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Interplay of Geopolitical Risk, Economic Growth, and Renewable Energy

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Abstract

Despite widespread consensus on the need for renewables-based energy systems, the deployment of green infrastructure remains uneven and structurally bottlenecked. Most macroeconomic literature broadly aggregates the energy transition into a one-dimensional, static factor, thereby concealing the dichotomy between decarbonization aspirations and economic reality. This paper bridges this gap by quantifying the macroeconomic, structural, and geopolitical determinants affecting renewable energy transition using panel data from 42 countries over 2002-2022. Methodologically, this study disaggregated the dependent variable into a three-tier supply-chain (installed capacity, generation, and end-use consumption) and leveraged a Two-Way Fixed Effects model with Driscoll-Kraay standard errors to account for cross-sectional dependence and heteroskedasticity. Global market integration and rising geopolitical tension were identified as significant drivers that incentivized countries to diversify their energy supply with domestic green infrastructure. At the same time, urbanization and lagging greenhouse gas emissions were negative determinants of green energy generation, pushing economies toward continued utilization of fossil-fuel energy grids. Perhaps most importantly, while higher levels of domestic income were positively correlated with renewable capacity buildup, they had a negative correlation with end-use consumption, demonstrating that developing economies revert to traditional approaches to meet the excess demand. Baseline regulatory quality was also found to be statistically insignificant across all models, implying that environmental decrees are insufficient to impact the energy transition on their own.

Keywords: *Geopolitics, Renewable Energy Transformation, Renewable Energy Consumption*

Introduction

Background of the Study

The defining macroeconomic and geopolitical challenge of the 21st century is the global transition toward renewable energy, which is no longer merely an environmental imperative. The global energy transition is not a smooth and linear progression away from fossil fuels; it is a complex structural tug-of-war between the long-term ambition to decarbonize and the harsh but immediate realities of economic growth. Strong international consensus and regulatory mandates to decarbonize the global economy are backed by the World Energy Investment Report of the International Energy Agency (IEA), which estimates that global investment in clean energy has reached unprecedented levels, of which roughly $2.2 trillion is destined for clean energy technologies (renewables, grids, and storage) in a single year. The actual deployment of green infrastructure is complex and thus remains highly asymmetrical. The global coal demand is at an all-time high of 8.8 billion tons in 2024. This is driven heavily by industrializing economies, as found in the Coal 2024/2025 Report of the International Energy Agency (IEA). The nation's ambition for rapid economic expansion results in a profound paradox. The aggressive pursuit of domestic wealth and industrialization generates massive, immediate surges in aggregate energy demand. An increase in Global electricity demand by 4.3% in 2024, according to the Electricity 2025 Report - International Energy Agency (IEA), is primarily driven by the heavy industry and manufacturing sectors in emerging economies. Since clean energy infrastructure is capital-intensive and require long term to be potentially deployed. Therefore, Sudden economic demand exceeds the capacity of deployed clean energy in the short term.

Demographic shifts and global instability highly impact Structural changes like the transition towards clean energy. Global prices and a stable supply chain of fossil fuels are vulnerable to worldwide conflicts and diplomatic disruptions. Therefore, nations are transitioning toward renewable energy to achieve energy sovereignty and avoid devastating manipulation. Approximately 80% of the global population (roughly 6 billion people) lives in countries that import fossil fuels. This makes the vast majority of the world highly vulnerable to geopolitical shocks and energy crises, according to the United Nations (via the International Renewable Energy Agency - IRENA). However, severe domestic bottlenecks such as Rapid, concentrated urbanization and entrenched, carbon-intensive legacy industries counter the transition. Additionally, it forces governments to depend on traditional production techniques, resulting in the carbon-lock-in cycle in the economy. United Nations Human Settlements Programme (UN-Habitat) reports that 75% of global primary energy is consumed in Urban areas and cities, currently making them responsible for roughly 80% of global greenhouse gas emissions.

Despite the prevailing complexity of these competitive macroeconomic forces, the existing literature treats the renewable energy transition as a single static variable. To truly understand the mechanics of energy transition, it must be analyzed as a multi-stage supply chain. This conventional approach critically blends the immense capital required to build physical infrastructure with the day-to-day realities of electricity flow and consumer end-demand. Variables like global wealth, structural constraints, and geopolitical threats impact the different stages of the transition, renewable capacity, generation, and consumption differently. Therefore, it is required to examine the multi-stage supply chain to understand the mechanism of energy transition.

Significance of the Study

Theoretically, this study makes a profound contribution to the prevailing macroeconomic and environmental literature by countering the assumption that the renewable energy transition is a uniform process. Through empirically separating the transition into three distinct supply-chain stages, installed capacity, actual generation, and end-user consumption, this research provides a required framework that interprets how variables like economic wealth and demographic shifts impact infrastructure and demand differently. Furthermore, the study enhances the literature by integrating the Caldara and Iacoviello Geopolitical Risk (GPR) index alongside traditional variables for formally testing the energy security hypothesis. Methodologically, by using a Two-way Fixed Effects model with Driscoll-Kraay standard errors across a 42-country panel, this research corrects for cross-sectional dependence and heteroskedasticity, which provides valid and efficient results for future researchers to study the interconnected impact more clearly.

Practically, the study offers functional information for policymakers, governments, and investors. The study alarms policymakers from solely relying on paper regulations by proving that standard regulatory quality fails to drive the transition independently. Instead, it emphasizes the integration of domestic economic wealth and trade openness to finance capital-intensive green infrastructure. Furthermore, exploring the rising energy demands in populated cities, it informs governments to implement precautionary and effective planning to avoid the unavailability of energy. Ultimately, the global instability endangers energy security persistently, which could be avoided when having empirical proof that accelerating domestic renewable energy is critically affected by geopolitical risk and climate mitigation strategies, as given by this study.

Problem Statement

Traditional frameworks characterize geopolitical risk (GPR) as a severe inhibitor that disrupts supply chains and depresses green investments. On the other hand, emerging research argues that GPR actually acts as a catalyst that forces nations to accelerate renewable adoption to secure strategic energy autonomy. This unresolved paradox leaves a critical gap in both academic consensus and energy policy formulation. Therefore, this study empirically investigates the non-linear dynamics between GPR and renewable energy adoption to determine whether global instability ultimately stunts sustainable development or inadvertently drives the quest for energy independence.

