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Financial development-energy consumption risk nexus

Bekhzod Kuziboev, Cem Işık, Mokhirakhon Mirkhoshimova, Samariddin Makhmudov, Feruz Kurbanov, Azka Amin, Stefania Pinzon

Bekhzod Kuziboev (email: bekhzod.kuziboev@gmail.com), Department of Economics, Urgench State University, Urgench, Uzbekistan

Cem Işık (*corresponding author*, email: cemisik@anadolu.edu.tr), Department of Economics, Faculty of Economics and Administrative Sciences, Anadolu University, Eskişehir, Turkey; University College, Korea University, Seoul, Republic of Korea; Baku Eurasian University, Economic Research Center (BAAU-ERC), Baku, Azerbaijan; Western Caspian University, Economic Research Center (WCERC), Baku, Azerbaijan; Advance Research Centre, European University of Lefke, Lefke, Northern Cyprus, Turkey

Mokhirakhon Mirkhoshimova (email: mokhira1995@gmail.com), Cluster Development Department, Center for Economic Research and Reforms, Tashkent, Uzbekistan

Samariddin Makhmudov (email: maxmudov_samariddin@mamunedu.uz), Department of Economics, Mamun University, Khiva, Uzbekistan

Feruz Kurbanov (email: feruzbek.qurbanov@gmail.com), Department of Tourism, Urgench State University named after Abu Rayhan Biruni, Urgench, Uzbekistan

Azka Amin (email: azka.amin@uniten.edu.my), Institute of Energy Policy and Research, Universiti Tenaga Nasional, Kajang, Malaysia

Stefania Pinzon (yajaira.pinzon@unl.edu.ec), Esai Business School, Universidad Espiritu Santo, Samborondón, Ecuador

Abstract

Currently, examining contribution of financial enhancement in achieving energy efficiency as well as mitigating uncertainties of energy consumption is gaining interest in the literature. Regarding this matter, this research tests the role of financial development on energy consumption risk in a global case applying the panel of 137 countries over the period 2000–2022. For the empirical analysis, Method of Moments Quantile Regression (MMQR), Fully Modified Ordinary Least Squares (FMOLS) and Canonical Cointegrating Regression (CCR) are used along with the second-generation unit root and cointegration tests. The findings reveal that growth of the financial sector impacts energy

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consumption risk negatively at all the quantiles from 10% to 90%, indicating 1% increase in financial development mitigates energy consumption risk by −0.003% at median (50%) quantile. The long-run estimations by FMOLS and CCR also indicate the negative effect. As a robustness, instrumental variable (IV) regressions such as Kiviet and Hausman–Taylor models are applied, and the outcome still remains as the previous ones, validating the theoretical linkage. Policy decisions should be implemented considering the economic development, globalization, digitalization and climate change vulnerability in the association of financial enhancement with energy consumption risk.

Keywords: Financial development, energy consumption risk, Method of Moments Quantile Regression, Fully Modified Ordinary Least Squares, Canonical Cointegrating Regression

JEL Classification: Q40, Q49, G10, G21, C33

1. Introduction

The increasing need to maintain energy security while reducing environmental risks has led to an increasing curiosity in the factors that influence energy consumption. In this case, financial enhancement is considered crucial when reducing the risk associated with energy consumption. The volatility, inefficiency, and environmental risk associated with unsustainable energy usage are together referred to as energy consumption risk. As economies strive for more environmentally friendly and secure energy systems, this has gained significant traction both academically and in terms of policy in discussions regarding how as well as how much financial development impact energy-related risk (Işık *et al*., 2025a).

In order to mobilize and distribute resources effectively, financial development includes advancements in financial markets, organizations, and accessibility. Effective financial systems guarantee that the required funds are directed towards energy market-price risk management, promotion of energy efficiency enhancements, and hedging of energy from renewable sources (Chiu and Lee, 2020). According to recent research, financial advancements might help reduce risk and shift energy consumption from non-renewable energy sources to renewable ones if they are supported by environmental regulations (Liu, 2023). There is factual support for this viewpoint in a variety of economies. Chiu and Lee (2020) look into how countries with stable macroeconomic conditions may be able to mitigate the volatility of energy consumption through financial development. Using a dynamic panel quantile model, Liu *et al*. (2023) discover that at higher quantiles of energy consumption levels, financial development lowers the accumulation of non-clean energy consumption. For Kazakhstan, Mukhtarov *et al*. (2020) observe an identical inverse correlation between consumption of energy as well as financial development, with financial depth lowering the likelihood of energy dependence.

