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A Cross-Country Examination of Mineral Import Demand and Wind Energy Generation: Empirical Insights from Leading Mineral Importers

Md. Monirul Islam
Ural Federal University
named after the First President of Russia B. N. Yeltsin,
Yekaterinburg, Russia
University of Dhaka,
Dhaka, Bangladesh
monirul.islam@bigm.edu.bd

Abstract. The relevance of this research lies in the utilization of mineral goods as critical industrial inputs for the manufacture of renewable energy machinery, which has sparked an increase in demand and prices for essential minerals. The purpose of the study is to examine the import-demand function for metallic mineral goods by applying the quantiles via moments (MM-QR) approach, considering the potential heterogeneity across the sample of the top 5 mineral-consuming (importing) nations. The dataset, covering the years 1996–2021, is analysed to test the hypothesis regarding the influence of wind production capacity on mineral-import requirements, considering the price of mineral goods, exchange rates, and income growth. We observe a monotonic favourable response of mineral import demands to wind power generation across all quantiles. However, when considering the quadratic form of wind energy generation, the mineral import demand shows a monotonic reverse trend as the size of wind energy generation expands. Our results reveal the unexpected finding of a monotonic positive effect of copper prices on mineral import demand, which contradicts the Marshallian price theorem. Conversely, the reaction of mineral imports to exchange rates remains consistently positive without modulation. Additionally, we observe a non-monotonic association between the income factor and mineral imports, indicating that the mineral import response to economic growth remains positive until a specific threshold is reached, beyond which it tends to stabilize. The theoretical and practical significance of these findings lies in boosting mineral goods trade to advance the clean energy transition goal for a decarbonized global environment.

Key words: mineral import; installed wind capacity; MM-QR approach; top five mineral importing countries.

JEL F12, F47, F64

1. Introduction

The Kyoto Protocol and the Paris Summit are two influential global platforms that have emphasized the importance of reducing CO_2 emissions. However, the latest COP26 conference in Glasgow has reasserted the goal of realizing a pathway to a carbon-neutral landscape by severing the link between economic growth and its negative environmental impacts, promoting sustainable energy generation [1].

As a result, businesses that apply co-benefiting models not only encourage the adoption of renewable energy but also generate profits. However, the growth of renewable energy capacity, especially wind installation capacity in many countries, heavily relies on mineral resources

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that are essential for the production and management of renewable technologies, including wind turbines [2].

Thus, the world is witnessing a significant surge in demands for mineral imports, and this trend has proven beneficial to multiple countries. As a result, there has been a widespread adoption of electric vehicles and renewable energy sources, which continues to drive the rapid electrification process[1].

Additionally, it is worth noting that, on average, renewable and wind technologies require more raw materials than conventional energy supplies [3].

Given this context, the central research question of this paper explores how the rise of wind energy production capacity in primary mineral-importing nations affects mineral trade.

The motivations for this research stems from several factors. Firstly, many nations that rely on mineral imports are acutely conscious of their obligation to cap global warming at a maximum of 1.5° Celsius higher than preindustrial heights, as articulated during the COP26 assembly [4].

Accordingly, the deployment of renewable technologies, particularly wind turbines, has assumed critical importance in their pursuit of these objectives [3]. Moreover, the transition to clean or renewable energy sources has emerged as a vital pathway towards environmental safety, with several governments spurred on by influential international forums committing to a sustainable energy system by 2050. Consequently, they seek to define the requisite installation power necessary to facilitate the disposition of cleaner power machineries in order to ensure long-term power safety and sustainability [5].

According to estimates from the IEA[2], reaching the worldwide objective of transitioning to clean energy requires the installation of wind and solar energy systems with capacities of 280 and 1,739 gigawatts, correspondingly. However, the ambitious goal of advancing renewable technology raises a crucial question about the abundance of current mineral reserves in supporting the necessary infrastructure for a successful transition to cleaner energy.

Secondly, clean energy machinery generally demands a larger quantity of raw materials compared to the traditional non-renewable power generation system. To illustrate, the construction of a solar energy plant with one megawatt of installed capacity requires approximately 4 tons of copper, whereas a conventional power plant only needs around a single ton. This heavy copper exploitation is also linked to wind power-yielding mechanisms, where between 0.20 and 0.759 gigatonnes of copper are required for operating a single wind generator[3].