Primary Research Hypothesis

The transition to renewable energy is not a linear outcome of domestic wealth and regulation, but rather an ambiguous tussle of macroeconomic variables. Geopolitical risk and global trade integration act as powerful facilitators, driving nations towards energy security. Whereas the rapid domestic economic growth, urbanization, and carbon emissions act as stern structural bottlenecks, due to the recurrent and enormous energy demands of industrialization.

Literature Review

Geopolitical Risk and Renewable Energy (Transition)

Renewable energy plays an important role in shaping the global energy dynamics. It constitutes a significant proportion of the total energy share. Though primarily adopted due to environmental safety imperative, but it has become the major player in the energy sovereignty approach now. Countries are massively investing in clean energy infrastructure to ensure the deployment of energy without external dependence or supply chain disruptions.

There is a negative relationship between the trend of energy transition and geopolitical risk (Bakhsh et al., 2024). The transition towards sustainable energy, as stimulated by environmental governance and economic complexity, is countered by GPR. The study results over 20 OECD Countries from 1990 to 2021 found potential for economic complexity and environmental governance as key drivers for the energy transition. The OECD countries are also being affected by the GPR in terms of RE consumption. GPR, CO2 emissions, and Natural Resource rent all negatively affect the RE consumption in OECD countries in varied proportion.

In G7 countries, geopolitical risk has significantly affected the deployment of renewable energy resources. GPR potentially reduced the deployment of solar PV by 1.98% and hydropower by 1.99%, approximately. Onshore wind energy possesses resilience to geopolitical risk, demonstrating no negative response. (Bello & Abdulwahab Hassan, 2024). Over the period analysis of 2010 to 2024 show the trend that in high-volatility regimes, GPR amplifies oil market volatility, while in low-volatility regimes, GPR has a dampening effect on oil market volatility (Chen et al., 2024).

There is a dynamic and inconsistently negative relationship between geopolitical risk and energy security in China (Zhang et al., 2023). China's 31 provincial panel data from 1994 to 2021 confirms that being the world's largest energy producer and consumer, China faces particular challenges due to its high reliance on imported oil and natural gas, therefore highly impacted by GPR, including conflicts and trade frictions in terms of energy security.

GPR stunts sustainable development by causing decreases in international trade, disruptions in global supply chains, and hindering technology in China (Li et al., 2025). The effect is amplified by the excessive natural resource rent, which causes the resource curse, leaving the country on a divested, unsustainable development path. On the contrary, FDI and technological innovation prove to be positively contributing to the sustainable growth of China.

GPR predicts the Global Financial Cycle (GFCy) by hypothesizing a negative relationship between the GPR and risky assets (Salisu et al., 2023). To examine the vulnerability of risky assets to geopolitical risk, the study examines global risky assets data historically from 1980 to 2019. An increase in GPR dispirits investments in risky assets, which further worsens the (GFCy). GPR Threats have a stronger negative impact than Acts, which represent the actual occurrence of these acts. Similarly, during the investigation of the effect of the GPR on RE consumption in 20 OECD countries, from 1970 to 2019, GPR significantly and negatively impacts renewable energy demand (Z. Zhao et al., 2023).

GPR plays a role as a catalyst for the RE transition in different nations. It drives RET more aggressively in ecologically disadvantaged countries, those with high CO2 emissions (He et al., 2025). The study tests observations from 41 countries from 2000 to 2021. A 1% increase in GPR is associated with a 1.946% improvement in RET. While High Trade openness results in a negative impact of GPR on RET. However, the Technological Innovation (TI) is crucial for GPR to drive RET. In the panel Analysis of 39 countries from 2003 to 2019 Geopolitical risks significantly promote energy transition, including both energy consumption and energy production transitions (S. Wang et al., 2023). A 1% increase in geopolitical risks contributes to a 0.2298% improvement in energy consumption transition and a 0.1859% in energy production transition. A mutual relationship exists where GPR drives RE (security), and RE redefines GPR (peace/new powers) through Two-way causality (Su et al., 2021).

Geopolitical tensions, i.e., the Russia-Ukraine conflict, started in Feb 2022, which led to the disruptions of fossil fuel, especially gas, supply to EU war has expressed the complex dependence of the EU on the Russian fossil fuel supply. (Issac Tesfu, 2024).

GPR in fossil fuel supplier countries has accelerated the transition to renewable energy across Europe (Hille, 2023). Fixed Effects Two-Stage Least Squares (FE-2SLS) estimation on 37 European countries over the data from 1991 to 2021 demonstrates that the transition is because of ensuring energy security. Contributory to this, the Russia-Ukraine war is one of the biggest GPR boosting factors and variables affecting EU countries. The EU plans to secure 63.5 billion cubic meters of gas through alternative imports, which include reliable suppliers, i.e., Norway, for the short term and Qatar, mainly for long-term transition. US – LNG is also widely prioritized as a reliable resource for energy import (Proedrou, 2023).

While high GPR in Russia creates insecurity for Europe, it simultaneously acts as a catalyst for investing and transformation to cleaner and renewable energy by the European countries. (Erdogan et al., 2024) highlights the mixed and variant causality patterns between GPR and cleaner energy transitions, emphasizing considering the importance of various complex dynamics. Study examines Bulgaria, Czechia, Germany, Romania, and Switzerland from Jan 2019 – Jan 2024 for Clean Electricity Generation (Hydro, Solar, Wind, Nuclear) against the GPR index.

GPR can have both negative and positive effects on Energy Security (ES). The research explicitly reveals a U-shaped non-linear effect of GPR on ES. (C.-C. Lee et al., 2024). Panel data analysis of 35 nations from 2005-2018 investigates the non-linear "double-edged sword" effect of GPR on ES and identifies Renewable Energy Technology Innovation (RETI) as the specific transmission mechanism.

GPR and immediate energy security led to an increase in fossil fuel consumption in the short term. The ARDL model indicated a negative correlation between fossil fuels and renewable energy consumption in the near term. In the long run, these risks have improved the investments in renewable energy driven by energy independence and sustainability. Energy consumption showed a positive relationship with renewable energy consumption. Similarly, fossil fuels also had a positive relationship with energy consumption, which was in the long term, after the economy stabilizes and has enough investments in clean energy projects (Eka Sudarmaji et al., 2025).

In the top 10 investing economies, GPR significantly reduces Renewable Energy Technology Budgets (RTB) in most countries, which include China, USA, France, India, Australia, Italy, and South Korea. On the contrary, Japan shows a positive effect. Whereas Germany and the UK show mixed results, positive at low risk, and negative at high risk (Zheng et al., 2024).