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Additionally, Ma and Fu (2020) in their multi-country analysis reveal that the global development of finance affects energy consumption patterns and that emerging economies, in particular, experience stronger risk-reducing effects. Anton and Nucu (2020) also emphasize that financial development increases clean energy use throughout the EU and thus increases energy resilience. Qayyum *et al*. (2021), in India's case, provide evidence that financial development, combined with technological innovation, decreases reliance upon non-renewable carbon-emitting sources. The mechanisms that decrease energy consumption risk via financial development have found more attention from literature in the recent past. According to Shen *et al*. (2021), green investments and financial development, for example, serve mechanisms to reduce GHG emissions and energy volatility in China. Kalai *et al*. (2023) have established the existence of a threshold effect whereby exceeding a specific limit could result in higher financial development causing favorable changes in energy sustainability. Li (2022) concurs regarding financial accessibility for all segments of society enhancing energy efficiency, more so in developing and emerging economies.

Increasingly, the literature supports the notion that, when it is applied to sustainable and inclusive financial tools, financial development can be an effective way to mitigate energy consumption risk. In the presence of regional and policy-related differences here and there, it is rather safe to assume that improving financial access and depth aids in renewable energy transitions and energy security. Current research, hence, attempts to further explore the dynamics by empirically assessing the risk-mitigating effects of financial development on energy consumption on a global panel of states.

2. Literature review

Energy consumption risk encompasses all forms of uncertainties and instabilities pertaining to energy supply, utilization, or cost; it represents a significant danger to energy security and sustainable development (Işık *et al*., 2025b). Numerous academics have suggested that structural and macroeconomic concerns are crucial components of energy consumption risk management. Of these, financial development can be considered as a crucial component in enhancing the energy transition to lower vulnerabilities and stabilize consumption patterns (Sadorsky, 2010), thus reducing risk. The evolution and expansion of financial markets and institutions, as well as aspects such as the regulatory environment, capital market depth, and the availability of financial services, are often associated with financial development. Mobilizing investment is one of the crucial channels that the financial development channel is connected to consumption of energy risk. As stated by Shahbaz *et al*. (2013), financial development and robust financial markets expand the amount of capital available

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for FDI in renewable energy infrastructure as well as in energy-efficient technologies, diminishing reliance on unstable carbon-intensive energy sources and possibly lowering energy consumption risks.

This study is the first empirical research to test the causal impact of financial development on energy consumption risk. Also, it introduces a novel, policy-relevant measure of energy consumption risk and quantifies the channels through which financial development affects risk. Additionally, the paper employs panel econometric methods and a battery of sensitivity checks to distinguish the financial channel from the structural and macroeconomic determinants.

Financial development (FD) lowers financing costs and relaxes borrowing constraints, enabling firms and utilities to invest in energy-saving capital, retrofits and low-carbon technologies. As stated by Shahbaz *et al*. (2013), financial development and robust financial markets expand the amount of capital available for FDI in renewable energy infrastructure as well as in energy-efficient technologies, diminishing reliance on unstable carbon-intensive energy sources and possibly lowering energy consumption risks. For Turkey, Mukhtarov *et al*. (2022) investigated that a 1% increase in FD raises renewable energy consumption by about 0.21%, consistent with FD mobilizing finance for cleaner investment. Specifically, work on green finance displays that directed instruments (green credit, green bonds) both ease financial constraints and spur technology adoption via a 'clean-biased technical progress" and financial-constraints channel. Guo *et al*. (2023) and related studies present mechanism tests where green finance rises renewable deployment and innovation; dynamic panel and mediation tests support causal pathways from financial instruments to project-level investment. At the same time, quantile and dynamic panel evidence (Xiaorui *et al*., 2023) demonstrate the energy-saving effect of FD is heterogeneous: it strengthens under green credit policies and at higher consumption quantiles, underscoring the role of policy-design in translating FD into risk-reducing investments. Using a system-GMM framework for EU countries over the period 1990–2017, no significant association is found for the EU-27, however in the old EU member states higher levels of financial development are associated with increased energy consumption. For the new members bank-based financial development exhibits an inverted U-shaped relationship with energy consumption (Coban and Topcu, 2013).

