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A Global Analysis of Trade Tension, Energy Security and Sustainable Transition

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We present global evidence on the impact of trade tensions (TTs) on energy security and the transition to renewable energy for a panel of 36 countries. In the short run, trade tensions increase energy security and carbon emissions, while in the long run, they reduce energy security and carbon emissions. The effects of trade tensions on energy security are more pronounced for the U.S. trade tensions than for the U.S.-China trade tensions.

I. Introduction

This study investigates the effects of trade tensions on energy security and the transition to renewable energy across a panel of 36 countries. Rising energy prices, driven by shifting trade relationships and geopolitical risks, have heightened the significance of trade tensions for energy security (Zhao et al., 2025). The pursuit of energy security is closely tied to renewable energy transitions, as nations invest to mitigate climate shocks and enhance energy availability, affordability, and accessibility. Notably, the recent U.S.-China tariffs on solar panels and related components, such as batteries and transition metals, directly link trade tensions to renewable energy investments. At the same time, research indicates that trade disruptions can stimulate domestic development by encouraging innovation and solutions that may offset trade deficits in the long term (Freund, 2023; Stepanov et al., 2024). Therefore, we hypothesize that trade tensions yield long-term benefits for energy security and emissions reduction, while they may reduce energy security and emissions reduction in the short term.

Theoretical perspectives suggest that trade tensions can disrupt energy supply chains in the short run, undermining energy security and emission reduction goals. However, these disruptions can also drive innovation, diversification, and investment in greener energy systems, leading to improved energy security and emissions reduction over the long term (Dunford & Han, 2025; Romer, 1990). Using annual data from 1995 to 2024 for 36 countries, the study finds that U.S. trade policy uncertainty influences energy security and sustainability. For robustness, the analysis is also conducted using the U.S.-China trade tension index.

Six distinct subsamples, namely Asia-Pacific (includes China, India, Japan, South Korea, Indonesia, Singapore, Australia, and New Zealand), America (includes United States, Canada, Brazil, Mexico, Argentina, and Chile), Europe (includes United Kingdom, France, Germany, Italy, Ukraine, Austria, Belgium, Portugal, Spain, Hungary, Switzerland, Finland, Denmark, Turkey, Norway, Poland, and Iceland), Africa (South Africa, Egypt, and Morocco), advanced economies (includes G7 countries), and emerging economies (non-G7 countries) are included in the analysis. Prior studies by Gao et al. (2024) and Zuo & Majeed (2024) have focused on trade uncertainty and renewable energy consumption in the U.S. and China. This study addresses a gap in the literature by offering a global perspective on the relationship between trade tensions, energy security, and sustainability. It utilizes diverse measures of trade tensions and accounts for heterogeneity across multiple subsamples.

The rest of the paper is organized as follows. Section II describes the methodology used in this study followed by main findings presented in Section III. Final section concludes the study.

II. Methodology

The study employs a sample of 36 countries that account for more than 85% of the world's gross domestic product. Following the specified theoretical background, the econometric formulation of a bivariate model linking trade tensions to energy transition and sustainable development is defined as follows:

$$S_{it} = \alpha + \beta K_{i,t-1} + \mu_i + \varepsilon_{it} \\ i = 1, 2, 3, \dots, N; t = 1, 2, \dots, T \quad (1)$$

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S_{it} is defined as the percentage change in total energy supply per capita or combustion from CO₂ emissions, which is specific to each country; K_{it} is the percentage change in either the U.S. trade policy uncertainty index or the U.S.-China trade index, which is general for all sampled nations; μ_i stands for country-specific effects, while ε_{it} is the stochastic error term.