Institutional Quality, Governance, and Supply Chain Barriers

The analysis of whether PU and GPR negatively affect RE production in major countries of the world. Through panel data econometrics and panel cointegration, 42 countries from the period 1990-2020 with 1302 observations, in the short run, there have been Heterogenous effects in different countries. For instance, a 1% increase in GPR led to a short-term decrease in RE production by 0.65% in Hong Kong and 0.01% in Poland, but a short-term increase of 0.12% in the UK and 0.01% in Denmark. While in the long run, there is no significant impact of PU and GPR on the RE production, (Petrović & Ostojić, 2025).

Economic policy uncertainty, urbanization, and GPR have a negative and regressive impact on REINV (Pata et al., 2023). The impact of Economic policy uncertainty is stronger than that of GPR. Study of G7 countries for 2004-2018 finds economic prosperity encourages investment in clean energy as found to be significantly positive and stimulative. Government efficiency (GOVEF) and regulatory quality (REGQ) as control variables were found to have no statistically significant effect on REINV in the G7 countries.

In 18 OECD countries from 1980 to 2014, Empirically, a 1% growth in Institutional Quality leads to a 0.65% increase in RE use (Rafiq et al., 2025). Along with this, an increase of 1% in GDP per capita is associated with a 1.27% increase in RE consumption.

Annual panel data analysis includes 24 countries from the period 2000-2022, finds that the Paris agreement significantly and positively impacts RE deployment (Berrich et al., 2024). Besides this, the supporting role of governance indicators is found to be relevant to give results such as a 1% increase in Political Stability and Government Efficiency leads to increases in REC by 1.13% and 1.66%, respectively. Besides, both green innovation and renewable energy have significantly improved the environmental quality by reducing CO2 emissions. But geopolitical risk has potentially lowered the environmental quality by undermining and allocating resources in projects and development ventures other than sustainable ones (Qamruzzaman et al., 2025).

GPR has a positive impact on the ET as it accelerates the transformation, and it demonstrates a long-term positive effect on energy transition, with a coefficient of 0.307, significant at the 1% level in the cross-country panel data analysis of 39 countries for 18 years from 2002-2020. While the governance is negatively associated with ET because of institutional inertia, the long-term negative association between governance quality (GOV) and energy transition (ET), with a coefficient of - 0.788, is statistically significant at the 1% level (H. Wang et al., 2025).

Increasing RE share reduces GPR while military spending moderates this relationship, which further enhances the GPR-reducing effect of RE on the United States & United Kingdom primarily and on the G7 comparatively for 30 years from 1990 to 2020. Through time series analysis for the US & UK and panel data analysis for the G7 countries , the study concludes that in the US and UK, the RE consumption has significantly reduced GPR. While increased Military spending positively contributes to the green transition (Yang et al., 2024). Similar results were observed for G7, except for specific countries, i.e., France, Canada, and Japan.

Over 70% of the world's photovoltaic cells are manufactured in China, creating vulnerabilities to trade disputes or diplomatic conflicts. The COVID-19 pandemic highlighted this fragility, causing delays and shortages in essential materials, which can halt operations and production (Yewande Mariam Ogunsuji et al., 2024).

In the examination of structural, financial, and geopolitical barriers constraining capital mobilization for energy transition in the Global South (J. Lee, 2025) uses data from 2010-2025 for developing economies. Results report a significant persistent gap in the capital available and the investments in clean energy in the developing countries. High upfront costs, rising interest rate levels, and investors' concerns, accompanied by other barriers, hinder the real progress in clean energy projects.

While exploring the interplay between Natural Resource Rents (NRR), Green Innovation (ENVT), and GPR on CO2 emissions in BRICS. Results exhibit that CO2 initially increases with economic growth but then eventually falls after a certain income level is reached, as tested through panel data from 1990-2018 using GMM. FDI has a positive and significant impact on CO2 emissions, validating the pollution haven hypothesis (PHH) (Y. Zhao et al., 2024). The study implies that though FDI increases economic growth of the country, it also enhances CO2 emission; therefore, the need for green FDI to combat all the climate change issues is needed, especially in the BRICS countries.

Previous studies have examined the determinants of renewable energy development as a single aggregate measure. Additionally, existing research does not particularly differentiate between capacity expansion and actual electricity generation, which serves as a prerequisite for promoting renewable energy consumption. The role of geopolitical risk remains underexplored, and along with other macroeconomic variables like trade and urbanization, it determines the framework of energy security in the nations. Besides this, many studies rely on orthodox panel estimators, which give biased and inefficient results because of not correct for cross-sectional dependence driven by global shocks. This study addresses these gaps by distinguishing between renewable energy capacity and generation and employing robust econometric techniques that account for cross-sectional dependence.

Econometric Methodology

We here develop a model that contemplates the explanatory variables, which is expanded through time period – time series as well as cross–sectional units. Such a variety of data is referred to as Panel data or time series cross-sectional data sometimes. The use of panel data analysis here serves multiple significant purposes. The use of a panel data structure allows this study to control for hidden, time-invariant heterogeneity across the 42 countries. This ensures that elementary and relatively fixed or slow varying characteristics, i.e., geography, climate & environment, and institutional history, do not bias the estimated relationship between the variables of the study. The multidimensional approach of the study increases the degrees of freedom and statistical power of the model, which provides more reliable and efficient parameter estimates than a static cross-sectional analysis. It is critical to isolate the model from Indiscernible global macroeconomic and environmental shocks, ensuring that international events do not artificially inflate the significance of the independent variables, which is achieved through the dimension of panel data analysis methodology because it permits the inclusion of year or country fixed effect models.

$$re_{it}^{j} = \beta_0 + \beta_1 gprh_{it} + \beta_2 gdppc_{it} + \beta_3 to_{it} + \beta_4 urban_{it} + \beta_5 ghgs_{it} + \beta_6 rq_{it} + \varepsilon i + \mu_{it}$$

Where as re_{it}^{j} shows renewable energy while j shows three dependent variables as Renewable Energy consumption (REC), Renewable Energy Electricity Generations (REEG), and Renewable Energy Electricity Capacity (REEC).

Here $gprh_{it}$ represents the historical geopolitical Risk indicator, $gdppc_{it}$ is Gross Domestic Product (GDP) per capita, to_{it} is Trade openness, $urban_{it}$ is the urbanization level, $ghgs_{it}$ are greenhouse gas emissions, rq_{it} is the Regulatory quality index, β_0 is the intercept or constant term, β_1 to β_6 are the estimated slope coefficients for each independent variable, ϵ_{it} is the error term, i denotes the cross-sectional unit (Country 1, 2, ..., 42), and t denotes the time period (Year) for the country i in year t.

