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Trade policy uncertainty and renewable energy transition in MENA: A quantile regression approach

Seyi Saint Akadiri[1+]
Ifedolapo Olabisi Olanipekun[2]

[1]*Institute of Graduate Studies and Research, Cyprus International University. Northern Cyprus, TR-10 Mersin, Turkey.*
[1]*Email: sakadiri@eul.edu.tr*
[2]*Department of Economics, Istanbul Gelisim University, Istanbul, Turkey.*
[2]*Email: ioolanipekun@aceondo.edu.ng*

(+ Corresponding author)

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ABSTRACT

The energy transition in the MENA region remains complex due to its heavy reliance on fossil fuels. Using quantile-on-quantile regression on panel data (2001–2023) for 13 MENA countries, this study examines the effect of global trade policy uncertainty on renewable energy transition, alongside income, oil rent, innovation, carbon dioxide emissions, and trade openness. The results reveal heterogeneous effects across quantiles. A 1% rise in trade policy uncertainty increases renewable energy transition by 0.26% at the 0.1 quantile but decreases it by 0.05% at the 0.9 quantile, implying that such uncertainty stimulates transition only in economies already shifting toward renewables. Income negatively affects transition (–0.82% to –0.34%), confirming a resource curse, while trade openness heightens fossil fuel dependence (–0.52% to –1.23% across quantiles). Conversely, oil rent and trade openness jointly promote renewable adoption (0.38%–0.46%), and innovation enhances transition (0.02%–0.11%). However, higher carbon dioxide emissions impede renewable growth (–0.33% to –0.53%). Overall, renewable energy progress in the MENA region is uneven, with fossil fuel-centric economies lagging. The findings highlight that while trade policy uncertainty may catalyze early-stage transitions, excessive openness and dependence on fossil resources limit renewable expansion in advanced stages. Hence, trade policies should integrate decarbonization goals, channel windfall gains into renewable projects, promote innovation spillovers, and dismantle trade barriers to accelerate sustainable energy transformation across the region.

Contribution/ Originality: This study investigates how global trade policy uncertainty influences renewable energy adoption in the MENA region. Using quantile regression, results reveal heterogeneous effects; uncertainty promotes adoption in early transition stages but diminishes later. Moreover, GDP per capita, CO_2 emissions, and trade openness hinder progress, reflecting persistent resource curse barriers.

1. INTRODUCTION

Amid the growing urgency of the international response to existential climate events and rising geopolitical tensions globally, the transition towards clean and sustainable energy systems has presented an enormous challenge, not least to traditional fossil fuel powers, as evidenced by fluctuating global energy prices, shifting trade patterns, and concerns over energy security. The MENA region, due to its heavy dependence on fossil fuels for economic affluence in recent years, is at the core of this conundrum, being the world's largest oil and gas exporter and, increasingly, the largest global investor in sustainable energies (IEA, 2022). The region has historically financed its social and economic budgets through its oil and gas revenues, to the extent that the concept of a just transition often refers to an energy transition, thanks to its abundant oil and gas reserves. Internally and externally, however, there is also a growing recognition of the need for an energy transition towards a diversified energy mix, a reduced carbon footprint, and resilience to global changes. Similar to the global context, the MENA countries are based on their understanding of their regional contexts, which actively initiate approaches towards energy transitions away from or in conjunction with reliance on extensive fossil fuel reserves.

We consider a range of possible external shocks. First, we model an external shock that is less frequently discussed within the literature on energy transition: uncertainty regarding global trade policy and trade levels (hereafter GTPU). Trade wars, changing tariff regimes, sanctions, and other globalization-related geopolitical frictions, including the decoupling of global supply chains, have substantial first-order effects on MENA countries through reduced export earnings and disruptions to imports of critical goods, such as green energy technologies. These shocks are particularly consequential for the MENA region because they magnify the vulnerabilities inherent in fossil-fuel dependence, while also creating opportunities for investment in more resilient, domestically anchored clean energy systems (Ahir, Bloom, & Furceri, 2022; Handley & Limão, 2017).