Financial development can accelerate the structural shift from fossil fuels to renewables by improving access to project finance and credit for renewables. Ma *et al*. (2020) (120 countries) report that financial expansion raises energy consumption globally but with pronounced geterogeneity: in developing states, growth tends to increase energy demand unless accompanied by appropriate energy policy. This implies finance alone is not

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sufficient – it must be directed to low-carbon investments to reduce energy risk. Mukhtarov *et al*. (2022) provide direct evidence that FD increases renewable penetration, which lowers vulnerability to fossil-fuel supply shocks. Zhao *et al*. (2023) report that green bonds improve renewable investment efficiency and liquidity, which directly reduces vulnerability to fossil fuel supply shocks. Using robust econometric methods such as CupFM (continuously updated fully modified), CubBC, GMM (generalised method of moments) on a global panel of 77 countries (2000–2018), Sun *et al*. (2023) find that financial development exacerbates energy poverty. The roleof FD in facilitating China's transition towards renewable energy and upgrading its energy structure was studied by Ji and Zhang (2019) using macro-level time-series data. Researchers reveal that FD is a critical driver of renewable energy growth accounting for 42.4% of its variation, capital market playing a dominant role.

Several studies emphasize that the effectiveness of financial development depends on macroeconomic stability and institutional quality. Chiu and Lee (2020) utilize panel smooth transition regression to display the FD and energy association changes sign depending on country risk: banking development has larger effects than stock-market depth, and FD reduces energy use only in low-risk regimes. Aslan *et al*. (2021), using panel-VAR for G-7 and developing countries, show that FD lowers energy consumption in advanced economies but raises it in emerging economies; equity and bond markets, in particular, increase long-run energy use. Ma *et al*. (2020) also find that financial expansion can raise energy consumption in poor states if not accompanied by regulation – for example FD may increase risk where institutions are weak. Tinta (2022) demonstrate that climate vulnerability and higher climate-related sovereign/firm risk raise the cost of capital and blunt FD's capacity to fund green projects; thus, risk-reducing role is attenuated in climate-vulnerable countries unless accompanied by policy support. The research by Liu *et al*. (2021) highlights the critical role of institutional quality in shaping the effectiveness of electricity sector reforms across South Asia, the Middle East and Europe. The findings show that deficiencies in governance and coordination among reform agencies limit the impact of reforms on energy efficiency and electricity access, whereas higher institutional efficiency enables up to a 13% increase in energy efficiency and a 62% rise in per capita electricity access.

Overall, the literature serves as a proof that financial development is a useful tool for lowering energy consumption risk by promoting clean energy investment, increasing energy efficiency, and discouraging dependence on non-renewable energy sources. This is especially true when financial development is backed by environmental policies like green credit. Based on the literature review, the following hypothesis can be postulated:

Financial development has a negative effect on energy consumption risk.

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3. Theoretical Background, Data and Methodology

3.1 Theoretical Background and Data

This research tests the effect of financial development on energy consumption risk in the panel of 137 countries (See Apex 1) over the period of 2000–2022. The dependent variable is energy consumption risk score. Energy consumption risk is a quantitative assessment of how much the amount of energy actually consumed by a country (or a specific entity) deviate from the expected statistical indicator in accordance with its level of economic development. If this difference is large, it indicates inefficient energy use or imbalances in the structure of the economy and high risk. This indicator is a component of the overall risk scores used in the Refinitiv/LSEG sovereign and ESG databases to assess the energy vulnerabilities and sustainability of countries.

In the construction of energy consumption risk score, the main risk themes used are energy policy, low-carbon energy and energy independence. More precisely, energy consumption risk covers all energy disbalances related to energy supply, demand, shortages, institutional and environmental disruptions in energy sector. Therefore, this is an appropriate risk proxy to our best knowledge.

The main independent variable is financial development represented by the share of domestic credit to private sector by banks in GDP. The specification of the model as follows:

$$ECR_{it} = a_0 + a_1 FD_{it} + \beta X'_{it} + \epsilon_{it} \quad (1)$$

where *ECR* is energy consumption risk, *FD* is financial development.

Theoretically, the link between energy consumption risk and financial development is affected by other various factors. Many researchers have emphasized the critical role of economic growth, globalization, digitalization and climate change vulnerability (sustainability) when defining the association between financial development and energy consumption risk.

Usman *et al*. (2023) examined Asian developing countries from 1991–2019 to assess how financial advancement, economic growth, urbanization and globalization impact energy consumption utilizing Dynamic Seemingly Unrelated Regression approach. Authors reveal that 1 unit increase in financial development is associated with 3.07% increase in energy consumption, moreover, 1 unit rise in GDP is linked to 0.329 increase in energy use, Finance-growth-energy nexus has been studied in Pakistan from 1972–2012 using GMM model (Komal and Abbas, 2015). Results demonstrated that economic growth positively impacts the energy

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consumption. Employing ARDL-PMG technique in China from 1997–2017, Wang *et al*. (2021) explore that in the long-term growth stimulates energy consumption whereas financial growth tends to diminish it. Shahbaz *et al*. (2013) analysed the linkage in the middle of GDP growth, energy consumption, financial development, CO_2 emissions in Indonesia between 1975–2011 performing Zivot–Andrews unit root test and ARDL methods. Authors found that economic development together with energy consumption tend to rise CO_2 emissions and financial advancement decreases it.