The Fixed Effects (FE) model

FE is designed to analyze the variant impact of variables that differ through time or other permanent and unnoticed characteristics. Unlike Pooled OLS or RE, the FE Model mathematically assigns a unique intercept value to every cross-sectional unit and evaluates unique results. It thus successfully uses the regression to exclusively measure how changes within a country over time influence the dependent variable in a special spectrum.

The FE model operates on the assumption that a country's atemporal characteristics are represented by (μi) are inherently correlated with the independent variables in the model.

$$lre_{it}^{j} = \beta_0 + \beta_1 lgprh_{it} + \beta_2 lgdppc_{it} + \beta_3 lto_{it} + \beta_4 lurban_{it} + \beta_5 lghgs_{it} + \beta_6 lrq_{it} + \varepsilon i + \lambda_t + \mu_{it}$$

It is the most logical and robust model for this study, because it solves the problem of omitted variable bias. In the context of the study and examined variables, country-specific characteristics have very nuanced effects on the explained variables, like RE generation, RE generational capacity, and RE consumption. Hence, the unnoticed traits are correlated with explanatory variables such as GDP per capita, GPR, and CO2 emissions, etc. The FE model successfully explains and deals with this relationship through uniquely evaluating each country by giving it its intercept value. Moreover, FE also controls the global shocks through observing their effects worldwide. The model explicitly incorporates year fixed effects λ_i. This ensures that global anomalies such as the 2008 financial crisis, fluctuations in global oil prices, or international climate agreements are absorbed by the model, which effectively prevents distortion of the relationships between the variables due to worldwide shocks.

Fixed Effect and Hausman Specification Test

It depends on how the regressors are linked to the unobserved and specific country traits. The research question is whether there is a significant correlation between the regressors and the unique cross-sectional country-specific traits. If there exists such a sort of correlation, which the Random Effect Model assumes to be zero, it will inconsistently estimate the results. This then leaves the Fixed Effect Model, which successfully acknowledges and drives the regression under the scope of such unique effects. The Hausman specification test is the classical test of whether the fixed or random effects model should be used.

Model Selection: The Hausman Specification Test

The Durbin-Wu-Hausman test, which is commonly referred to as the Hausman test, serves as the absolute investigative tool to decide between the Fixed Effects (FE) and Random

Effects (RE) estimators. It explores whether there is a significant correlation between the regressors and the country-specific traits.

The Hausman test evaluates two competing hypotheses by comparing the coefficient estimates generated by both the FE and RE models.

The hypotheses are: The Null Hypothesis (H_0) assumes that the unobserved country-specific effects are completely uncorrelated with the explanatory variables. If this is true, the Random Effects model is both consistent and highly efficient. On the contrary, the Alternative Hypothesis (H_a) assumes that the unobserved effects are correlated with the explanatory variables. If this is true, the RE estimates become heavily biased and inconsistent, making Fixed Effects the only mathematically valid option.

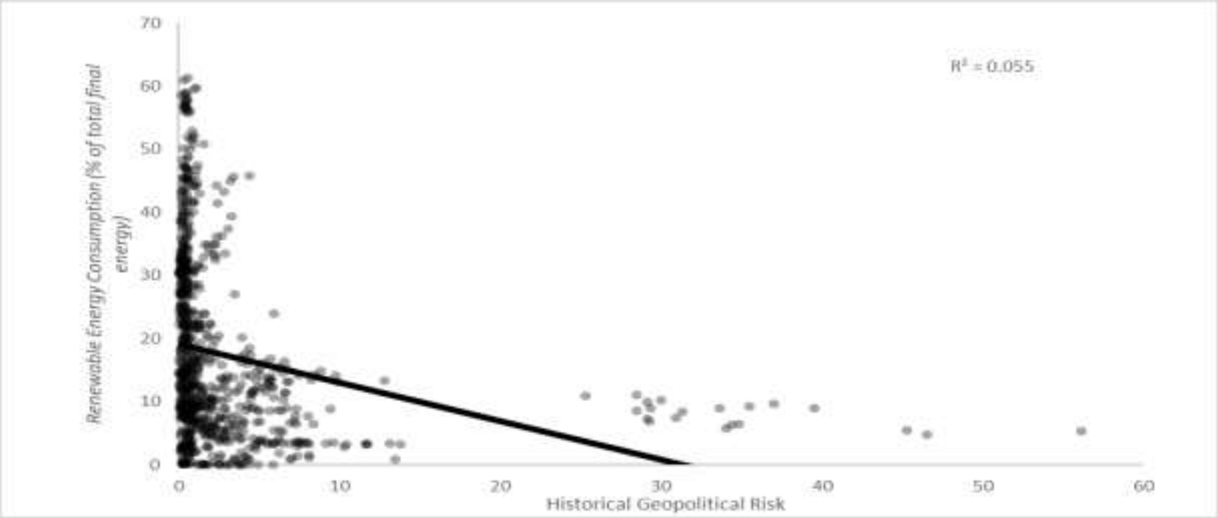
The test calculates a Chi-square. $\chi 2$ statistic based on the variance between the two sets of coefficients. The math proves that the Random Effects assumption has failed. If the difference between the FE and RE estimates is systematically large, and the FE model is econometrically and statistically valid, to apply.

$$W = (\hat{\beta}_{FEM} - \hat{\beta}_{REM})'[v(\hat{\beta}_{FEM}) - v(\hat{\beta}_{REM})]^{-1}(\hat{\beta}_{FEM} - \hat{\beta}_{REM}) \sim \chi^2$$

For the empirical strategy of this research, the Hausman test provides the definitive justification for the model specification. Because the structural, geographical, and institutional baselines of the 42 sampled countries are inextricably linked to their macroeconomic outputs, such as GDP per capita and urbanization.

