) statistics are computed for the case of intercept and trend. Critical values are taken from Pesaran et al. (2001) for the case of a finite sample n=35. For model 1 (resp. model 2), the maximum number of lags selected are equal to 2 (resp. 4) and 5 (resp. 4) for the dependent and independent variables, respectively. The Akaike information criterion (AIC) is used to determine optimal lags. Diagnostic tests include serial correlation (Breusch-Godfrey serial correlation LM test), heteroskedasticity (Breusch-Pagan-Godfrey(BPG) test), and normality (Jarque-Bera test); the probability of rejecting the null hypothesis is provided. The LM test is made with lag=2.

Statistical levels of significance at 1% and 5% are denoted by ^{a} and ^{b}, respectively.

Long-run parameter estimates are listed in Table 3. All these estimates are statistically significant at the 1% or 5% levels, except the constant term for model 1. An increase in arms exports seems to have a positive long-run impact on renewable energy consumption in the USA. We can give two explanations for this: first, arms exports bring more money for the US government that can be used to encourage investments in green innovation or renewable energy projects. Second, arms exports are in general increased when there are political tensions or arms conflicts in the Middle East and this incites the USA to look for renewable energy resources as an energy resource in place of fossil fuels imported from the Middle East. This interesting result is new because the relationship between arms exports and renewable energy consumption has not been treated econometrically before.

Interestingly, an increase in military expenditures has a long-run positive impact on US renewable energy consumption. Several reasons may explain this new and very interesting result. First, civil renewable energy technology may have already benefited from military renewable energy technology improvements, leading to increasing renewable energy production and consumption in the USA. These military technology improvements may be due to the increase of the US military budget and in particular to the increase of the R&D budget of the defense department. Second, an important increase in military expenditures due to political or armed conflicts in which the USA is directly or indirectly engaged incites the US authorities to look for less costly and more secured renewable energy resources. More net energy imports incite to renewable energy use. This denotes the long-run worry of the USA regarding its energy security and the important fossil energy bill it has to support when its NEI are increased. This result is similar to that reached by Ben Youssef (2020) for the USA case.

An increase in military expenditures reduces net energy imports in the long-run. This proves that higher military expenditures, usually associated with more direct military interventions in the Middle East region, have led to less political stability and more armed conflicts in this region leading sometimes to World economic perturbations and less fossil energy secured supply. However, an increase in arms exports increases net energy imports in the long-run. This signifies that supporting the stability of political regimes in the Middle East region to assure a stable World supply of fossil energy by providing allies with high tech weapons is an effective strategy. These last two insightful results are new and have not been shown before. Let us recall that Bove et al. (2018) have considered 149 countries and gravity models to show that an increase in NEI or military burden (% of GDP) increases arms exports, while in our study we show that an increase in arms exports (resp. military expenditures) increases (resp. decreases) net energy imports. An increase in renewable energy consumption makes the USA less energy-dependent from abroad as it reduces its NEI. Finally, economic growth needs more energy than the United States can produce and appears to be putting pressure on energy imports.

Table 3. Estimates of long-run elasticities

	Exogenous variables						
Model/ endogenous variable	C	re	nei	ae	me	e	Y
Model 1: re	23.414 (0.394)	-	3.337 (0.006)[a]	1.172 (0.009)[a]	1.670 (0.004)[a]	-9.327 (0.034)[b]	-
Model 2: nei	-36.773 (0.001)[a]	-1.091 (0.055)[b]	-	0.666 (0.011)[a]	-0.599 (0.007)[a]	-	1.796 (0.000)[a]

Statistical levels of significance at 1% and 5% are denoted by [a] and [b], respectively.

We verify the stability of our long-run estimated coefficients employing the cumulative sum (CUSUM) and the cumulative sum of squares (CUSUMS) statistics. These statistics have been developed by Brown et al. (1975). We can suppose that the estimated coefficients of a given regression are stable when the plots of these statistics are within the critical bounds of 5%. These statistical test results are given in Figures 1 and 2, showing that these statistics are well within the critical values at the significance level of 5%. Therefore, we can consider that all our long-run ARDL estimated coefficients are stable.