Saud *et al*. (2018) explored the impact of financial development on energy demand considering globalization aspects. The findings infer that financial enhancement positively effects energy demand while globalization impact is negative. The examination of impact of globalization in the financial-energy nexus in Next-11 states from 1990–2014 concluded that monetary development stimulates energy consumption and global integration increases the energy needs (Saud *et al*., 2018). The interconnection in the middle of financial development, energy demand, GDP growth and globalization for BRI countries from 1990–2016 has been conducted by Lu *et al*. (2021). According to the DSUR model results, a 1% rise in financial development brings about a 0.049% decrease in energy usage, while a similar 1% grow in globalization results in a 0.621% reduction. Solarin *et al*. (2019) tested the influence of ICT, financial development and industrial development on electricity demand in Malaysian economy during 1990–2015.

Mukhtarov *et al*. (2022) found that sustainable clean energy usage responds positively of financial development, with a 1% increase in financial development corresponding to a 0.21% increase in renewable energy use. Alsagr and van Hemmen (2021) revealed that financial development promotes clean energy consumption in developing markets from 1996–2015 utilizing GMM model by improving access to finance and facilitating energy transition. Anton and Nucu (2020) examined the effect of monetary development on green energy demand in EU states over 1990–2015 using panel FE model and found all representations of financial expansion have encouraging impact on the amount of renewable energy consumption. The association between financial development and renewable energy consumption in 34 UMIC developing economies during 1994–2015 was analysed by Shahbaz *et al*. (2021) by using FMOLS approach. Authors concluded that financial improvement surges the usage of clean energy.

Apex 2 denotes the definition, notation and sources while Table 1 includes the descriptive statistics of the variables used in this work.

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Table 1: Descriptive statistics

Variable	Observation	Mean	Standard deviation	Minimum	Maximum
ECR	3,082	53.819	29.541	0.01	100
FD	3,082	52.273	42.782	–24.877	304.575
EG	3,082	14382.03	20007.17	110.460	133711.8
GLOB	3,082	62.070	14.538	25	90
DGN	3,082	39.538	32.053	–0.3	100
CLV	3,082	0.438	0.095	0.25	0.68

Source: Authors' own calculations

3.2 Methodology

3.2.1 Method of Moments Quantile Regression

The MMQR technique provides insight on the empirical estimates. The standard quantile regression is as follows:

$$Q_{y_{(i,t)}}(\tau|x_{(i,t)}) = (\boldsymbol{x}^{\boldsymbol{\tau}}_{\boldsymbol{(i,t)}}\beta_\tau) \tag{2}$$

where $Q_{y(i,t)}(\tau|x_{(i,t)})$ represents the τ-th quantile of the dependent variable ln *ECR*, $\boldsymbol{x}^{\boldsymbol{\tau}}_{\boldsymbol{(i,t)}}$ is the vector of variables *FD*, ln *EG*, ln *GLOB*, *DGN* and ln *CLV*, and β is the parameter of these variables at a particular quantile of τ.

MMQR produces more consistent results compared to other non-linear techniques (Awan *et al*., 2022) and mean regressions. More specifically, MMQR allows to estimate the effect of independent variables at different quantiles of the conditional distribution of dependent variable whereas mean regression only perform the outcome at median quantile. Also, MMQR is robust to heteroscedasticity since it estimates the effect at different quantiles, however mean regression is dominated by central observations and ignores tail risks. Additionally, MMQR also accounts for heteroscedasticity by enabling asymmetries that vary depending on location. Moreover, MMQR outperforms other panel quantile methods because it also counts for endogeneity along with heterogeneity. MMQR handles the endogeneity by analysing reverse causality, *i.e.*, the impact of the explained variable