Existing research has examined traditional drivers of renewable energy adoption, including economic growth, fossil fuel prices, technological readiness, and environmental pressures (Apergis & Payne, 2010; Bilgili, Koçak, & Bulut, 2016; Sadorsky, 2009). However, the influence of trade policy uncertainty remains largely unexplored, especially in the MENA context. Even more critically, most empirical work relies on mean-based estimation techniques, which assume a uniform effect across countries and risk obscuring the very differences that matter for policy. In reality, MENA countries are far from homogeneous: some are early adopters of renewable technologies with strong policy frameworks, while others are at the very start of their transition, facing capacity constraints and limited infrastructure. Under these conditions, the effect of GTPU is unlikely to be constant; it may spur innovation in early-stage countries but have little marginal effect where adoption is already high.

This heterogeneity makes the MENA region particularly well-suited to a quantile regression perspective. Unlike traditional mean-reversion models, quantile methods capture the entire conditional distribution of renewable energy adoption, allowing us to observe how GTPU influences countries differently depending on whether they are at the lower, median, or upper end of the transition spectrum. This is crucial for tailoring policy: what works for a high-capacity renewables leader like Morocco may be irrelevant, or even counterproductive, for a fossil-dependent economy just beginning to diversify.

Against this backdrop, this study investigates how global trade policy uncertainty affects the renewable energy transition in MENA countries, compared to structural factors such as income, oil rents, technological level, emissions, and trade openness, and how its effects vary at high, mid, and low levels of renewable energy transition. This study examines the asymmetric effects of trade policy uncertainty on the pace and direction of the energy transition in MENA economies, explicitly distinguishing between renewable and non-renewable energy deployment from 1995 to 2023, to determine whether policy uncertainty systematically accelerates, delays, or reconfigures the region's decarbonisation trajectory. The framework controls for structural variables, including income, oil prices, emissions, climate-friendly technological innovation, and trade openness, producing a more nuanced and policy-relevant understanding of transition dynamics. The results reveal that GTPU can serve as a constructive force for the adoption of clean energy, especially among countries at lower quantiles of adoption. However, economic growth, trade openness, and emissions consistently exert negative pressure. At the same time, higher oil prices and investment in climate-friendly technology emerge as strong positive drivers, particularly in the higher quantiles, where the transition is already underway.

The rest of the paper is structured as follows: In Section 2, we discuss the theoretical background, including a review of the literature and the research gap. The data, methodology framework, and baseline model are discussed in Section 3. The empirical results and discussions of the estimated equations are presented in Section 4, while Section 5 concludes with policy implications.

2. THEORETICAL FRAMEWORK AND LITERATURE REVIEW

2.1. Theoretical Framework

Both the Environmental Kuznets Curve (EKC) and the Porter Hypothesis provide important theoretical foundations for examining characteristics of policy, trade, or structure that may influence renewable energy development.

The EKC proposes that relatively poorer economies experience increasing environmental harm as they develop until their wealth enables them to invest in green technologies and regulatory institutions (Grossman & Krueger, 1995). The curve implies a quadratic functional form between a country or region's income and environmental quality. The same pattern is expected to hold regarding renewable energy development as green technologies gain traction in wealthier economies.

Conversely, the Porter Hypothesis suggests that environmental regulation can spur innovation and resource efficiency, driving both economic and environmental well-being (Porter & Linde, 1995). The unintended consequence of trade policy uncertainty may function as a form of environmental regulation-like friction, causing countries to invest away from fossil fuel reliance to mitigate exposure and toward renewable alternatives.

Finally, in the same way that uncertainty surrounding environmental regulation has a meaningful impact on investment decisions, real options theory explains how uncertainty influences optimal decisions over time (Dixit & Pindyck, 1994). With respect to energy investments, global trade uncertainty can lead countries to prioritise energy technologies that are less reliant on international supply chains and more reliant on domestic resources, thereby veering investment toward domestic alternatives. The utility of these theories together is to emphasise how structure, uncertainty, and policy are considered holistically rather than separately in the energy transition process. Structure, external uncertainty, and policy are interconnected, where changes in one may have implications for the others. The countries capitalising on those signals for change are more likely to navigate the energy transition successfully.