We use the panel ARDL model proposed by Pesaran & Smith (1995) and Pesaran et al. (1999), with extensive procedural and empirical illustrations provided by Salisu & Ndako (2018). The model addresses the issue of dynamic heterogeneity that is often associated with panels with large N and large T . In line with the objectives of the study, Equation (1) is re-specified in a linear Panel ARDL (p, q) form as follows:

$$\begin{aligned} \Delta S_{it} = & \vartheta_i(S_{i,t-1} - \psi_{0i} - \psi_{1i}K_{i,t-1}) \\ & + \sum_{j=1}^p \lambda_{ij}\Delta S_{i,t-j} + \sum_{j=0}^q \gamma_{ij}\Delta K_{i,t-j} + \nu_{it} \\ & i = 1, 2, 3, \dots, N; t = 1, 2, \dots, T \end{aligned} \quad (2)$$

where Δ is the first difference operator; γ_{ij} measures the short-run relationship between the two variables, while ϑ_i captures the long-run equilibrium in the model and represents the speed at which deviations of short-run dynamics adjust to the long-run equilibrium. The study refers to Salisu & Ndako (2018) for additional derivations on the mean group¹ (MG) and pooled mean group² (PMG) estimators.

Annual data on total energy supply per capita and CO₂ emissions from combustion are obtained from The Energy Institute (<https://www.energyinst.org/statistical-review/re-sources-and-data-downloads>). Monthly data on the U.S. trade policy uncertainty and the U.S.-China Trade index are sourced from https://www.policyuncertainty.com/trade_cimpr.html, credited to Baker et al. (2016) and Rogers et al. (2024). Aggregation to annual data was performed by averaging all monthly observations.

Our sole focus on energy supply as an index of energy security is justified by its centrality to various perspectives of energy security, such as availability, affordability (i.e., prices), and stability (Kim et al., 2025). Thus, the energy security index adopted in this study captures the behavior of energy-vulnerable economies in the face of supply disruption. In addition, the intensity of CO₂ emissions has been shown to significantly decrease as countries adopt more renewable and efficient energy systems (Lau et al., 2023; Pakrooh et al., 2025).

The current study acknowledges the limitations of the empirical inquiry in addressing other dimensions of energy security, such as import dependency and energy diversification. Additionally, transforming monthly indices into annual averages may obscure the effects of volatility in energy supply and trade tensions.

III. Results

The section begins with the presentation of results with a preliminary analysis of trade tensions, energy security, and sustainable transition. Table 1 shows that advanced (196.21), Asia-Pacific (177.13), and European (172.65) economies record a greater supply of energy per capita than other blocs and regions, highlighting higher levels of energy security. The Asia-Pacific (1447.67), advanced (1295.27), and American (1151.48 ± 133.91) economies had higher CO₂ emissions from combustion than other regions (mean = 640.28 ± 1497.92).

The main results of the empirical analysis conducted in this study are presented in Tables 2–3 and Tables A and B in the appendix. The following outcomes are deduced: (i) In the short run, the total energy supply per capita for the full sample, Asia-Pacific, America, and advanced economies was significantly and positively disrupted by the U.S. trade tensions (see Table 2). However, this positive disruption is accompanied by higher carbon emissions (see Table 3), indicating that impacted nations retreat from their renewable energy commitments in response to trade tensions to offset the effects. (ii) In the long run, the total energy supply per capita for the full sample, Asia-Pacific, America, and advanced economies is significantly and negatively impacted by the U.S. trade tensions (see Table 2), showing that sustained trade tensions adversely affect energy supply. This negative disruption is accompanied by lower carbon emissions (see Table 3), highlighting that impacted nations develop more energy-smart and efficient technologies over a prolonged exposure to trade tensions. As noted by Lau et al. (2023), such renewable energy infrastructures lead to a substitution effect between fossil and green energy, where countries reduce their per capita energy consumption or ecological footprint through green and energy-efficient technologies. However, renewable energy infrastructures also require significant initial capital investments, a highly skilled workforce, and novel technology (referred to as the technology base effort), which may disrupt long-run energy supply and security. (iii) Interestingly, compared to the U.S.-China trade tensions (see Tables provided in the appendix), the U.S. trade tensions (see Tables 2–3) have a more pronounced and significant impact on all economies and blocs, underscoring the notion that the U.S. trade tensions target a wider range of economies and blocs and have a greater effect than the latter, particularly regarding energy security and sustainability.