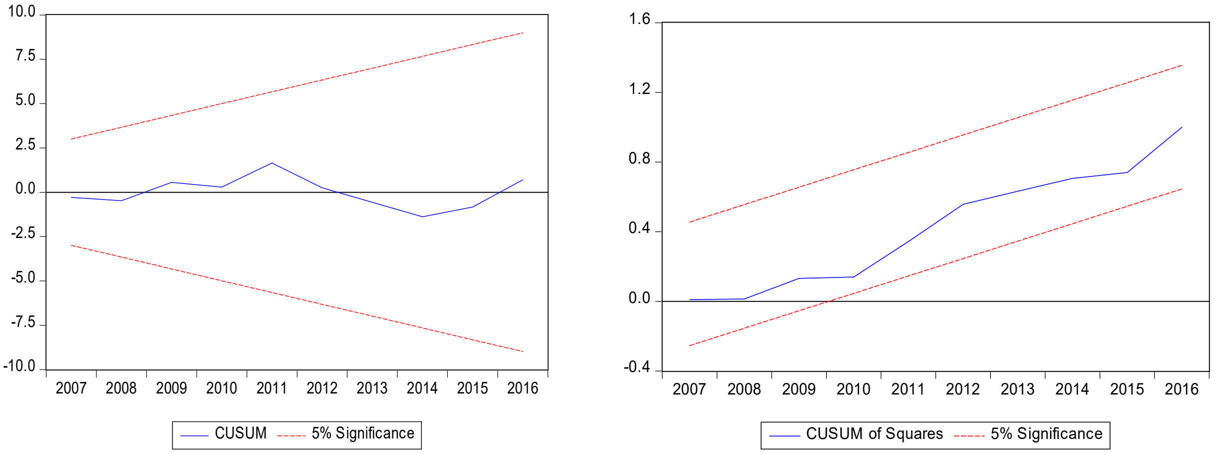

Fig.1. CUSUM and CUSUMS of recursive residuals for re

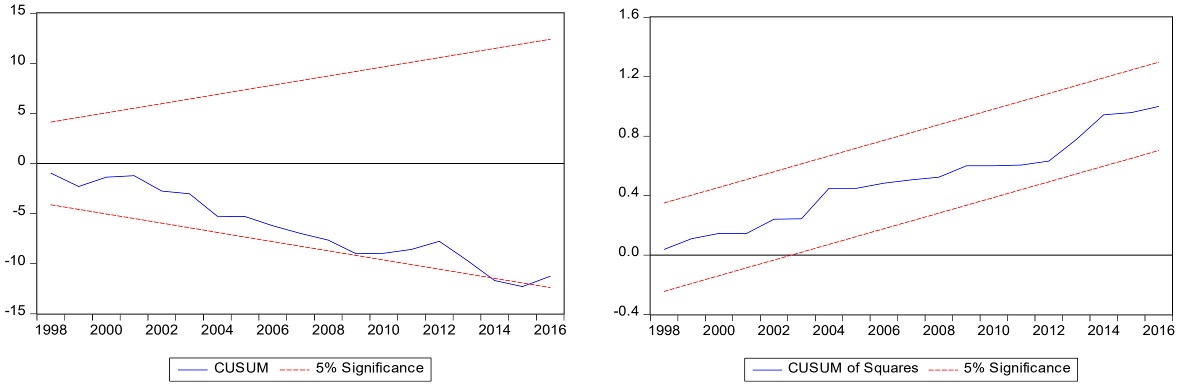

Fig.2. CUSUM and CUSUMS of recursive residuals for nei

3.3. Causality of Granger

We evaluate the direction of causalities between our considered variables by using the procedure of Engle and Granger (1987). As all our variables are integrated of the same order, the vector error correction model is used. Consider a model comprising k variables $X_i, i = 1, \ldots k$; to build its VECM representation, we have to take at each time a variable as endogenous and the other variables become exogenous leading to a representation of the error correction model (ECM). Consider $X_l, l = 1, \ldots, k$ is the endogenous variable, then our model's ECM representation is:

$$\Delta X_{l,t} = \delta_l + \sum_{i=0}^{q} \phi_{l,1,i} \Delta X_{1,t-i} + \ldots + \sum_{i=1}^{q} \phi_{l,l,i} \Delta X_{l,t-i} + \ldots + \sum_{i=0}^{q} \phi_{l,k,i} \Delta X_{k,t-i} + \theta_l ECT_{t-1} + v_{l,t} \qquad (4)$$

We denote the first difference operator, the vector autoregressive (VAR) lag length, and the lagged error correction term by Δ, q, and ECT_{t-1}, respectively; the adjustment speed from the short to the long-run equilibrium is denoted by θ_l, and the residual term by $v_{l,t}$.

Before running the vector error correction model, we have to show that our variables are cointegrated in the long-run. We will follow a three steps procedure. We begin by choosing the optimal lag length. For this purpose, we run the standard VAR model with a maximum lag equal to two. Several criteria are employed which are Log-likelihood (LogL), Log-likelihood ratio (LR), final prediction error (FPE), Hannan-Quinn (HQ) information criterion, Akaike information criterion, and Schwarz information criterion (SIC). Table 4 indicates that one is the optimal lag to consider.