Trends in Data

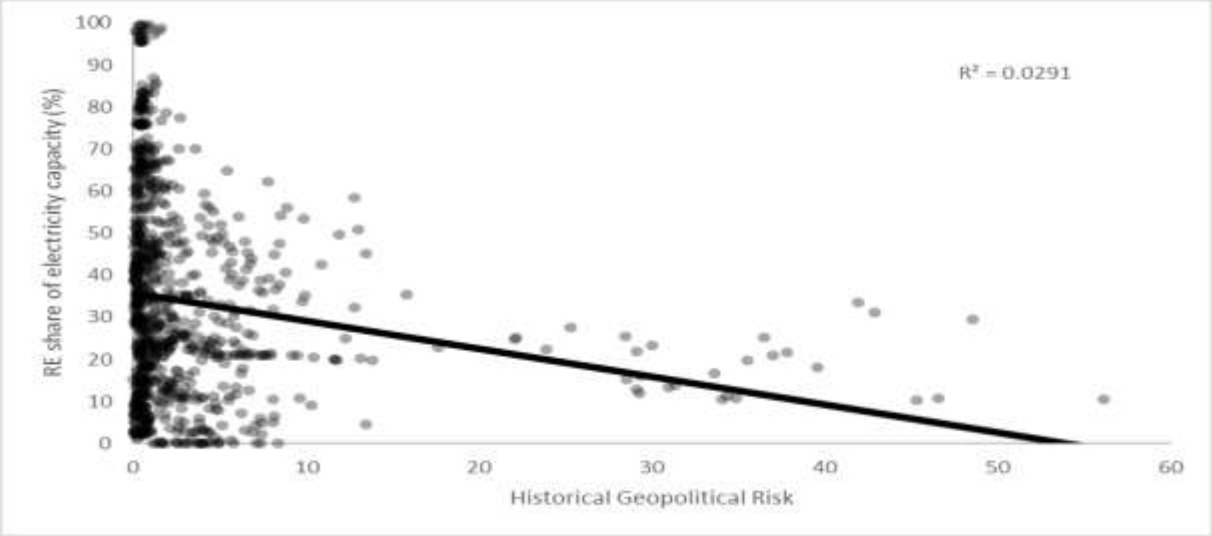
Figure 1: Raw Bivariate Correlation between Historical Geopolitical Risk and Renewable Energy Consumption



In Figure 1, the scatter plot displays the uncontrolled relationship between Geopolitical Risk (GPR) and Renewable Energy Consumption (% of total final energy), with an R^2 = 0.055. This pilot visualization does not substantially explain macroeconomic variables or country-specific fixed effects.

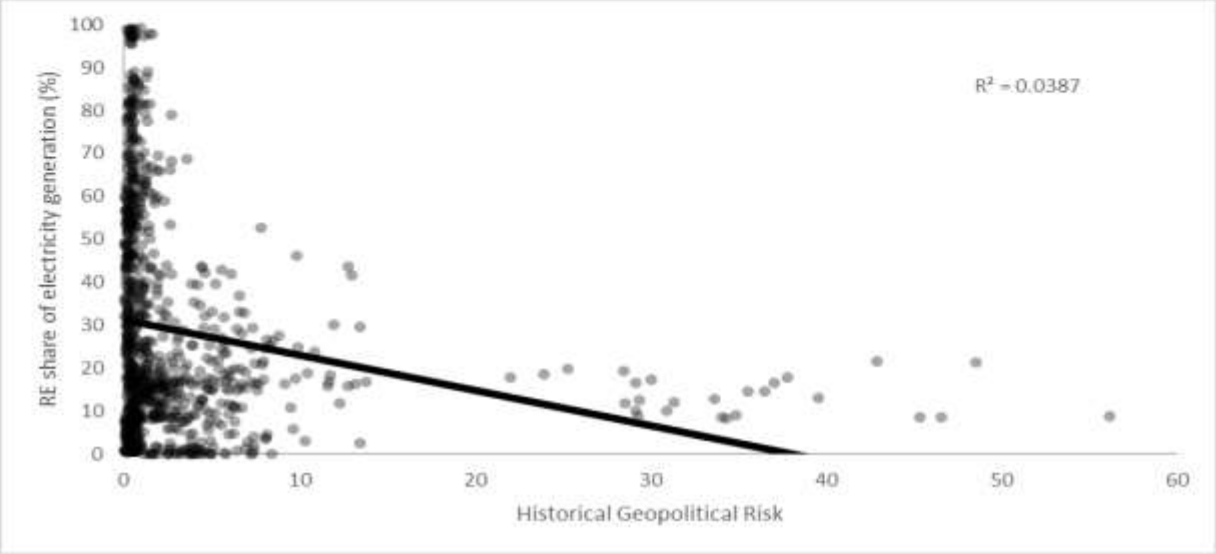
Source: Author's calculation.

Figure 2: Raw Bivariate Correlation between Historical Geopolitical Risk and Renewable Energy Capacity



The scatter plot in Figure 2 displays the uncontrolled relationship between Historical Geopolitical Risk and Renewable Energy share of electricity capacity (%), with an $R^2 = 0.0291$. Similar to consumption trends, this preliminary visualization does not significantly show the critical cross-sectional dependence, which will be addressed in this study.
Source: Author's calculation.

Figure 3: Raw Bivariate Correlation between Historical Geopolitical Risk and Renewable Energy Generation



The scatter plot in Figure 3 displays the uncontrolled relationship between Historical Geopolitical Risk and Renewable Energy share of electricity generation (%), with an $R^2 = 0.0387$. Consistent with the preliminary trends for capacity and consumption, this visualization indicates a negative correlation. This distribution fails to justify the structural bottlenecks and cross-sectional dependence that are corrected in the primary econometric models.
Source: Author's calculation.

Data and variables

Variable	Definition	Source	Time period
Renewable Energy Consumption	The share of renewable energy in a country's total final energy consumption.	World Development Indicators (WDI)	2002-2021
Renewable Energy Capacity	The maximum potential amount of electricity that could instantaneously be produced by the existing installed renewable energy sources in a given area.	International Renewable Energy Agency (IRENA)	2002-2024
Renewable Energy Generation	The actual amount of energy (electricity or heat) produced over a period of time is derived from natural processes that are replenished at a faster rate than they are consumed.	International Renewable Energy Agency (IRENA)	2002-2023
GDP Per Capita	A country's Gross Domestic Product divided by its midyear population.	World Bank	2002-2024
Trade Openness	The sum of a country's exports and imports of goods and services, measured as a percentage of its Gross Domestic Product (GDP).	World Bank	2002-2024
Urbanization	The proportion of the total national population living in geographic areas formally classified as urban.	World Development Indicators (WDI)	2002-2024
Greenhouse Gas Emission	The release of gaseous constituents into the atmosphere, primarily from human anthropogenic activities.	World Development Indicators (WDI)	2002-2024
Regulatory Quality	A metric capturing the perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development.	World Development Indicators (WDI)	2002-2024
Geopolitical Risk	The threat, realization, and escalation of adverse events associated with wars, terrorism, and political tensions between states, which affect the peaceful course of international relations.	Caldara and Iacoviello Geopolitical Risk (GPR) Index	2002-2024