In addition to copper, the manufacturing process of renewable energy equipment, specifically for wind power generation, necessitates the utilization of various other mineral goods, such as cadmiums, lithium for EVs, and nickels/cobalt for energy storage [5, 1]. As a result, mineral importations have become increasingly important for economies dedicated to achieving cleaner energy goals and aligning with the worldwide transformations towards cleaner energy.

Finally, the global climate is heavily influenced by the substantial greenhouse gas emissions from the largest consumers of mineral goods, namely the USA, China, Japan, Germany, and the Netherlands. As a result, these countries are seeking to produce clean energy through the utilization of

[1] https://www.forbes.com/sites/sap/2021/11/29/cop26-takeaways-renewables-replace-fossil-fuels-as-metals-become-a-major-force/?sh=3c1e93c92676

[2] https://www.iea.org/reports/energy-technology-perspectives-2017

[3] https://www.mrs.org/spring2010

critical minerals to decrease the reliance on fossil fuels within their energy mix systems. This approach serves to minimize the consequences of climatic events and enhance the utilization of renewable energy and complementary non-carbon technologies, thereby allowing for practical and sustainable business practices[1].

As a result, there is a discernible market demand for critical minerals in these countries, making them a critical component of their industrial development strategies. Nevertheless, these countries face significant geopolitical, economic, technological, and environmental risks in securing a steady supply of minerals, which is an even greater concern than that for fossil fuels. Despite these challenges, these mineral-importing countries continue to increase the importation of minerals to boost renewable technology production [6].

Therefore, it is imperative to prioritize mineral trade for facilitating the transition to cleaner energy, particularly in the context of wind power, and effectively address the risks associated with environmental degradation in these nations.

Driven by the aforementioned motivations, we have set forth a primary research objective to examine whether there is a correlation between the cumulative mineral import requirements and the installed wind capacity within the top five nations in terms of mineral imports during the period of 1996–2020.

To achieve our research objective, we employ the quantiles via moments (MMQR) procedure, devised by Machado & Silva [7]. This quantile-based technique is robust in considering the location and scale of quantile distributions over time, while concurrently examining cross-sectional heterogeneity and time-variant factors among different entities within the panel [8].

Employing this steadfast approach reveals that the proliferation of wind energy generation acts as a monotonic catalyst to stimulate mineral import demands in all quantiles ranging from q10-q90.

Furthermore, our findings reveal that the elasticity of copper prices does not fully adhere to the Marshallian price and demand-centric theorem across all quantiles. We also observe that the exchange rate and income growth have a positive effect on mineral demand in the top five mineral importing economies, whereas income made an insignificant but negative impact in the upper quantiles of our study.

Our research makes a significant contribution to the prevalent empirical investigations in several ways.

Firstly, we delve into the demand dynamics of metallic mineral goods within the import-demand function procedure using innovative panel econometric techniques. This analysis covers the top five mineral importers, providing valuable insights into the dynamics of mineral demand.

Secondly, we recognize the importance of wind energy production as a crucial technological innovation for accelerating the global transition to clean energy. This aligns with previous studies proposed by Sohag et al. [9] and Islam et al. [1], highlighting the significance of wind energy in achieving sustainable energy transitions.

Thirdly, our focus is on aggregate (total) mineral imports as the dependent variable, which is an underexplored area in the sustainability literature on the relationship between the mineral market and wind power deployment.

Fourth, this study's results have substantial implication for policymakers in mineral-consuming nations, providing valuable insights into their growing portfolio of mineral import-dependent energy transformations.

Moreover, our results can inform the formulation of mineral-centric co-benefit

[1] https://www.oecd.org/dev/developing-countries-and-the-renewable-energy-revolution.htm

policies aimed at promoting a global shift towards cleaner energy and achieving a decarbonized global landscape.

The purpose of the study is to examine the import-demand function for metallic mineral goods by applying the quantiles via moments (MM-QR) approach, considering the potential heterogeneity across the sample of the top 5 mineral-consuming (importing) nations.

Research hypothesis:

H1: Mineral resource trade, especially mineral imports, contributes to the expansion of the global cleaner (wind) energy transition.