IV. Conclusion

This study contributes to the literature on trade tension, energy security, and renewable energy transition by ana-

¹ It is assumed that all parameters (long-run and short-run) differ across countries or entities.

² It is assumed that long-run relationships are common across units, but the short-run dynamics and error-correction speeds differ. We find this assumption to be more fitting for the current inquiry, as long-term responses to trade tensions are expected to converge across countries. However, these assumptions are tested for each model using Hausman's test to decide the best fit.

Table 1. Descriptive statistics

	Full Sample	Asia	America	Europe	Africa	Advanced	Emerging
Total Energy Supply							
Mean	158.818	177.1333	146.3271	172.6468	47.37653	196.2056	149.7934
Max	903.532	649.1912	355.6465	903.532	102.9409	355.6465	903.532
Min	10.55273	10.55273	31.512	37.8222	13.80795	93.02262	10.55273
Std. Dev.	133.9146	154.7662	121.9204	129.4788	31.79054	80.49267	142.4402
No. obs.	1080	240	180	570	90	210	870
CO₂ Emissions							
Mean	640.2837	1447.666	1151.482	206.0242	215.1781	1295.271	482.1833
Max	11172.85	11172.85	5885.034	914.8445	475.9517	5885.034	11172.85
Min	1.813847	27.98577	42.28093	1.813847	27.14705	254.2081	1.813847
Std. Dev.	1497.922	2450.287	1880.498	203.1834	163.1448	1674.629	1408.127
No. obs.	1080	240	180	570	90	210	870
The U.S.-China Trade Tension Index							
Mean			103.9192				
Max			199.5386				
Min			56.54682				
Std. Dev.			36.16974				
The U.S. Trade Policy Uncertainty							
Mean			118.3419				
Max			797.1224				
Min			28.73999				
Std. Dev.			156.2814				

Note: This table reports descriptive statistics of all variables used in this study.

lyzing the effects of the U.S. trade tensions and the U.S.-China trade tensions on energy security and sustainable transition. On a global scale, the results emphasize that these trade tensions are accompanied by higher short-run energy security and increased carbon emissions, indicating that in response to trade tensions, countries tend to retreat from their renewable energy commitments to offset the shocks. Conversely, in the long run, the opposite holds true, highlighting the broader trade-offs between short-run energy security and long-run sustainability. The study draws policymakers' attention to the importance of energy

technology, diversification, energy supply chain decoupling strategies, and the Carbon Border Adjustment Mechanism (CBAM), among other measures, in building resilience to trade tensions and ensuring long-term benefits. The highlighted limitations (refer to section II) may serve as motivation for future studies.

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Table 2. Panel ARDL model highlighting the effects of the U.S. trade tension on energy security (TES)