Results & Discussions

Table 1: Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
rec	860	17.608	14.424	0	61.4
reec	966	33.952	23.945	0	99.55
reeg	924	29.006	25.269	0	99.23
gprhc	989	2.855	6.086	0	56.14
gdppc	989	24553.005	21398.523	793.62	90605.023
to	989	80.432	59.292	1.39	442.62
urban	989	73.523	16.198	25.55	100

ghgs	989	9.877	6.221	1.817	41.016
rq	989	.649	.93	-2.17	2.23

The descriptive statistics are crucial to have for checking the health of variables in the study, which are given in Table 1. There are 860 observations for renewable energy consumption (rec) and 989 for macroeconomic and institutional indicators such as geopolitical risk (gprhc) and GDP per capita (gdppc), which explains the unbalanced panel of the dataset. The data exhibits significant variations in scale. For instance, GDP per capita demonstrates a maximum value of 90,605.02 and a mean of 24,553.00, whereas regulatory quality (rq) ranges from -2.17 to 2.23. Furthermore, the geopolitical risk index (GPRHC) displays prominent volatility, which is at a maximum value of 56.14 compared to a low mean of 2.85. This disparity in unit scales requires the use of logarithmic transformations for macroeconomic variables in the subsequent regression estimations to ensure econometric stability and prevent scale distortions.

Table 2 : Matrix Correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) rec	1.000								
(2) reec	0.719	1.000							
(3) reeg	0.755	0.943	1.000						
(4) gprhc	-0.250	-0.198	-0.210	1.000					
(5) gdppc	0.082	0.344	0.222	0.212	1.000				
(6) to	-0.059	-0.102	-0.144	-0.257	0.053	1.000			
(7) urban	-0.212	0.192	0.204	0.094	0.507	-0.143	1.000		
(8) GHGs	-0.242	-0.071	-0.068	0.278	0.425	-0.200	0.432	1.000	
(9) rq	0.086	0.213	0.104	0.090	0.774	0.146	0.361	0.365	1.000

The results for preliminary variable relationship and multicollinearity are given in the pairwise Pearson correlation matrix in Table 2. Initial descriptive evidence highlights that the geopolitical risk is inversely associated with renewable energy adoption. The geopolitical risk indicator (gprhc) shows negative linear correlation across all three renewable energy proxies, empirically given as. rec (-0.250), reec (-0.198), and reeg (-0.210).

Furthermore, the correlation matrix reveals a severe positive correlation between renewable energy generation (reeg) and renewable energy capacity (reec), which is 0.943. Due to the reason that this correlation value exceeds the multicollinearity threshold of 0.80, incorporating reec and reeg in a single regression equation simultaneously would result in severe multicollinearity and inflated standard errors. Therefore, these are dealt with separately in the model of the study to have efficient results. Additionally, a strong correlation is observed between GDP per capita and rq (0.774), which aligns with the theoretical expectation that higher-income nations exhibit stronger institutional quality.

At first, the model analyses REEC as an explanatory variable through the following regression line:

$$lreec_{it} = \beta_0 + \beta_1 lgprh_{it} + \beta_2 lgdppc_{it} + \beta_3 lto_{it} + \beta_4 lurban_{it} + \beta_5 lghgs_{it} + \beta_6 lrq_{it} + \varepsilon i + \lambda_t + \mu_{it}$$

Table 3: Dependent variable - Renewable Energy Electricity Capacity

	(1)	(2)	(3)
Variables	FE	FE (robust)	FE (Driscoll–Kraay)
lgprh	0.187*** (0.0367)	0.125* (0.0732)	0.125** (0.0449)
lgdppc	1.238*** (0.0859)	0.746** (0.298)	0.746*** (0.132)
lto	0.238*** (0.0761)	0.343 (0.250)	0.343** (0.146)
lurban	-0.532** (0.255)	-1.468 (0.913)	-1.468*** (0.293)
lghgs	-1.477*** (0.0816)	-0.783** (0.347)	-0.783*** (0.128)
rq	-0.139** (0.0601)	-0.0123 (0.207)	-0.0123 (0.0407)
Constant	-4.277*** (0.832)	2.273 (3.299)	2.273 (1.356)
Observations	966	966	966
R-squared	0.456	0.509	
Number of Countries	42	42	42
Country FE		YES	
Year FE		YES	

Standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 1 presents the estimation results for the first stage of the energy transition: installed renewable capacity REEC. After framing the fundamental infrastructural drivers of RE transition, the study now analyzes the operational output. This is shifting the dependent variable to actual renewable energy generation (REEG) to get more realistic insights into RE in action.

But before the study interprets all the results, it’s crucial to have a look at the data being processed and made ready for effective econometric analysis. Table 2 shows values for three important econometric tests results which serve to be critical for having significant and valid results of estimation. The tests are;

Table 4: Econometric Tests

	Dependent Variables		
Test	REC	REEG	REEC
Heteroskedasticity	72.387 (0.0000)	9084.43 (0.0000)	21709.39 (0.0000)
Autocorrelation	72.387 (0.0000)	62.262 (0.0000)	383.769 (0.0000)
Cross-sectional Independence	-1.663 (0.0963)	3.287 (0.0010)	1.781 (0.0750)

Econometric Tests

Heteroskedasticity Test:

Econometrically defined, Heteroskedasticity occurs when the variance of the error terms is not constant across all observations. It means the spread of the errors differs massively between groups while handling panel data. In the panel analysis of the study, 42 various countries are examined, where massive economies would have surely larger standard errors in contrast to smaller economies when macroeconomic data is included. The null hypothesis of this test assumes homoskedasticity (constant variance). Across all three dependent variables (REC, REEG, REEC), the p-values are 0.0000. Because $p < 0.01$, the study decisively rejects the null hypothesis, confirming that significant evidence is available for the presence of heteroskedasticity in the panel.

Autocorrelation Test:

Autocorrelation refers to the correlation of the error term of a country in one specific year with its own error term from previous years. Macroeconomic and energy data are inherently persistent over consecutive years of their policy and infrastructural development. If not tested the model will treat every single year as complete random noise. The null hypothesis assumes no first-order autocorrelation, and p-values are 0.0000 across all three models. Hence, the study rejects the null hypothesis at the 1% significance level, proving that autocorrelation exists in the panel.