The rest of this study is structured in the following way. Section 2 portrays an outline of the methodologies exercised. Section 3 delineates the empirical outcomes and relevant discussions. The concluding section summarizes the key findings and implications for policy.

2. Literature review

The literature in the context of global clean energy metamorphosis influenced by the metallic minerals appeared dramatically in the last five years.

Specifically, scholarly investigations pertaining to the interconnection between clean energy and mineral commodities emphasize the importance of forecasting scenarios [10, 11]. Some strands of analyses examined the region-centric capacity of mineral goods for generating cleaner electricity but did not encompass the full range of available samples [12, 13]. Some researchers also focused on the risky landscape of mineral goods exploitation [14, 15], and the governing, economic, societal, and political uncertainty issues concerned with mineral extraction [16, 17].

Bazilian [18] and Fernandez [19] showed apprehensions regarding the mineral resources' availability in specific global nations, which creates bottlenecks for metal exploitation.

García & Guzmán [20] measured the pricing of the critical minerals in the international markets.

Church & Crawford [21] and Aldakhil et al. [22] inspected the liaison among technology innovation, expanses for R&D, metallic mineral extraction, green energy necessity, accentuating the ecological concern.

Nassani et al. [23] and Bainton et al. [24] elucidated a comprehensive picture of how environmental sustainability, carbon content, and neutrality facts are linked to the mining activities of metallic minerals.

Sprecher & Kleijn [25] and Vakulchuk & Overland [26] accentuated the necessity of the crucial mineral commodities to set the potential power consumption strategy.

Mineral trade, particularly the import and export portfolios of mineral goods, has been considered by many authors when assessing the relevance of global mineral trade volumes in driving the growth of cleaner energy production worldwide.

Islam et al. [6] discovered the positive implications of geopolitical risks, where policy-driven economic uncertainties have adverse impacts on the import requirements of mineral commodities in the United States.

Islam et al. [27] identified the diverse influencing factors of decomposed geopolitical events, such as geopolitical turmoil "threats" and "acts," within the context of Chinese mineral assets' import portfolios. They employed the quantile-based QARDL and Q-Q regression procedures, taking into account the broad data properties.

Yu et al. [28] conducted a study using theories on the "global value chain" and "energy transition" to analyze the relationship between clean power technology, prices, trade, and mineral resources across leading resource-abundant nations from 1995 to 2020. The findings indicate that the initial adoption of renewable energy technology has a positive impact on the demand for mineral resources. However, over the long term, there is a decline in mineral resource demand. Employing a fixed effect model across nations, the study observed a positive correlation between mining demand and the growth of industry value and trade openness over an extended period. Moreover, the trading of mineral resources exhibits a multiplier effect on mining demand, further influencing the dynamics of the industry.

Islam et al. [29] scrutinized China's mineral import portfolio of critical minerals for solar energy production from 1996 to 2019. This study revealed the significant role of mineral import volumes in the expansion of China's solar energy generation, which is a crucial aspect of the global transition towards cleaner energy.

Li et al. [30] examined the relationship between renewable electricity generation, financial development, clean fuel and technology access, GDP, R&D spending, and electricity accessibility in low- and middle-income economies from 2000 to 2021. It also explores the impact of natural resources on economic growth in the same group from 1973 to 2022. Using time series analysis and Granger causality, the study finds that GDP and financial development play a significant role in increasing electricity accessibility. Additionally, renewable electricity production, access to clean fuels and technologies, and energy efficiency significantly enhance electricity accessibility in these economies. The influence of natural resource rents on economic growth follows an asymmetric pattern, initially insignificant but gaining importance over time.

Hotchkiss et al. [31] examined two approaches used to identify critical minerals in countries that are actively transitioning to clean energy. Given the commitments of the United States and the United Kingdom to expand their use of renewable energy technologies, the identification of critical minerals holds significant significance for these economies. The paper assesses the methodologies employed in the identification of critical minerals and their implications for these two nations.

Islam et al. [4] conducted a comprehensive study and explored the positive contribution of Russian mineral goods supply to global and Chinese renewable energy generation from 2011 to 2021, utilizing monthly data. The research also found the advantageous role of labour within the renewable energy industry, while considering the externalities associated with geopolitics that impact this industrial process.