Table 4. Selection of the VAR lag order

Lag	LogL	LR	FPE	AIC	SIC	HQ
0	147.2230	NA	1.26e-11	-8.069885	-7.803254	-7.977844
1	372.1917	359.9500*	2.66e-16	-18.86810	-17.00168*	-18.22381*
2	412.7438	50.97975	2.48e-16*	-19.12822*	-15.66201	-17.93168

The lag order chosen by the criterion is indicated by *.

The second step tries to show the existence of a long-run cointegration between our variables through the Johansen and Juselius (1990) cointegration test. Table 5 provides the results for the trace statistic case with intercept and no trend and shows the presence of two cointegrating equations at the 5% significance level. The Max-eigenvalue test indicates the presence of three cointegrating equations at the 5% significance level. To conclude, we can run the VECM model because of the presence of a long-run relationship between our variables.

Table 5. Cointegration test of Johansen and Juselius

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	5% Critical Value	Prob.
None *	0.709931	118.7055	95.75366	0.0005
At most 1 *	0.625199	75.38821	69.81889	0.0168
At most 2	0.559124	41.04060	47.85613	0.1874
At most 3	0.199727	12.37593	29.79707	0.9180
At most 4	0.104511	4.577858	15.49471	0.8519
At most 5	0.020204	0.714378	3.841466	0.3980

The rejection of the hypothesis at the significance level of 5% is denoted by *.

Consider system equations (4) and the equation related to the endogenous variable X_l. The Fisher statistics of the Wald test is used on the estimated parameters $\phi_{l,j,i}$ to show the presence of a short-run causality running from the variable X_j to X_l. We deduce the presence of a long-run causality running from all the exogenous variables to X_l, when the estimated parameter θ_l is negative and significant (t-Student is used).

The Portmanteau autocorrelation test for residuals helps us for checking the robustness of the VECM. For example, there is no residual autocorrelation up to lag 12 as the Q-statistic is equal to 336.046 with a probability of rejecting the null hypothesis of 0.999, and the adjusted Q-statistic is equal to 415.117 with a probability of 0.638. Table 6 reports our short and long-run causalities.

Table 6. Tests of Granger causality

Endogenous variables	Short-run						ECT
	Δre	Δnei	Δae	Δme	Δe	Δy	
Δre		8.652	0.209	0.150	2.377	0.085	0.476
		(0.003)^{a}	(0.647)	(0.698)	(0.123)	(0.770)	[3.386]^{a}
Δnei	2.447	-	0.122	0.012	0.010	0.874	-0.207
	(0.118)		(0.726)	(0.914)	(0.919)	(0.350)	[-1.631]^{c}
Δae	0.148	0.688	-	0.058	3.085	10.502	-0.463
	(0.700)	(0.407)		(0.810)	(0.079)^{c}	(0.001)^{a}	[-2.407]^{b}
Δme	2.179	0.209	0.039	-	0.022	0.001	-0.041
	(0.139)	(0.647)	(0.843)		(0.883)	(0.979)	[-0.470]
Δe	0.010	1.751	0.100	0.968	-	0.170	0.006
	(0.922)	(0.186)	(0.751)	(0.325)		(0.680)	[0.151]
Δy	6.4E-5	0.334	0.301	0.428	0.001	-	-0.027
	(0.994)	(0.563)	(0.583)	(0.513)	(0.974)		[-0.939]

1 is the optimal lag used. P-values and t-statistics are within parenthesis and brackets, respectively. Statistical significance at the levels of 1%, 5%, and 10% are denoted by ^{a}, ^{b}, and ^{c}, respectively.

From Table 6 we can see that the error correction terms of the net energy imports and the arms exports equations are both negative and statistically significant. Therefore, we have a long-run causality running from RE, AE, ME, E, and GDP to net energy imports. These constitute new and interesting results not reached before by the literature because most of the literature, except Bove et al. (2018) and Ben Youssef (2020), has not considered the variable net energy imports. However, these two previous studies did not found any long-run causality between RE and NEI. In our study, renewable energy production and consumption reduces the dependency of the US on fossil energy and thus has a long-run impact on its net energy imports. Arms exports increase contributes to the stability of political regimes, especially in the Middle East region, and contributes to assuring a steady World supply in fossil energy, leading to a long-run impact on net energy imports. During the last two decades, and particularly between 2001 and 2011, the USA has experienced a high increase in military expenditures, which was coupled with direct military intervention in the Middle East. This has engendered more armed conflicts in this region and did not helped to secure World's provision in fossil energy and thus has impacted NEI of the US in the long-run. Economic growth needs more energy and, as expected, has a long-run impact on net energy imports in the USA.