Cross-Sectional Independence Test:

This tests the assumption that a shock to one country's error term does not affect the error terms of other countries. The null hypothesis assumes cross-sectional independence. For energy generation (REEG), the p-value is 0.0010, rejecting the H_0 at the 1% level. But for (REEC) and (REC), the p-values are 0.0750 and 0.0963, respectively, which are significant at the 10% confidence level. Thus, the final verdict explains cross-sectional dependency in the model.

Diagnostic testing for autocorrelation. Interdependence and heteroskedasticity reject the null hypothesis. So, the study uses Driscoll-Kraay standard errors mathematically designed to be robust, ensuring the final coefficients are highly reliable, as given in Column 3 of the estimation results.

$$lreeg_{it} = \beta_0 + \beta_1 lgprh_{it} + \beta_2 lgdppc_{it} + \beta_3 lto_{it} + \beta_4 lurban_{it} + \beta_5 lghgs_{it} + \beta_6 lrq_{it} + \varepsilon i + \lambda_t + \mu_{it}$$

Table 5: Dependent Variable - Renewable Energy Generation

	(1)	(2)	(3)
Variables	FE	FE (robust)	FE (Driscoll Kraay)
lgprh	0.115*** (0.0344)	0.0542 (0.0716)	0.0542 (0.0436)
lgdppc	0.925*** (0.0820)	0.478* (0.265)	0.478*** (0.110)
lto	0.296*** (0.0708)	0.368* (0.208)	0.368** (0.145)
lurban	0.165 (0.242)	-0.663 (0.847)	-0.663*** (0.151)
lghgs	-1.540*** (0.0775)	-0.921*** (0.324)	-0.921*** (0.136)
rq	-0.240*** (0.0568)	-0.132 (0.149)	-0.132** (0.0569)
Constant	-4.486*** (0.789)	1.482 (3.195)	1.482 (1.010)
Observations	924	924	924
R-squared	0.471	0.522	
Number of Countries	42	42	42
Country FE		YES	YES
Year FE		YES	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

While Table 3 highlights the supply-side dynamics of renewable generation, understanding the full macroeconomic picture requires evaluating end-user demand. That is given in Table 4, which completes the sequence by modeling the impact of these same explanatory variables on renewable energy consumption.

The model follows as;

$$lrec_{it} = \beta_0 + \beta_1 lgprh_{it} + \beta_2 lgdppc_{it} + \beta_3 lto_{it} + \beta_4 lurban_{it} + \beta_5 lghgs_{it} + \beta_6 lrq_{it} + \varepsilon i + \lambda_t + \mu_{it}$$

Table 6: Dependent Variable - Renewable Energy Consumption

	(1)	(2)	(3)
Variables	FE	FE (robust)	FE (Driscoll–Kraay)
lgprh	0.0872*** (0.0305)	0.0980 (0.0667)	0.0980* (0.0552)
lgdppc	0.189*** (0.0630)	-0.211 (0.190)	-0.211 (0.130)
lto	0.339*** (0.0530)	0.332** (0.140)	0.332*** (0.0724)
lurban	-0.00325 (0.186)	-0.531 (0.491)	-0.531*** (0.134)
lghgs	-1.162*** (0.0584)	-0.739*** (0.266)	-0.739*** (0.128)
rq	-0.115*** (0.0423)	-0.0396 (0.116)	-0.0396 (0.0608)
Constant	1.842*** (0.611)	6.795*** (2.236)	6.795*** (0.752)
Observations	860	860	860
R-squared	0.411	0.466	
Number of Countries	43	43	43
Country FE		YES	YES
Year FE		YES	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Discussions

Economic Growth and Market Integration

lgdppc and lto exhibit differing results in stages of transformation. An increase of 1% in GDP per capita causes an increase of 0.746%, while 0.343 due to trade openness in the REEC. But in actual real amount of RE generated is influenced less than the capacity. 1% increase in the GDP per capita and trade leads to 0.478% and 0.368% in REEG. This explains that trade has more effect on RE generation than on the capacity of RE production, which more realistic and practical factor in the field of energy security. On the very contrary, the increase in GDP per capita by 1% cause decrease in REC by 0.211%. which can be justified because the more income nations have, the more rigorously they are driven towards industrialization to power large-scale infrastructure and production, which leads to a lack of interest in RE. while the trade has an almost consistent 0.332% increasing effect on Rec.

Demographic Shifts and Environmental Pressures

Analyzing the structural and environmental constraints reveals a stark narrative regarding population dynamics and legacy pollution. Across the models, urbanization (lurban) emerges as a severe structural bottleneck for green infrastructure. A 1% expansion in the urban population triggers a massive 1.468% contraction in installed renewable capacity (REEC). When evaluating actual energy generation (REEG) and consumption (REC), urbanization maintains its negative trajectory with coefficients of 0.663% and 0.531%. Findings suggest that the abrupt demographic shift surpasses the deployment of green infrastructure throughout the cities, causing the acceptance of a traditional fossil fuel-driven policy framework.

Similarly, legacy environmental degradation acts as a restrictive weight rather than a catalyst. A 1% increase in baseline greenhouse gas emissions (lghgs) decreases renewable capacity by 0.783%. This restrictive effect persists in the generation and consumption models, where a 1% rise in emissions corresponds to a 0.921% and 0.739% shift, respectively. The results for GHGS are persistently harming, it's because heavily carbon-intensive capital-dependent countries have no sufficient resources to invest in RE transition due to economic burden, leading to a spiral of using fossil fuels again for coping with the raising demand and population.

Institutional Frameworks and Geopolitical Stability

Finally, the analysis evaluates the macro-level impact of governance and international stability. The phenomenon of GPR analysis supports the energy security hypothesis of countries, which states that governments are compelled to accelerate their domestic RE transition as international threats disrupt the supply chain and prices of fuels to ensure energy security. Geopolitical risk (lgprh) acts as a significant positive driver; a 1% escalation in global risk indices accelerates renewable capacity installation by 0.125%. The risk factor impact slightly diminishes in the case of altering actual generation by 0.0542% and consumption by 0.0980%.