In summary, prior studies have primarily concentrated on evaluating the present status of mineral reserves, their utilization, and exploring potential extraction methods for the future. However, recent research published between 2023 and 2024 has shed light on the significance and utilization of critical mineral goods, particularly metallic mineral commodities, in driving the expansion of cleaner energy industries. These minerals serve as crucial industrial inputs for the operation and manufacturing of cleaner energy machinery. Given the abundance of research focused on the mineral requirements for global clean energy expansion, this empirical investigation aims to develop key hypothesis as outlined below:

H1: *Mineral resource trade, especially mineral imports, contributes to the expansion of the global cleaner (wind) energy transition.*

However, previous research did not consider the disaggregated phenomenon of cleaner energy transformation, specifically focusing on wind energy production, within the context of leading mineral goods-consuming nations. Additionally, there is a notable scarcity of literature that examines the import demands of critical minerals and their role in the expansion of wind power generation in these nations. Therefore, our research aims to fill this gap by analyzing the actual and growing

Table 1. **Data narratives**

Code	Variables' names	Measurement	Sources
MI	Mineral import demand	Cumulative import-size of mineral goods in metric ton (thousand)	British Geological Survey, & WITS (https://wits.worldbank.org/)
IWC	Wind installation power	Cumulative installation capability of wind energy in gigawatts, capturing the onshore and offshore-based generation of electricity	Our World in Data (https://ourworldindata.org/)
COP	Copper price	Copper price (per pound)	Macrotrends (https://www.macrotrends.net/charts/precious-metals)
EXR	Exchange rates	Real exchange rates index (2010 = = 100)	World Bank (https://data.worldbank.org/products/wdi)
GDP	Gross domestic product (GDP)	Yearly ratio of GDP growth	

Note: The logarithmic forms of dataset are considered for estimation purpose.

volumes of clean energy influenced by the import requirements of mineral goods within these nations, employing sophisticated econometric procedures.

3. Materials and methods

This section encompasses the data sources, model estimation and econometric procedures used for this study.

3.1. Data narratives

According to the British Geological Survey[1], the USA, China, Japan, Germany, and the Netherlands are ranked as the world's top five mineral importing countries. However, our study focuses on investigating the reply of mineral goods import in these countries to the significant cleaner/sustainable energy factors — the installed wind capacity — over the period of 1996–2021.

It is assumed that increasing wind energy production enhances the demands for mineral goods importations in these nations, particularly as wind power machineries, namely wind turbine, generator, cells, and power storage batteries require a substantial amount of minerals for their manufacture and operation.

As a result, these top mineral-consuming nations import the commodities from other exporters, leading to an increase in their mineral import growth. This investigation employs the cumulative mineral importation (MI) as the dependent variable, which responds to the wind energy deployment in the context of these countries, while the installed wind capacity (IWC) serves as an independent variable (Table 1).

More specifically, factors encompassing host country's economic progress level, mineral prices, and exchange rates have a significant influence on the demands for mineral goods importations. These variables are taken into account in the analysis of the mineral import-demand function. Specifically, the Marshallian price-demand theorem states that higher import costs result in lower import size of the commodity [32].

[1] https://www2.bgs.ac.uk/mineralsuk/statistics/UKStatistics.html

Moreover, exchange rate depreciation and income growth affect the volume of mineral imports in host countries. Additionally, the importance of renewable energy for environmental preservation drives investments in renewable energy projects [33].

Therefore, our analysis of mineral-import requirements in relation to cleaner energy metamorphosis, including wind energy generation, incorporates variables, namely mineral price, exchange rate, and host economy's income growth. Furthermore, to avoid size effects, all variables have been transformed into natural logarithmic form.