	Full Sample		Asia		America		Europe	
	mg	pmg	mg	pmg	mg	pmg	Mg	pmg
Ec	-1.0533*** (0.0026)	-1.0455*** (0.0439)	-0.9103*** (0.0994)	-0.8994*** (0.0991)	-0.9978*** (0.0499)	-0.9832*** (0.0412)	-1.1279*** (0.0612)	-1.1236*** (0.0605)
Short Run (TES)	0.0108*** (0.0015)	0.0107*** (0.0007)	0.0074** (0.0032)	0.0088*** (0.0018)	0.0179*** (0.0036)	0.0154*** (0.0010)	0.0109*** (0.0016)	0.0104*** (0.0008)
Long Run (TES)	-0.0116*** (0.0026)	-0.0099*** (0.0017)	-0.0063* (0.0036)	-0.0095*** (0.0035)	-0.0212*** (0.0063)	-0.0167*** (0.0039)	-0.0114*** (0.0041)	-0.0083*** (0.0024)
Constant	0.3687 (0.2836)	0.3666 (0.2731)	1.5229*** (0.5805)	1.5354*** (0.5852)	0.8542* (0.4624)	0.8046* (0.4243)	-0.4073 (0.3613)	-0.4111 (0.3367)
Hausman Test	0.6		45.59***		0.85		0.82	
No. of Countries	36		8		6		19	
Obs.	1080		240		180		570	
	Africa		Advanced		Emerging			
	mg	pmg	mg	pmg	mg	pmg		
ec	-1.0722*** (0.2241)	-1.0654*** (0.2203)	-1.1922*** (0.0673)	-1.1906*** (0.0584)	-1.0197*** (0.0514)	-1.0109*** (0.0507)		
Short Run (TES)	0.0044 (0.0064)	0.0045*** (0.0009)	0.0150*** (0.0011)	0.0152*** (0.0013)	0.0097*** (0.0017)	0.0093*** (0.0007)		
Long Run (TES)	-0.0077 (0.0084)	-0.0046 (0.0060)	-0.0121*** (0.0019)	-0.0119*** (0.0029)	-0.0114*** (0.0033)	-0.0089*** (0.0021)		
Constant	1.2339	1.2247 (1.0166)	-0.8753*** (0.2069)	-0.8677*** (0.2046)	0.6689** (0.3256)	0.6569** (0.3109)		
Hausman Test	0.29		-0.01		0.99			
No. of Countries	3		7		29			
Obs.	90		210		870			

Notes: Values in parentheses are the standard errors. All the variables are expressed in percentage change or returns. ***, ** and * indicates statistical significance at 1%, 5%, & 10% levels, respectively. Also, ec denotes the error correction term. The acronym mg refers to mean group while pmg refers to pooled mean group. The lack of significance of the chi-square values of the Hausman test indicates that the pmg model is preferred.

Table 3. Panel ARDL model highlighting the effects of the U.S. trade tension on emissions (CEM)

	Full Sample		Asia		America		Europe	
	mg	pmg	mg	pmg	mg	pmg	mg	pmg
ec	-1.0480 *** (0.0397)	-1.0386 *** (0.0386)	-0.8848 *** (0.1180)	-0.0119 *** (0.0045)	-1.0164 *** (0.0596)	-0.9948 *** (0.0498)	-1.1143 *** (0.0422)	-1.1103 *** (0.0403)
Short Run (CEM)	0.0152 *** (0.0021)	0.0153 *** (0.0009)	0.0081 ** (0.0040)	0.0097 *** (0.0021)	0.0235 *** (0.0041)	0.0209 *** (0.0013)	0.01698 ** (0.0028)	0.0171 *** (0.0012)
Long Run (CEM)	-0.0162 *** (0.0027)	-0.0157 *** (0.0021)	-0.0083 * (0.0045)	-0.0119 *** (0.0045)	-0.0298 *** (0.0076)	-0.0252 *** (0.0051)	-0.0162 *** (0.0036)	-0.0155 *** (0.0029)
Constant	0.6519 (0.4014)	0.6463 * (0.3906)	2.2024 *** (0.7991)	2.2397 *** (0.8042)	1.7979 *** (0.5129)	1.7256 *** (0.4710)	-0.7354 (0.4559)	-0.7144 * (0.4309)
Hausman test	0.07		1098.86 ***		0.66		0.12	
No. of Countries	36		08		06		19	
Obs.	1080		240		180		570	
	Africa		Advanced		Emerging			
	mg	pmg	mg	pmg	mg	pmg		
ec	-1.1267 *** (0.1649)	-1.1192 *** (0.1609)	-1.1478 *** (0.0330)	-1.1442 *** (0.0319)	-1.0239 *** (0.0477)	-1.0148 *** (0.0463)		
Short Run (CEM)	0.0068 (0.0089)	0.0072 *** (0.0019)	0.0218 *** (0.0017)	0.0217 *** (0.0005)	0.0136 *** (0.0025)	0.0128 *** (0.0011)		
Long Run (CEM)	-0.0099 (0.0097)	-0.0082 (0.0063)	-0.0209 *** (0.0019)	-0.0207 *** (0.0038)	-0.0151 *** (0.0034)	-0.0131 *** (0.0025)		
Constant	3.0126 *** (1.1485)	3.0115 *** (1.1639)	-0.6083 * (0.3215)	-0.6190 * (0.3412)	0.9562 ** (0.4772)	0.9348 ** (0.4618)		
Hausman test	0.06		0.00				0.71	
No. of Countries	03		07				29	
Obs.	90		210				870	