2.2. Literature Review

The energy transition literature has recently incorporated factors such as external economic shocks and institutional quality, but primarily across fossil fuel-independent economies. The region of interest, the MENA region, and other oil-producing regions have been excluded from both the analysis of economic shocks in the energy sector and the interaction effects with institutional quality. Sadorsky (2009) and Apergis and Payne (2010) report a significantly positive impact of income on renewable energy consumption in developed economies, while affirming that in fossil fuel-dependent countries, economic growth heavily relies on carbon-intensive sectors, such as industries, which in turn boost the demand for fossil fuels. A study by Rafiq, Paramati, Alam, Hafeez, and Shafiullah (2025) confirms that income and institutional quality significantly increase the share of renewable energy consumption. In contrast, financial development hampers it, especially in the short term, according to Saadaoui (2022).

In his meta-analysis, Popp (2019) finds that rising oil prices drive investment in clean energy; however, the effect is less pronounced in MENA nations due to fossil fuel subsidy programs and a lack of policy adjustments. Similarly, according to IRENA, countries with a greater bias towards clean technology development experience greater success in renewable energy deployment. Institutional capacity further amplifies this effect; in the MENA region, strong governance and policy coherence enhance the effectiveness of R&D investments (Saadaoui, 2022).

While Zhang and Da (2015) find that rising emissions sometimes prompt policy shifts toward renewables, the impact varies depending on the strength of regulatory measures. In the MENA region, panel quantile evidence supports the EKC hypothesis, indicating that increased economic complexity and renewable energy usage significantly reduce CO_2 emissions (Al-Ayouty, 2024). Trade is often viewed as a conduit for the diffusion of clean technology (Sadorsky, 2011), but in oil-exporting contexts, openness can actually entrench fossil fuel dependence

(Alola, Yalçiner, Alola, & Saint Akadiri, 2019). Recent evidence from the MENA region using the CS-ARDL (1997–2023) finds that institutional quality, openness, and GDP per capita all improve environmental quality, suggesting that trade alone is insufficient without strong governance (Abbas, Malik, & Abdul Rahman, 2025).

Trade policy uncertainty affects firm behaviour, investment flows, and macro stability (Ahir et al., 2022; Handley & Limão, 2017). In China, TPU has mixed effects: one study finds adverse effects on energy firms' financial investment (Li, Lin, Lan, Zhan, & He, 2023) while others show TPU reduction improves firm-level pollution outcomes via export and innovation channels (Xi, Zhang, Zhou, & Wu, 2024). A panel analysis also reveals an asymmetric relationship between TPU and renewable energy consumption in China (Zuo & Majeed, 2024). Notably, no study explicitly links TPU to the energy transition in the MENA region, marking a significant empirical gap.

MENA's renewable energy uptake is accelerating. Solar capacity increased by approximately 25% in 2024, reaching 24 GW (AC) (PV Magazine, 2025). The IEA predicts that the MENA region will add 62 GW of renewables over the next five years, with solar energy accounting for more than 85% of this growth (World Economic Forum, 2024). In Morocco, the country's target is expected to generate around 762,000 net job-years over 30 years, averaging 25,000 new jobs annually (World Bank, 2022a). World Bank analyses similarly suggest that clean energy investments could become significant employment generators across the MENA region (World Bank, 2022b, 2023).

2.3. Research Gap

The expanding literature on renewable energy transition is not without its gaps. The first gap pertains to the neglected influence of global trade policy uncertainty on the renewable energy transition. Given that the trade energy network between countries has a significant influence on the renewable energy transition, the experience of regions like the MENA, which have heavily fossil fuel-dependent economies, warrants further exploration. While existing studies have focused on aspects such as economic growth and emissions, GTPU has received little attention in explaining energy transition trends. In addition, there have been concentrated efforts to discuss how domestic structural realities, such as domestic capital, economic structure, or technology, alone shape the energy mix, yet external trade-related shocks remain underexplored.