3.2. Model construction

A particular consumer's demands (j) for a certain commodity (i) are determined by their income (y_j), the price of the commodity (p_i), and the prices of other goods (p_n). We can express a consumer's utility behaviour in the following manner:

$$q_{ij} = f\left(y_j, p_i, p_n\right). \tag{1}$$

The cumulative demand of the consumers is converted into a demand equation (Q) that is contingent upon the cumulative outputs/income (Y) and the price of products within the economy:

$$Q_i = f\left(Y, p_i, p_n\right). \tag{2}$$

In cases where the domestic supply of goods in a country falls short of meeting demand, the economy resorts to importing from outer nations. Consequently, the import demands function relies on factors such as the nation's income (Y), the market pricing of commodities ($p_i^{\$}$, $p_n^{\$}$), and the other (complementary or substitute) commodities' comparative price in local and international arena, which is reflected in the exchange rate (e) [34]:

$$Q_i^{MI} = \left(Y, p_i^{\$}, p_n^{\$}, e\right). \tag{3}$$

Our modelling approach examines the demand for mineral goods in the five largest mineral goods-consuming nations. In this model, we include wind energy (*iwc*) as a tech innovation, drawing idea from previous studies [1, 9]. As a result, the final equation derived from the theories can be expressed:

$$\begin{aligned} Q_{i,t}^{MI} &= \alpha_0 + \alpha_1 Y_t + \alpha_2 p_{i,t}^{\$} + \\ &+ \alpha_3 p_{k,t}^{\$} + \alpha_4 exr_t + \alpha_5 iwc_t + \mu_{i,t}. \end{aligned} \tag{4}$$

Where $Q_{i,t}^{MI}$ illustrates the importation of mineral commodities in their cumulative form; Y hows the *GDP* growth; $p_i^{\$}$ are the market pricing of imported commodities (copper); *exr* denotes the real exchange values; and *iwc* refers to the installed wind capacity.

3.3. Econometric procedures

This subsection demonstrates the economic background of cross-sectional dependency (CD), panel unit-root inquiry, e.g., CADF, and quantile via moments (MM-QR) techniques.

3.3.1 Cross-sectional dependency (CD) inquiry

Commencing our empirical model analysis, we explore the interdependence between cross-sectional squads. The panel data's reliance on cross-section units may stem from significant impacts arising from economic ties, globalized, and other interconnected relationships. Earlier investigations that disregarded the CD issues in panel estimation process could lead to results that are inconsistent or biased, as it tangles with CD in the panel squads.

Henceforth, Breusch & Pagan [35] introduced the LM examination procedure to investigate the existence of CD issues. The calculation procedure of the LM statistic is given below:

$$LM = T\sum_{i-1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^2. \tag{5}$$

In this equation, T delineates the time-spans, N expresses the quantity of cross-sectional squads, and $\hat{\rho}_{ij}^2$ illustrates the cross-sectionally correlated residuals stemming from the OLS procedure. A notable limitation of the LM inquiry process is its applicability when dealing with a substantial quantity of T and a comparatively limited size of N. In order to address this hitch, Pesaran [36] devised the LM inquiry technique designed to assess the CD test outlined below:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i-1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}\right). \quad (6)$$

The underlying postulation of the null hypotheses for both inquiries posits that cross-section squads are unrelated and not influenced by any form of dependency, as observed in the alternative hypothesis.

3.3.2 Panel unit-root inquiry

To ensure the accuracy of our findings and prevent misleading outcomes, we assess the stationarity characteristics of the data. In order to achieve this, we utilize the second-generational unit-root inquiry devised by Pesaran [37], specifically the CADF inquiry.

The technique is effective in identifying potential problems related to cross-sectional dependency and slope heterogeneity. As a result, we can now present an illustration of the CADF regression using the equation provided below:

$$\Delta Y_{it} = \alpha_i + b_i Y_{i,t-1} + \\ + c_i \overline{Y}_{t-1} + c_i \overline{\Delta Y_t} + \omega_{it}. \quad (7)$$

In the equation, Δ refers to the adjustment parameters, Y illustrates the investigated variable, $\overline{Y}_t$ and $\overline{\Delta Y_t}$ delineate the $\frac{1}{N}\sum_{i=1}^{N} Y_{it}$ and $\frac{1}{N}\sum_{i=1}^{N} \Delta Y_{it}$, correspondingly, and ω_{it} is the disturbance mechanism.

3.3.3 Quantiles via Moments (MM-QR) procedure

Given the substantial variation in the distribution of mineral imports among countries worldwide, the current study employs the panel quantiles via moments (MM-QR) model, following the framework proposed by Machado & Silva [7]. This innovative approach estimates regression-based quantiles by approximating conditional means, while also offering valuable insights into how the independent variables influence the entire conditional allocation.