Notes: Values in parentheses are the standard errors. All the variables are expressed in percentage change or returns. ***, ** and * indicates statistical significance at 1%, 5%, & 10% levels, respectively. Also, ec denotes the error correction term. The acronym mg refers to mean group while pmg refers to pooled mean group. The lack of significance of the chi-square values of the Hausman test indicates that the pmg model is preferred.



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APPENDIX

Table A. Panel ARDL model highlighting the effects of the U.S.-China trade tension on energy security (TES)

	Full Sample		Asia		America		Europe	
	mg	pmg	mg	pmg	mg	pmg	mg	pmg
ec	-1.0394 ^{***}	-1.0384 ^{***}	-0.8852 ^{***}	-0.8877 ^{***}	-0.9742 ^{***}	-0.9704 ^{***}	-1.1199 ^{***}	-1.1161 ^{***}
	(0.0447)	(0.0438)	(0.0986)	(0.0939)	(0.0597)	(0.0665)	(0.0598)	(0.0598)
Short Run (CEM)	0.0099	0.0136 ^{***}	0.0573 [*]	0.0467 ^{**}	0.0251 ^{**}	0.0316 ^{***}	-0.0085	-0.0058
	(0.0110)	(0.0052)	(0.0317)	(0.0189)	(0.0118)	(0.0076)	(0.0132)	(0.0056)
Long Run (CEM)	-0.0309	-0.0288 ^{**}	-0.1304 ^{**}	-0.0722 ^{***}	-0.0521 ^{***}	-0.0674 ^{**}	0.0093	-0.0017
	(0.0200)	(0.0124)	(0.0573)	(0.0272)	(0.0118)	(0.0285)	(0.0231)	(0.0175)
Constant	0.3234	0.3563	1.7492 ^{***}	1.7254 ^{***}	0.7640 ^{**}	0.7953 ^{**}	-0.5208	-0.5154
	(0.2833)	(0.2681)	(0.6415)	(0.5883)	(0.3713)	(0.3989)	(0.3175)	(0.3255)
Hausman test	0.02		1.34		-0.40		0.53	
No. of Countries	36		08		06		19	
Obs.	1080		240		180		570	
	Africa		Advanced		Emerging			
	mg	pmg	mg	pmg	pmg		mg	
ec	-1.0717 ^{***}	-1.0659 ^{***}	-1.1726 ^{***}	-1.0717 ^{***}	-1.0659 ^{***}		-1.1726 ^{***}	
	(0.2249)	(0.2297)	(0.0412)	(0.2249)	(0.2297)		(0.0412)	
Short Run (CEM)	-0.0304	-0.0319 ^{***}	0.0272 ^{**}	-0.0304	-0.0319 ^{***}		0.0272 ^{**}	
	(0.0197)	(0.0010)	(0.0125)	(0.0197)	(0.0010)		(0.0125)	
Long Run (CEM)	0.0232	0.0356	-0.0472 ^{***}	0.0232	0.0356		-0.0472 ^{***}	
	(0.0411)	(0.0429)	(0.0113)	(0.0411)	(0.0429)		(0.0113)	
Constant	0.9871	0.9677	-0.7634 ^{***}	0.9871	0.9677		-0.7634 ^{***}	
	(1.0916)	(0.9753)	(0.2339)	(1.0916)	(0.9753)		(0.2339)	
Hausman test	7.34 ^{***}		-0.10		0.33		7.34 ^{***}	
No. of Countries	03		07		29		03	
Obs.	90		210		870		90	