The second gap pertains to relying solely on conditional mean regression techniques that obscure distributional heterogeneity, whereas quantile regression studies that explore asymmetric effects are limited. Given that countries operate at varying levels of the renewable energy transition, further exploration of the asymmetric response of structural determinants and policy shocks over the distribution is warranted. The third gap pertains to the inconclusive evidence regarding the influence of socioeconomic and business openness on the renewable energy transition in the MENA region. Key variables of interest, namely, income, oil rents, trade openness, and emissions, have garnered attention regarding their individual roles in the renewable energy transition. However, the joint influence of these variables, along with their interaction, lies at the intersection of MENA's unique socio-political and economic context, characterized by its oil rent economies and varying unintended stakeholder influence and capacity.

In addressing the aforementioned gaps, this study is the first to empirically examine the influence of GTPU on the renewable energy transition in the MENA region, while integrating the roles of domestic capital, income, oil rents, trade openness, and emissions. Additionally, the study employs panel quantile regression techniques, providing a novel perspective on estimating heterogeneous effects at different quantiles across stages of the renewable energy transition. In doing so, it provides evidence of preferential thresholds within the examination of the GTPU-renewable energy transition and beyond, making a significant contribution both theoretically and empirically to a better understanding of what drives or constrains the renewable energy transition in MENA countries.

3. METHODOLOGY AND DATA

3.1. Model and Data

Following the existing literature, we empirically examine the nexus between trade policy uncertainty and the energy transition in the MENA region. In this regard, we specify the renewable energy (REN) adoption equation as a function of global trade policy uncertainty (GTPU), other determinants of energy transition, which include income (INCOME), oil price (OIL), climate-friendly technology (TECH), and EMISSION. High income and technological advancements are expected to facilitate the energy transition, while rising oil prices and climate change concerns are expected to spur the adoption of clean energy. Finally, trade increases the opportunities for deploying new energy technologies in areas of need. The model is further specified in the logarithmic form of variables as[1]:

$$lREN_{it} = \beta_0 + \beta_1 lGTPU_{it} + \beta_2 lINCOME_{it} + \beta_3 lOIL_{it} + \beta_4 lTECH_{it} + \beta_5 lEMISSION_{it} + \beta_6 lOPEN_{it} + \varepsilon_{it} \quad (1)$$

Where β_0 is the intercept, $\beta_1 - \beta_6$ are the respective coefficients of energy transition determinants, and ε_{it} is the error term.

The energy transition in MENA countries is captured by the share of renewable energy in total energy consumption. Income is represented by per capita GDP measured in US dollars at 2015 constant prices. Emission refers to the total carbon dioxide (CO_2) emissions, and trade openness is the share of a country's total imports and exports in its GDP. This data has been obtained from the World Development Indicators database. Global trade policy uncertainty is represented by the Total World Trade Uncertainty (WTU) index constructed by Ahir et al. (2022). This index is available at https://worlduncertaintyindex.com/data. The oil price is the WTI spot price in US dollars per barrel, as reported by the US Energy Information Administration. Technology is proxied by the ratio of GDP allocated to funding environmentally sound technologies obtained from the Global Green Growth Index database. All variables are used at an annual frequency, covering the period from 2001 to 2023. A balanced panel dataset of these variables is constructed for 13 MENA countries, which are exclusively determined by data availability. These countries include Algeria, Egypt, Iraq, Israel, Jordan, Lebanon, Libya, Malta, Morocco, Qatar, Tunisia, the United Arab Emirates, and Yemen.

3.2. Estimation Methods

Due to the possibility of heterogeneity in the underlying properties of the data series, conditional mean regressions may be inappropriate for the panel of countries. To this end, this paper employs panel-quantile-type estimation techniques that can provide more reliable inferences from panel data models. This procedure begins with the preliminary Hausman test, which helps determine whether to use fixed effects or random effects methods of estimation. If the null hypothesis that the random effect is a more consistent method is rejected, then the fixed effect is more appropriate to use.