Notably, standard institutional metrics do not appear to be the primary engine of the energy transition in this panel. Regulatory quality (rq) remains statistically insignificant across all three models and exhibits negligible negative coefficients. Empirically, a 1% increase in rq leads to a decrease of 0.0123% in installed capacity (REEC), 0.123% decreases in REEG, and 0.0396% in REC. The data imply that when economic wealth and global trade integration determine the direction of the economy, baseline regulatory environments do not independently drive the transition.

Table 7 FE (Driscoll–Kraay) Estimatin Values

Variables	REEG	REEC	REC
lgprh	0.0542 (0.0436)	0.125** (0.0449)	0.0980* (0.0552)
lgdppc	0.478*** (0.110)	0.746*** (0.132)	-0.211 (0.130)
Lto	0.368** (0.145)	0.343** (0.146)	0.332*** (0.0724)
lurban	-0.663*** (0.151)	-1.468*** (0.293)	-0.531*** (0.134)
lghgs	-0.921*** (0.136)	-0.783*** (0.128)	-0.739*** (0.128)
rq	-0.132** (0.0569)	-0.0123 (0.0407)	-0.0396 (0.0608)
Constant	1.482 (1.010)	2.273 (1.356)	6.795*** (0.752)

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 7 presents the FE (Driscoll–Kraay) Standard Errors for all three independent variables, which are Renewable Energy Electricity Capacity (REEC), Renewable Energy Generation (REG), and Renewable Energy Consumption (REC).

Conclusions and Policy Recommendations

Conclusion

This study's empirical investigation of the complex interplay between macroeconomic realities, structural shifts, and geopolitical instability on the renewable energy transition definitively concludes that the global energy transition is not a linear, but rather a severe, structurally complex phenomenon, when tested across a 42-country panel from 2002 to 2022. Between two opposites, the integration into global markets (Trade Openness) and the urgent need for sovereign energy security (Geopolitical Risk) act as powerful catalysts, driving nations to aggressively expand their green infrastructure on one side. But these promoting variables are tactfully encountered by raising energy demands in urbanized cities. Ultimately, the data proves that sudden demographic and industrial shifts severely jam the transition, which forces economies to use traditional fossil-fuel requiring productions.

Crucially, this study demonstrates that treating the renewable energy transition as a single variable hinders the profound macroeconomic realities. By separating the transition into three distinct supply chain stages: capacity, generation, and consumption, the analysis revealed that the drivers of green infrastructure are systematically different from those of consumer demand. While domestic wealth (GDP per capita) successfully finances the initial installation of renewable capacity, its impact drops significantly regarding actual generation, followed by a complete reversal into a negative force regarding end-user consumption. This confirms that as economies grow wealthier and rapidly industrialize, their immediate aggregate demand outpaces their green capacity. This leads to severe carbon-intensive energy production dependent on powering large-scale production. Most notably, global trade integration remains the only consistent and positive driver across the entire supply chain.

Finally, the empirical rejection of regulatory quality as a significant driver across all three models implies that standard, theoretically framed policies and regulations do not fuel renewable energy transition independently. Under the influence of global trade, economic wealth, and international conflicts, the direction of an economy is dictated exogenously, proving that domestic environmental laws lag in forcing a transition. Therefore, this study concludes that a successful renewable energy framework requires the active mobilization of global trade, capital deployment to overcome urban bottlenecks, and a strategic recognition that clean energy is the ultimate protector against geopolitical vulnerability rather than mere reliance on regulatory mandates and government policies.

Policy Recommendations

This raises a potential need for policy regulation after the empirical estimation proves the regulatory quality to be insignificant in determining the transition. Authorities should actively focus on deploying capital for green energy infrastructure rather than setting paper targets to achieve environmental and climate-resilient goals. Though economic wealth drives initial capacity but is incapable of providing for consumers during rapid industrialization. Therefore, states must re-evaluate their policies and provide targeted financial subsidies and tax incentives aimed at industrial-scale renewable integration. By subsidizing the industrial sector in establishing the green infrastructure, the countries could avoid the trap of going back to fossil fuels in order to supply the rising demand of urbanized cities.

Governments and authorities should prioritize the decentralized provisions of renewable energy, like microgrids and mini supply stations, like solar grade stations, for instance. It is mandatory in order to control the overwhelming demand in urbanized societies. Through effective localization of the renewable energy source, like commercial rooftop solar plants, etc., urbanized neighborhoods can be saved from traditional transmission and improvision problems efficiently.

Over the longer course, it is highly recommended to ensure domestic energy security through essentially reframing the polices to utilize renewables as necessary for a better future rather than responding to it like a climate change mitigation strategy. GPR demonstrates a positive impact on the transition, thus Governments should actively engage in global trade via establishing special economic corridors focusing on tariff elimination and promotion of green technology with allied nations. This could result in the timely securing and deployment of fundamental infrastructure, driving the transition across the country.

The Limitations

While the study gives valuable insights using the Driscoll-Kraay standard errors, it treats renewable energy as a single aggregate metric. This could be divided into units of specific technology like photovoltaic solar panels, offshore wind mills, and hydropower stations, etc. Additionally, the static fixed effect model might not significantly capture the dynamic impact of geopolitical risk and relevant variables on the renewable energy transition because of the effects of the capital investment over the long term. The channel of transmission is though inferred but not directly tested.

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Countries in Panel

Table 8: Countries

Sr. #	Country Name	Country Code	Sr. #	Country Name	Country Code
1	Argentina	ARG	23	Mexico	MEX
2	Australia	AUS	24	Netherlands	NLD
3	Belgium	BEL	25	Norway	NOR
4	Brazil	BRA	26	Peru	PER
5	Canada	CAN	27	Philippines	PHL
6	Chile	CHL	28	Poland	POL
7	China	CHN	29	Portugal	PRT
8	Colombia	COL	30	Russian Federation	RUS
9	Denmark	DNK	31	Saudi Arabia	SAU
10	Egypt, Arab Rep.	EGY	32	South Africa	ZAF
11	Finland	FIN	33	Spain	ESP
12	France	FRA	34	Sweden	SWE
13	Germany	DEU	35	Switzerland	CHE
14	Hungary	HUN	36	Thailand	THA
15	India	IND	37	Tunisia	TUN
16	Indonesia	IDN	38	Türkiye	TUR
17	Israel	ISR	39	Ukraine	UKR
18	Italy	ITA	40	United Kingdom	GBR
19	Japan	JPN	41	United States	USA
20	Korea, Rep.	KOR	42	Venezuela, RB	VEN
21	Malaysia	MYS	43	Viet Nam	VNM
22	Hong Kong	HKG			