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on the explanatory variables. Furthermore, MMQR takes endogeneity into account by applying fixed effects. To incorporate unobserved heterogeneity among countries Equation (2) can be formulated as Equation (3):

$$Q_{y_{(i,t)}}\left(\tau \middle| a_i, x_{(i,t)}\right) = a_i + x'_{(i,t)}\beta(\tau_k) \tag{3}$$

where a_i denotes the individual fixed effect. Moreover, Equation (3) can be expressed within the MMQR framework as:

$$\ln ECR_{(i,t)} = \alpha_i + X'_{(i,t)}\beta + \left(\delta_i + Z'_{(i,t)}\gamma\right)U_{(i,t)} \tag{4}$$

In Equation (4), the model for the conditional quantile can be expressed as:

$$Q_{\ln ECR_{it}}(\tau|X_{it}) = \left(\alpha_i + \delta_i q(\tau)\right) + X'_{it}\beta + Z'_{it}\gamma q(\tau) \tag{5}$$

According to Machado and Silva (2019), since $q(\tau) = F_U^{-1}(\tau)$, it follows that $P(U > q(\tau)) = \tau$. To address the optimization issues caused by the sample quantile, the model is expressed as:

$$\min_q \sum_i \sum_t \rho_\tau(A_{(i,t)} - (\delta_i + Z'_{it}\gamma)q) \tag{6}$$

where $\rho_\tau(A) = (\tau - 1)AI\{A \leq 0\} + TAI\{A > 0\}$ represents the checking function.

3.2.2 Cross-sectional Dependence, Unit Root Test, Cointegration Test, FMOLS, DOLS and CCR

In this study, rather than exclusively employing the MMQR method, a series of supplementary panel data tests are conducted to ensure the robustness and reliability of the empirical findings. These include tests for cross-sectional dependence, unit roots, and cointegration, complemented by long-run parameter estimations utilizing FMOLS, DOLS and CCR techniques.

The analysis commences with the assessment of cross-sectional dependence. To this end, the Lagrange Multiplier (LM) test statistic, initially proposed by Breusch and Pagan (1980), is applied to detect the presence of the dependence across cross-sectional units within the panel dataset:

$$\mathrm{CD}_{\mathrm{LM}} = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}^2 \tag{7}$$

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Let $\hat{\rho}_{ij}^2$ denote the estimated corresponding correlation metrics of the residuals derived from OLS regressions. A statistically significant value of the test statistic provides solid empirical evidence to reject cross-sectional independence, suggesting that residuals are correlated across individual units. The presence of such cross-sectional dependence implies that the conventional OLS standard errors may be biased, thereby necessitating the adoption of alternative estimation techniques to obtain consistent inference.

The Lagrange Multiplier test can yield biased outcomes when applied to large samples. The CD test (Pesaran, 2004) statistic is designed to evaluate the assumption of cross-sectional independence under the null among panel units, and its expression is given by:

The CD statistic calculation is as follows:

$$\mathrm{CD} = \sqrt{\frac{1}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} (T\hat{\rho}_{ij}^2 - 1)} \tag{8}$$

The presence of CD requires that panel data methods properly account for this issue. In our study, the stationarity properties of the variable are investigated through the CIPS developed by Pesaran (2007), which explicitly accommodates dependence among cross-sectional units. The computation of the CIPS statistics are shown as follow:

$$\Delta Z_{it} = \alpha_i + \rho_i Z_{i,t-1} + \beta_i \bar{Z}_{t-1} + \sum_{j=0}^{k} \gamma_{ij} \Delta \bar{Z}_{i,t-1} + \sum_{j=0}^{k} \delta_{ij} Z_{i,t-1} + v_{it} \tag{9}$$

The concluding step consists of calculating the CIPS statistic, defined aa the mean of the individual CSDF statistics, according to the following formula:

$$\mathrm{CIPS} = \frac{1}{N} \sum_{i=1}^{N} t_i(N,T) \tag{10}$$

Westerlund (2005) panel cointegration test test explores the null hypothesis of no cointegration through the use of determining whether the residuals from the estimated pane regression possess a unit root, employing variance ratio statistics. Importantly, the Westerlund test does not require a precise specification of the data generating process and is capable of accommodating slope heterogeneity, as well as different intercept and trend configurations, along with individual-specific short-run dynamics.