The panel method of moments quantile regression (PMMQR) with fixed effects, as demonstrated by Machado and Silva (2019) is a more effective approach for addressing individual effects in models and endogeneity that may exist in the explanatory variables. This approach is also robust in the presence of non-normality, heteroscedasticity, and outliers, which may be present in the data; thus, it can provide reliable estimates. This model is specified as:

$$Q_Y(\tau \mid X_{it}) = [\alpha_i + \delta_i q(\tau)] + Z_{it}\beta + X'_{it}\gamma q \quad (2)$$

Where $Q_Y(\tau \mid X_{it})$ represents the quantile distribution of $lREN$, this depends on the location of the explanatory variables. Machado and Silva (2019) refer to $\alpha_i(\tau) \equiv \alpha_i + \delta_i q(\tau)$ as the scalar coefficient that represents the quantile-τ for the ith individual fixed effect or the distributional effect at τ. X'_{it} is the vector of explanatory variables

[1] Based on these methods of estimation, Equation 1 is estimated using the exceptional cases of quantile estimator codes – mmqreg and *qregpd* – in STATA.

defined earlier, while Z_{it} represents a vector of the explicitly differentiable transformations of the X'_{it} components. $[\alpha', \delta, q(\tau), \beta', \text{and } \gamma']'$ are the vector of the parameters.

The nonadditive fixed effect, as demonstrated by Powell (2022) is employed for a robustness check and comparison. This approach provides reliable results even though the time length is short. This model preserves the non-separable disturbance error term, and it specifies the individual effect as an integral component of each explanatory variable. The nonadditive approach is expressed as:

$$Y_{it} = X'_{it}\beta(U^*_{it}); \text{ where } U^*_{it} \sim U(0,1) \text{ and } U^*_{it} = f(\alpha_i; U_{it}) \qquad (3)$$

Y_{it} represents the dependent variable, X'_{it} is the vector of regressors, *and* U^*_{it} is the non-separable disturbance term. The panel quantile regression requires that $P\left(Y_{it} \leq X'_{it}\beta(\tau) \middle| X'_{it}\right) = \tau$ for an individual country i in a given year t in a particular quantile τ.

4. RESULTS AND DISCUSSION OF FINDINGS

4.1. Results

Table 1A shows a clear rejection of Hausman's null hypothesis, which validates the preference for fixed effects estimations. The results of the panel MMQR with fixed effects are reported in Table 1B. The location coefficients (mean effects) are significant. However, the significance of the scale coefficients (variance effects) indicates that trade policy uncertainty and oil prices are homogeneous, while others are heterogeneous. This validates the need to rely on the quantile coefficients for drawing inferences.

Table 1A. Hausman test summary.

Chi-Sq. Statistic	20.549 -0.002

Table 1B. Panel method of moments quantile regression (MMQR) with fixed effects.

	lGTPU	lINCOME	lOIL	lTECH	lEMISSIONS	lOPEN
Location	0.136 (0.089)	-0.541 (0.000)	0.409 (0.080)	0.074 (0.000)	-0.430 (0.000)	-0.560 (0.042)
Scale	-0.074 (0.127)	0.166 (0.010)	-0.028 (0.839)	0.030 (0.010)	-0.084 (0.088)	-0.564 (0.001)
Quantile						
0.1	0.259 (0.077)	-0.816 (0.000)	0.456 (0.283)	0.024 (0.489)	0.290 (0.052)	0.372 (0.460)
0.2	0.220 (0.075)	-0.729 (0.000)	0.441 (0.219)	0.040 (0.179)	-0.334 (0.008)	0.079 (0.851)
0.3	0.198 (0.076)	-0.679 (0.000)	0.433 (0.181)	0.049 (0.069)	-0.360 (0.002)	-0.090 (0.816)
0.4	0.141 (0.090)	-0.552 (0.000)	0.411 (0.087)	0.072 (0.000)	-0.425 (0.000)	-0.522 (0.082)
0.5	0.105 (0.128)	-0.472 (0.000)	0.397 (0.047)	0.087 (0.000)	-0.466 (0.000)	-0.797 (0.001)
0.6	0.088 (0.170)	-0.432 (0.000)	0.390 (0.036)	0.094 (0.000)	-0.486 (0.000)	-0.930 (0.000)
0.7	0.069 (0.255)	-0.391 (0.000)	0.383 (0.031)	0.102 (0.000)	-0.507 (0.000)	-1.072 (0.000)
0.8	0.057 (0.341)	-0.363 (0.000)	0.378 (0.031)	0.107 (0.000)	-0.521 (0.000)	-1.165 (0.000)
0.9	0.048 (0.422)	-0.343 (0.000)	0.375 (0.033)	0.111 (0.000)	-0.531 (0.000)	-1.233 (0.000)

Note: P-values are in parentheses.