We also have a long-run causality running from RE, NEI, ME, E, and GDP to arms exports. These are worth considering results as no preceding research has studied the causal relationships between arms exports and one of the variables considered in our model. Let us remind that Bove et al. (2018) used gravity models about 149 countries and showed that NEI, military burden (% of GDP), and economic growth increase arms exports. Renewable energy production and consumption increase reduces the dependency of the US economy on fossil energy and thus diminishes the need for securing foreign fossil energy supply, and this has a long-run impact on arms exports. Net energy imports increase puts pressure on the need of securing the supply of fossil energy, particularly that from the Middle East, and this seems to have a long-run effect on arms exports designed to reinforce the stability of political regimes in this region. Higher military expenditures have a long-run impact on arms exports at least for three reasons: *i)* this may imply a higher R&D budget for US weapons improvements making them more attractable for foreign buyers; *ii)* this may denote that the US has decided to intervene militarily directly to secure the supply in fossil energy, without a great need for arms exports; *iii)* lastly, the arms production capacity of the US becomes greater, inciting it to look for exportation. Economic growth increase has a short and long-run impact on arms exports because: a*)* it implies a higher need for fossil energy supply, and this pushes the US to increase its arms exports to secure its supply in energy; b*)* it enables to get the necessary funds for R&D leading to the improvement of US weapons and thus increasing arms exports. We have a short-run unidirectional causality running from net energy imports to renewable energy consumption due to the important bill of imported fossil energy that pushes the US for renewable energy use. This result is following that of Ben Youssef (2020).

4. Conclusion

This paper estimates the long-run impact of military expenditures and arms exports on renewable energy consumption and on net energy imports. We also evaluate the causal relationships between renewable energy consumption, net energy imports, military expenditures, and arms exports. Annual data concerning the US spanning the period 1980-2016 are used. The autoregressive distributed lag approach is used to evaluate long-term elasticities, then the long-term cointegration between all considered variables is established, and Granger causalities analysis is made by using the vector error correction model approach. We show the presence of unidirectional long-term causalities running from RE, AE, ME, E, and GDP to net energy imports, and RE, NEI, ME, E, and GDP to arms exports.

In the US, arms exports have a positive long-run effect on renewable energy consumption. Indeed, arms exports bring more money for the US government that can be used to promote investments in renewable energy projects or green innovation. Also, the increase in arms exports could be linked to political or armed conflicts in the Middle East prompting the United States to seek renewable energy resources as an alternative to imported fossil fuels. This result deserves to be taken into consideration because the relationships between arms exports and the consumption of renewable energy have not yet been approached econometrically.

Military expenditures increase is beneficial to renewable energy production and consumption in the US. This may be explained by the R&D externalities that have already benefited civil renewable energy technology from military renewable energy technology improvements. These military technology ameliorations may be caused by the US military budget increase and especially the increase of the defense department R&D budget. Moreover, a significant increase in defense spending due to political and military tensions directly or indirectly involving the United States pushes the American authorities to seek renewable resources that are cheaper and more secure.

Net energy imports incite to renewable energy use in the long-term, and we have short-term causality running from NEI to RE. This expresses the United States' concern about its energy security and the heavy fossil fuel bill it must bear when its NEI grows, prompting it to use more renewables. In this respect, renewable energy consumption increase reduces NEI in the long-run because it makes the US less energy-dependent from abroad.

While military spending reduces net energy imports in the long run, arms exports increase them. This shows that the increase in US military spending, generally synonymous with more direct military interventions in the Middle East region, has led to less political stability and an increase in armed conflict in this region, sometimes leading to World economic disruptions and less security of fossil fuel supply. However, supporting the stability of political regimes in the Middle East region to ensure a steady global supply of fossil fuels by providing allies with high-tech weapons is an effective strategy to secure the supply of fossil fuels. These last two revealing results are new and worth considering.

Given our econometric results, we can draw the following conclusions and future policy recommendations. In the last decades, the US high military expenditures and direct interventions in armed conflicts, particularly in the Middle East region, have not contributed to secure the provision of the US in fossil energy, but rather they have increased political tensions and created international economic perturbations that reduced the US provision in foreign fossil energy. However, this increase in military expenditures seems to have created R&D spillovers from military renewable energy innovation to the civil one. Meanwhile, arms exports helped to secure the supply of foreign fossil energy of the US while boosting renewable energy production and consumption. Therefore, our recommendations are twofold: Any time the

United States feels threatened in its external fossil fuels supply, it should choose to provide its allies with sophisticated weapons to ensure their security and stability rather than intervening militarily in a direct manner; Second, we recommend an increase in the US defense R&D budget allocated to renewable energy because of its positive impact on the consumption of renewable energy in the United States.

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