To implement the Westerlund (2005) test, the initial step involves extracting the estimation errors produced by Equation (1). Subsequently, these residuals are subjected to a unit root utilizing the following autoregressive model of order one AR(1):

$$\hat{\varepsilon}_{it} = \rho_i \hat{\varepsilon}_{it-1} + u_{it} \tag{11}$$

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The variance ratio statistics employed to assess cointegration are formulated as follows:

$$VR_G = \frac{1}{N}\sum_{i=1}^{N}\frac{\sum_{t=1}^{T}E_{it}^2}{R_i} \tag{12}$$

$$VR_p = \frac{\sum_{i=1}^{N}\sum_{t=1}^{T}E_{it}^2}{R_i} \tag{13}$$

$E_{it} = \sum_{j=1}^{t}\varepsilon_{ij}$ and $R_i = \sum_{t=1}^{t}\varepsilon_{it}{}^2$. The employed tests are demonstrated to be free from nuisance parameters, with the asymptotic distributions of the test statistics derived under the null hypothesis of no cointegration. The presence of cointegration across the entire panel is evaluated using panel statistic VR_p, whereas the group mean statistic VR_G is utilized to assess cointegration within subsets of the panel. Therefore, considering the existence of CD and heterogeneity within the panel dataset, the Westerlund (2005) panel cointegration test provides an appropriate framework to investigate the long-term equilibrium relation in the middle of energy consumption risk also its determinants.

In order to robust the results obtained by MMQR, FMOLS and CCR methods are employed to further estimate the long-run parameters. Moreover, Kiviet's (2020) IV technique and Hausman–Taylor IV (1981) regression are used to further robust the findings under the endogeneity assumption.

4. Empirical Findings

4.1 Preliminary tests

As a first step CD test is run. The null-hypothesis is the absence of CD among the variable. The rejection of the null-hypothesis occurs if *p*-value of CD-test statistic is statistically significant at least at 5% level. Since the outcome represented in Table 2 shows the *p*-values are statistically significant at 1% level, the presence of the cross-sectional dependence is confirmed.

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Table 2: Cross-section Dependence (CD) test results

Variable	CD-test statistic	*p*-value
ln *ECR*	–3.999	0.000
FD	–114.863	0.000
ln *EG*	–387.149	0.000
ln *GLOB*	–351.507	0.000
DGN	–402.882	0.000
ln *CLV*	–184.643	0.000
Joint test		
LM	15,000	0.000
LM adj*	69.04	0.000
LM CD*	13.74	0.000

Source: Authors' own calculations

The existence of the CD leads to the application of the second-generation methods. Therefore, CIPS unit root test is conducted whose results are shown in Table 3. According to them, all the variables, ln *ECR*, *FD*, ln *EG*, ln *GLOB*, *DGN*, ln *CLV*, are stationary at their first differences.

Table 3: The findings of unit root test

Variables	CADF		CIPS	
	I(0)	I(1)	I(0)	I(1)
ln *ECR*	1.373	–19.261***	–1.041	–2.754***
FD	1.812	–9.743***	–1.458	–3.458***
ln *EG*	–7.094***	–14.171***	–2.396***	–3.626***
ln *GLOB*	–6.806***	–22.559***	–2.573***	–4.997***
DGN	–0.204	–9.414***	–1.296	–3.339***
ln *CLV*	–6.510***	–23.608***	–2.895***	–5.060***

Source: Authors' own calculations

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Since the stationary of the variables are achieved, Westerlund cointegration test must be applied as a further step. The null-hypothesis of Westerlund cointegration test is the absence of the long-run relationship among the variables. The null-hypothesis is dismissed when the test statistics of variance ratio is statistically significant at 1% and 5% levels. Due to the result in Table 4, *p*-value of variance ratio is statistically significant at 1% level, indicating the existence of the long-term association among the variables employed in the work.

Table 4: The outcome of cointegration test

	Statistics	***p*-value**
Variance ratio	–3.416	0.000

Source: Authors' own calculations

4.2 Main results

Table 5 contains the findings estimated by the means of MMQR method. The results show that financial development negatively and significantly impacts on energy consumption risk all over the world across all the quantiles, 10–90%. More precisely, at median quantile 1% increase of financial development leads to −0.003% decrease in energy consumption risk. This is in line with the theoretical linkage. Moreover, the outcome resembles Demirtas *et al*. (2025) who find that financial development stimulates renewable energy consumption in the United Kingdom. Alam *et al*. (2024) obtain both similar and controversial findings to the results of this study. More precisely, they find that financial development curbs renewable energy consumption whereas non-clean energy consumption is positively effected by financial development.