The panel quantile approaches reveal considerable heterogeneity across the MENA region in the coefficients for trade policy uncertainty and structural predictors of renewable energy. Most importantly, GTPU's coefficients reveal a positive yet decreasing relationship with RE adoption across quantiles, and the estimates become insignificant after the 0.5 quantile. Specifically, at the 0.1 quantile, a 1% increase in GTPU corresponds to an increase in renewable energy capacity by approximately 0.26% ($p = 0.077$), while at the 0.9 quantile, the point estimate decreases to 0.05% ($p = 0.422$). The relatively weak relationship at higher quantiles aligns with prior literature that discusses how policy uncertainty or trade uncertainty diversifies firms' portfolios, enabling more short-term investments at lower adoption levels, as firms and governments focus on resilience against external demand shocks (see Zuo and Majeed (2024), for a similar argument).

Income has a negative and significant coefficient across quantiles, with the coefficients ranging from approximately –0.82% to –0.34%. In the case of the MENA region, it may suggest that continued increasing income levels have followed a carbon-intensive development pattern, with increasing fossil-fuel rents that crowd out green capacity investment, which supports the regional dimension of the NGHD threshold along with regional studies (Boulanouar, Essid, Farid, and Mahjoub (2025), for growth–emission threshold analysis.

Estimates confirm a positive effect of oil rents on renewable energy adoption, ranging from 0.38% to 0.46%. The effect is most potent in the middle and higher quantiles of the dependent variable. This evidence aligns with a mixed impact of hydrocarbon assets: oil-dominated economies may be slow to transition, but oil wealth can accrue and be diverted to finance structural change and renewable projects if institutional configurations enable high reinvestment rates, e.g., through sovereign wealth fund-led diversification or direct investments in the green sector. A recent study similarly finds a nonlinear or threshold effect of the share of oil rents in GDP in shaping indicators of renewable energy investments (Baudino, 2024).

Furthermore, we observe that technological progress is a consistent positive driver across quantiles, with estimates moving from a small and imprecise effect at the 0.1 quantile (≈0.02%, $p>0.4$) to a clearly significant effect at the upper tail (≈0.11%, $p<0.001$). This monotonic strengthening aligns with an extensive body of literature that documents innovation and the diffusion of green-related technologies as key drivers of sustained renewable energy growth, as well as essential elements for overcoming deployment coordination bottlenecks (Han, Peng, Guo, Aslam, & Xu, 2025).

The emissions of high-income countries demonstrate a significant adverse effect on adoption, with the decline becoming more pronounced in higher quantiles (≈approximately –0.33% to –0.53%). This is likely tied to the concept of carbon lock-in: nations with deeply rooted, emissions-heavy infrastructure, institutions, and value chains established over time will face substantially greater political and economic costs to transition away from these systems in favor of renewable technologies. Evidence and theories about the role of emissions in lock-in and renewable adoption emphasize similar concerns (Justice, Nyantakyi, & Isaac, 2024).

Changes in trade openness seem to accrue decreasing benefits over time (the respective estimates are about –0.52% at q=0.4; –0.98% at q=0.5; −1.09% at q=0.6, and −1.23% at q=0.9). In the context of MENA, stronger trade relations may lead to long-lasting trade patterns based on fossil fuel-shifting specializations and affect Morocco's import structure, decreasing the potential for the domestic green transition; the latter echoes a theory positing that trade openness can stimulate clean energy industries but only if exports favor green technologies and if carbon-reducing policies are in place. Our results also echo previous findings, showing that trade openness tends to make countries more dependent on their initial comparative advantages in fossil fuel production/consumption, unless accompanied by focused green industrial development policies, thanks to capital accumulation and industrial know-how (Ghazouani, Boukhatem, & Sam, 2020).

This evidence offers a practical policy insight: trade policy uncertainty can spur short-term diversification and initial-stage renewable integration, but deeper decarbonisation in advanced transition countries is impeded by structural characteristics of the economy sectoral exposure, emissions intensity, and trade integration that necessitate complementary policies (green public investment, technology diffusion initiatives, and trade strategies reinforcing decarbonisation goals).