Notes: Values in parentheses are the standard errors. All the variables are expressed in percentage change or returns. ***, ** and * indicates statistical significance at 1%, 5%, & 10% levels, respectively. Also, ec denotes the error correction term. The acronym mg refers to mean group while pmg refers to pooled mean group. The lack of significance of the chi-square values of the Hausman test indicates that the pmg model is preferred.

Table B. Panel ARDL model highlighting the effects of the U.S.-China trade tension on emissions (CEM)

	Full Sample		Asia		America		Europe	
	mg	pmg	mg	pmg	mg	pmg	mg	pmg
ec	-1.0279 *** (0.0415)	-1.0238 *** (0.0402)	-0.8534 *** (0.1119)	-0.8555 *** (0.1088)	-0.9737 *** (0.0671)	-0.9571 *** (0.0778)	-1.1086 *** (0.0459)	-1.1047 *** (0.0432)
Short Run (CEM)	0.0323 ** (0.0143)	0.0287 *** (0.0073)	0.0710 * (0.0410)	0.0614 ** (0.0262)	0.0171 (0.0208)	0.0315 *** (0.0113)	0.0323 * (0.0186)	0.0252 *** (0.0068)
Long Run (CEM)	-0.0726 *** (0.0269)	-0.0486 *** (0.0156)	-0.1295 * (0.0731)	-0.0676 * (0.0346)	-0.0421 (0.0384)	-0.0777 ** (0.0381)	-0.0720 * (0.0379)	-0.0478 ** (0.0218)
Constant	0.6209 (0.4037)	0.5888 (0.3819)	2.3573 *** (0.8679)	2.3443 * (0.8043)	1.4257 *** (0.3293)	1.4816 *** (0.3777)	-0.6655 (0.4875)	-0.7349 * (0.4228)
Hausman test	1.19		0.93		61.78 ***		0.61	
No. of Countries	36		08		06		19	
Obs.	1080		240		180		570	
	Africa		Advanced		Emerging			
	mg	pmg	mg	pmg	pmg			Mg
ec	-1.0806 *** (0.1915)	-1.0695 *** (0.2019)	-1.1300 *** (0.0237)	-1.1316 *** (0.0256)	-1.0022 *** (0.0503)			-0.9997 *** (0.0484)
Short Run (CEM)	-0.0402 *** (0.0149)	-0.0486 *** (0.0144)	0.0461 *** (0.0153)	0.0488 *** (0.0129)	0.0289 * (0.0174)			0.0212 ** (0.0084)
Long Run (CEM)	0.0145 (0.0639)	0.0442 (0.0464)	-0.0698 *** (0.0104)	-0.0739 *** (0.0286)	-0.0733 ** (0.0335)			-0.0366 ** (0.0185)
Constant	2.5290 (1.1719)	2.4279 ** (1.0697)		-0.5582 (0.3490)	0.9111 * (0.4804)			0.8477 * (0.4522)
Hausman test	0.45		-0.02		1.74			
No. of Countries	03		07		29			
Obs.	90		210		870			

Notes: Values in parentheses are the standard errors. All the variables are expressed in percentage change or returns. ***, ** and * indicates statistical significance at 1%, 5%, & 10% levels, respectively. Also, ec denotes the error correction term. The acronym mg refers to mean group while pmg refers to pooled mean group. The lack of significance of the chi-square values of the Hausman test indicates that the pmg model is preferred.