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Table 5: The outcome estimated by MMQR

Variables	Dependent variable: ln *ECR*				
	Quantiles				
	10%	25%	50%	75%	90%
FD	−0.004*** (0.001)	−0.004*** (0.000)	−0.003*** (0.000)	−0.003*** (0.000)	−0.002*** (0.000)
ln *EG*	0.733*** (0.083)	0.544*** (0.065)	0.355*** (0.049)	0.193*** (0.042)	0.103** (0.041)
ln *GLOB*	−0.251 (0.297)	−0.309 (0.236)	−0.367* (0.195)	−0.417** (0.185)	−0.444** (0.192)
DGN	−0.008*** (0.001)	−0.005*** (0.001)	−0.003*** (0.000)	−0.001* (0.000)	−0.000 (0.000)
ln *CLV*	3.873*** (0.936)	2.988*** (0.706)	2.103*** (0.536)	1.340*** (0.487)	0.920* (0.513)
Constant	1.794 (1.271)	3.021*** (0.981)	4.246*** (0.761)	5.303*** (0.669)	5.885*** (0.686)

Notes: ***, ** denote statistical significance at the 1% and 5% levels, respectively. Standard errors are in parentheses.

Source: Authors' own calculations

Regarding control variables, economic growth leads to a rise in energy consumption risk across all the quantiles from 10% to 90%. This is contrary to the findings obtained by Ali *et al*. (2025) who indicate that economic growth promotes clean energy consumption and the outcomes resemble the ones obtained by Tiwari (2022) who reveal that economic growth reduce energy consumption. As for globalization, a rise in globalization decreases energy consumption risk at the quantiles of 75–90%. This is coherent with the findings of Hu *et al*. (2025) who claim that global clean energy growth strengthens energy market resilience, however, increases the risks associated with crude oil markets. It should be noted that digitalization has a negative effect on energy consumption risk at the quantiles from 10% to 50%, This outcome is similar with the ones obtained by Khan *et al*. (2025) who reveal that digitalization promotes energy efficiency. Lastly, climate change vulnerability contributes to energy consumption risk across the quantiles of 10–75%. This outcome is coherent with the results by Gu *et al*. (2024) who reveal the climate risk enhance energy consumption risk.

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As a robustness to MMQR results, the study applied FMOLS and CCR models. FMOLS method is cointegrating regression which is superior to POLS in the presence of endogeneity and serial correlation. Moreover, in order to mitigate statistical misleading and inclination, CCR is used as a robustness to FMOLS. The findings are shown in Table 6. The outcome obtained by both FMOLS and CCR is similar which is negative effect of financial development on energy consumption risk.

Table 6: Robustness estimations by FMOLS and CCR

Dependent variable: ln *ECR*		
Variables	**FMOLS**	**CCR**
FD	−0.003***	−0.003***
ln *EG*	0.062***	0.071***
ln *GLOB*	−0.437***	−0.459***
DGN	0.003***	0.006***
ln *CLV*	−0.167	−0.195

Note: ***, ** denote statistical significance at the 1% and 5% levels, respectively.
Source: Authors' own calculations

Hausman–Taylor IV regression copes with endogeneity allows time-invariant variables to be included in the regression as instruments for the variable of interest. The outcome is represented in the second column of Table 8. They show that financial development negatively impacts of energy consumption risk.

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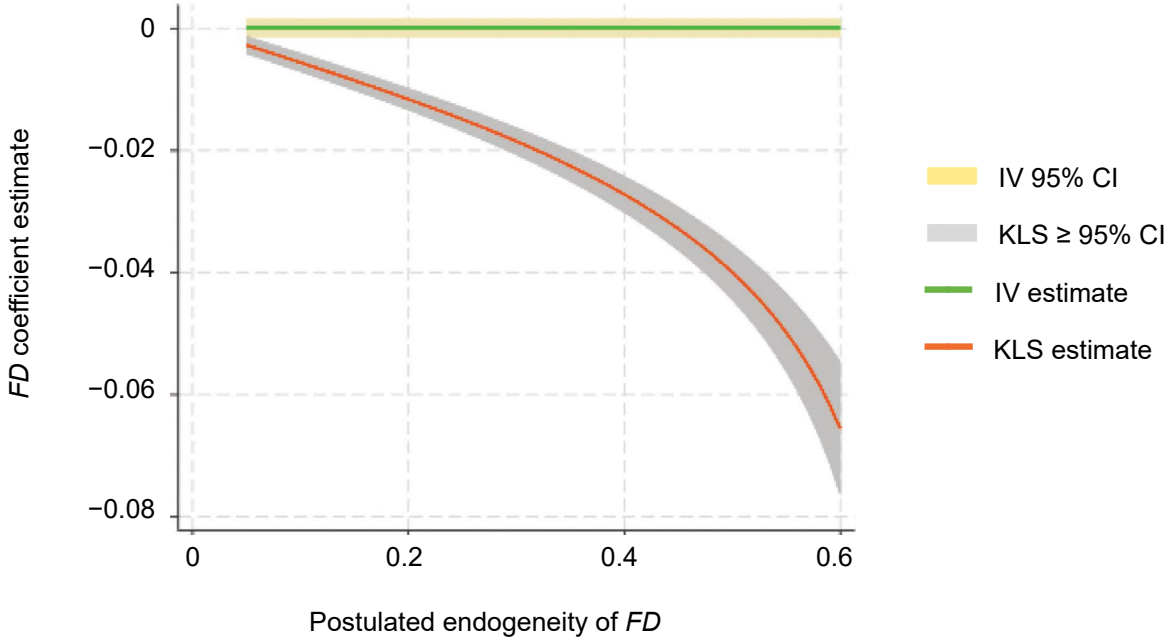
Table 7: Robustness to endogeneity