In Table 2, the quantile regression with nonadditive fixed effects estimation provides similar indications that global trade policy uncertainty has a statistically significant positive effect on renewable energy adoption, except in the 7th and 9th quantiles. Similar to the MMQR results, income, trade, and emissions also have significant adverse effects on the adoption of renewable energy. Furthermore, there are significant indications that increases in oil prices and the adoption of climate-friendly technologies lead to increased consumption of renewable energy. With this evidence, this study establishes that the response of renewable energy adoption to global trade policy uncertainty and other variables is heterogeneous across quantiles.

Table 2. Panel quantile regression with nonadditive fixed effects.

Quantile	*lGTPU*	*lINCOME*	*lOIL*	*lTECH*	*lEMISSIONS*	*lOPEN*
0.1	38.191 (0.711)	-20.146 (0.705)	50.134 (0.661)	0.679 (0.780)	62.144 (0.699)	-142.523 (0.686)
0.2	0.250 (0.065)	0.463 (0.179)	-1.304 (0.008)	-0.139 (0.017)	-2.609 (0.000)	-1.211 (0.062)
0.3	0.384 (0.000)	-0.705 (0.000)	0.543 (0.000)	0.044 (0.000)	-0.535 (0.000)	0.161 (0.000)
0.4	0.191 (0.000)	-0.717 (0.000)	0.875 (0.000)	0.025 (0.077)	-0.610 (0.000)	-0.523 (0.000)
0.5	0.141 (0.005)	-1.157 (0.000)	0.078 (0.723)	0.119 (0.000)	-0.523 (0.000)	-0.507 (0.000)
0.6	0.133 (0.000)	-0.774 (0.000)	0.367 (0.000)	0.114 (0.000)	-0.405 (0.000)	-0.015 (0.599)
0.7	-0.237 (0.362)	-0.548 (0.000)	-1.002 (0.264)	-0.015 (0.909)	-0.424 (0.000)	-0.198 (0.480)
0.8	0.016 (0.000)	-0.516 (0.000)	0.274 (0.000)	0.089 (0.000)	-0.450 (0.000)	-0.692 (0.000)
0.9	1.505 (0.767)	-1.849 (0.625)	1.289 (0.645)	0.085 (0.783)	-0.673 (0.541)	1.487 (0.784)

Note: P-values are in parentheses.

4.2. Summary of Findings

The MENA region stands at a pivotal moment as it navigates the tension between a long-standing reliance on fossil fuels and the global momentum toward a low-carbon future. While the region continues to play a dominant role in oil production and exports, it now faces intensifying pressures from the international community, shifting trade dynamics, and growing climate vulnerabilities at home, which are accelerating its energy transition. The research findings suggest that GTPU primarily promotes the use of renewable energy sources in immature renewable energy markets. Global trade uncertainty can catalyze countries to transition away from fossil-fuel-dominated energy sources and toward more resilient domestic energy systems.

Another crucial finding from the econometric study is the empirical evidence of several structural impediments that persistently constrain change. The negative relationships found between income, emissions, trade openness, and renewable energy consumption suggest more deep-rooted issues, specifically the rentier nature of many MENA economies, the need to promote fossil fuel exports, and the lack of enforcement of climate targets. These characteristics of MENA economies are difficult to overcome during an energy transition that requires extensive adaptation and transformation. This also demonstrates that the region's energy transition is limited by the underpreparedness of domestic institutions and the lack of domestic commitment to longer-term policies. Significant external shocks may trigger or facilitate some change, yet their effects are likely to fall short of what is needed to stimulate the energy transition. The interplay between external disruptions and domestic constraints thus underscores the heterogeneity in renewable energy adoption across the MENA landscape.

5. CONCLUSION AND POLICY INSIGHTS

5.1. Conclusion

This study provides robust evidence on the heterogeneous impacts of global trade policy uncertainty and structural factors on renewable energy adoption in the MENA region, using advanced quantile-based panel techniques. The results indicate that GTPU can be a constructive force in driving the adoption of clean energy, particularly in countries with lower levels of renewable energy consumption. However, economic growth (as measured by income), trade openness, and emissions are consistently found to have a negative impact, suggesting that progress in renewable energy development does not automatically accompany increased affluence or international integration. Conversely, rising oil prices and investment in climate-friendly technology have a strong positive effect, particularly at higher quantiles, where renewable energy adoption is already relatively advanced. These findings underscore the need for tailored strategies that are specific to each country's unique stage in the energy transition process.

5.2. Policy Insights

Given these arguments and empirical evidence, the 'what-policies-to-implement' question should be addressed in the MENA region by dropping non-enforceable rhetoric, deliverables without numbers or deadlines, and ad-hoc notions of bridging the gap between present and aspirational trade and energy intents. Instead, policymakers of MENA jurisdictions should adopt more legally enforceable and results-based frameworks in the following three steps:

Make trade policy uncertainty a tantalising opportunity by breaking the inertia around national renewable energy share targets through legally binding constitutional infrastructure investment obligations, with accompanying gradient escalation and depreciation penalties, under the national investment law, which regional regulations require prospective national development multipliers to report each year for independent verification and publish on prescribed dates. Monitor and report progressively elevated, legally binding national multipliers for infrastructure development projects in non-renewable energy sectors that include an increasing proportion of specified public infrastructure investment. This investment should or must be allocated to overlaid renewable energy-capable, climate-resilient infrastructure to promote a decrease in fossil fuel dependence. Infrastructure investment crowds out economic expansion.

Adopt trade policy-focused green integration policies to supplant the popular approach of cross-subsidising renewable energy infrastructure project implementation, creating higher or lower national investment multipliers. Consider eliminating zero-or-negative tariff barriers to the unintended consequential increase in foreign parts procurement as a by-product of green industrial policies under the jurisdiction's most(least) favoured nation clauses. Include temporarily pausing compliance-determinant, scale-adjusted quantity escalations on binding maximum thresholds, thus initiating investor-state arbitration under jurisdictional or bilaterally agreed dispute settlement arrangements with prospective national multipliers or target penalties for non-compliance.

Implement a trade policy as an environmental policy, mandating the installation of continuous emissions monitoring systems for Scope 1 emissions of facilities consuming more than a prescribed minimum quantity of fossil fuels annually by a defined date, and determining facility emissions baselines if not already established. Adopt legislating intensity-based numerical compliance targets or cap-and-trade regimes establishing tradable domestic permit schemes amongst other large-scale points polluted, which allow point sources of Scope 1 emissions above legally binding levels to purchase unretired carbon offset tradable certificates from voluntary renewable electricity projects approved under a specified regulation, one-to-one, remitting them for retirement in a prescribed future year. Allocate at least an increasing share of net revenues before transfers to the sovereign green transition fund, with its receipts constrained by empowerment legislation to avoid discretion over investments in prescribed low-carbon infrastructure projects and technologies.

Direct the fund receipts into carbon-free reservoirs and prescribed low-carbon infrastructure projects, all constrained from receiving additional allocations during prescribed periods of price spikes or running sequential and consecutive or aggregate countable years for competing, windfall oil revenue over-dependence if not indemnified from losses or lock-in constraining campaigns against oil price spikes, ineffective multipliers, or extended timeframes for windfall transfers.

5.3. Limitations and Future Research Directions

A key limitation of this study is that it focuses on a limited number of 13 MENA countries, and other data regions with different numbers of countries do not capture the unique trade, economic structure, and energy context of the MENA.

A second limitation is that quantile regression estimates the level of heterogeneity in a quantile-specific manner but does not necessarily address endogeneity issues stemming from reverse causality between variables such as trade openness, economic growth, and renewable energy adoption. A third limitation is that trade/policy uncertainty, as well as renewable energy variables, are aggregated. Their aggregation does not fully capture the sector-specific effects that trade uncertainty may have on renewable energy adoption, which is influenced by trade exposure.

Future analyses should employ instrumental variable techniques/causal identification strategies, including indicators of governance and institutional quality, and disaggregate the variables of renewable energy adoption into specific sectors. Conducting studies across multiple regions with varying resource endowments and trade openness could position the MENA countries within the broader global energy transition conversation.

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