Dependent variable: ln *ECR*		
Variables	**Kiviet (2020) IV regression**	**Hausman–Taylor IV regression**
FD	−0.005*** (0.000)	−0.003*** (0.000)
ln *EG*	0.195*** (0.032)	0.341*** (0.031)
ln *GLOB*	0.424** (0.185)	−0.334* (0.178)
DGN	−0.006*** (0.001)	−0.004*** (0.000)
ln *CLV*	0.242** (0.110)	1.396*** (0.311)
Constant	1.016 (0.625)	3.789*** (0.674)

Note: ***, ** denote statistical significance at the 1% and 5% levels, respectively. Standard errors are in parentheses. As an instrument, the lagged values of financial development are applied based on "naïve approach". This approach is gaining an interest in literature recently (Arif, 2021).

Source: Authors' own calculations

Figure 1: The graphical pattern of the effect of financial development on energy consumption risk due to Kiviet IV regression



Source: Authors' own elaboration

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5. Conclusion, Policy Implications and Limitations

5.1 Conclusion

Although previous studies try to show the role of financial development to achieve energy efficiency and security, reduce energy poverty and uncertainty, the necessity of financial development to mitigate energy consumption risk is neglected. The present research examines the effect of financial development on energy consumption risk all over the world case, filling the existing gap in the literature. The theory suggests the negative effect of financial development on energy consumption risk which is validated by the outcome of this study. Therefore, the results shed the light on the academic community.

Admittedly, well-established financial system allows to cope with risks related to energy consumption. More specifically, financial resources are necessary to invest energy-saving and energy-efficient technologies. As a result of the latest technology, risks such as energy leakage waste are properly managed. Furthermore, energy consumption is decreased further leading to avoid energy shortages. Consequently, energy consumption risk is mitigated.

In contrast, economic development, globalization, digitalization and climate change also play key roles to mitigate energy consumption risk through financial development. More precisely, financial development relies on the well-organized economic system, economic growth rate determines the amount of the investment which might be spent on energy sector. Without healthy economic system financial development cannot be achieved. Moreover, globalization is also affecting on the energy consumption risk-financial development relation. Globalization is occurring in each aspect of life, including financial system. Various financial markets and consequences caused by globalization impacts on energy consumption patterns, and thus related risks. Furthermore, digitalization should be also taken into account in the association between financial growth and energy consumption risk. Because, on the one hand financial system requires digital development, on the other hand it is vulnerable to it. Highly reliance of financial development on digitalization plays an crucial role in shaping energy consumption. Another key factor in the energy consumption risk-financial development nexus is climate change vulnerability. As a result of climate change vulnerability, financial development is degraded because of lack of resources, leading to the heightened energy consumption risk. Apart from that climate change vulnerability directly impacts on energy consumption, too.

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5.2 Policy Implications

Policymakers who operate in the area that converging financial system and energy sector should be aware of that an increase in financial development leads to a fall in energy consumption risk. Policy implications must be considered based on this relation. Moreover, the policymakers have to take economic development, globalization, digitalization and climate change vulnerability into account when shaping the landscape of energy consumption. Therefore, policymakers should not only focus on financial development, but also: contributing to economic development to make it possible to allocate financial resources for energy sector; paying attention to the aspects of globalization occurring in financial system that might affect on energy consumption; identifying patterns of digital development that is beneficial or harmful in the finance-energy nexus; and determining the key points of financial system being affected by climate change and thus energy consumption.

5.3 Limitations

This research has some limitations although it addresses the novel relation from financial development on energy consumption risk. More specifically, reverse causality also exists between financial growth also energy consumption risk. The theory supports the effect of energy consumption risk on financial development, but this is not investigated in this work. However, this drawback can be addressed in the future studies.

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