The MMQR technique enables analysts to discern diverse impacts across quantiles, providing a comprehensive understanding beyond traditional methods such as the OLS. Importantly, the MMQR technique proves advantageous when the cross-sectional data-driven modelling framework incorporates separate impact and endogenous regressors.

Based on the experiential arrangement, it can be stated that considering the available data $\{(\mathrm{Y}_{\mathrm{it}}\ X_{it}')'\}$ from a panel comprising n individuals $i = 1, 2, \ldots, n$ over T time periods $t = 1, \ldots, T$, the inference of conditional quantiles $\mathrm{Q}_{\mathrm{Y}}(\tau \mid X)$ for a location-scale framework, which can be formulated as follows:

$$Y_{it} = \alpha_i + X_{it}'\beta + (\delta_i + Z_{it}'\gamma)U_{it}. \quad (8)$$

In this context, the regressed variable Y_{it} represents mineral goods imports (*MI*), and its random conditional quantiles are dependent on a k-vector of covariates X_{it}. The method utilizes conditional means to evaluate the conditional quantiles by combining assessments of the location and scale functions. This approach enables us to capture the separate effects of the regressors on both the location and scale on the regressed indicator.

Moreover, X_{it} denotes the vector of regressors, which include installed wind capacity (*IWC*), quadratic form of installed wind capacity (*IWC2*), copper prices (*COP*), exchange rates (*EXR*) and economic growth (*GDP*) with $\Pr = \{\delta_i + Z'_{it}\gamma > 0\} = 1$.

The parameters (α_i, δ_i), $i = 1, \ldots, n$, correspond to the fixed effects specific to each individual in the dataset, while Z is a k-vector that contains known differentiable transmutations of the factors of X. The order $\{X_{it}\}$ is direly exogenous, meaning it is *iid* for any fixed i and is also independent throughout different i values. The error terms U_{it} are also *iid* throughout both i and t, and they are statistically independent of X_i.

Furthermore, the error terms U_{it} are normalized to satisfy the moment conditions. Therefore, the model can be expressed in the following manner:

$$Q_Y(\tau \mid X_{it}) = (\alpha_i + \delta_i q(\tau)) + \\ + X'_{it}\beta + Z'_{it}\gamma q(\tau). \tag{9}$$

The scalar coefficient $\alpha_i(\tau) \equiv \equiv \alpha_i + \delta_i q(\tau)$ refers to the fixed effect specific to individual i at quantile-τ, representing the effect on the distribution at τ. Unlike the typical fixed effects, the distributional impact is not limited to a simple shift in location.

Rather, it captures the impact of time-invariant distinctive characteristics that can have diverse impacts on the parts of the conditional distribution of Y. This approach enables us to explore how the heterogeneous covariance impacts of indicators related to mineral imports vary under different conditions.

3.3.4 Driscoll Kraay's standard errors (DKSE) technique

To appraise the long-term validity of our result, we utilize the DKSE technique (Driscoll & Kraay [38]). This method is effective in evaluating robustness as it can handle commotion terms in diverse panels that exhibit spatial (cross-sectional) dependence (CD). The CD is particularly noticeable when i and j represent different panels, which is a common challenge when analysing macroeconomic data over extended periods.

The DKSE procedure first examines issues such as heteroscedasticity, CD, and autocorrelation to identify any potential problems. It then incorporates the average values of regressors and their associated errors in the model, which are utilized to generate cross-sectionally robust standard errors through a weighted HAC (heteroscedasticity and autocorrelation consistent) estimator [39].

The fixed effect parameter adheres to a twin-step implementation process, where all variables $z_{it} \in \{y_{it}, x_{it}\}$ in the model undergo within-transformation in the initial step. This ensures the appropriate application of the fixed effects estimator:

$$\tilde{z}_{it} = z_{it} - \underline{z}_i + \overset{=}{z}. \tag{10}$$

In this equation, $\bar{z}_i = T_i^{-1} \sum_{t=t_{i1}}^{T_i} z_{it}$ and $\overset{=}{z} = \left(\sum T_i\right)^{-1} \sum_i \sum_t z_{it}$. It is important to note that the second step involves the within-estimator, which is based on the OLS estimator of $\tilde{y}_{it} = \tilde{x}'_{it}\,\varnothing + \tilde{\varepsilon}_{it}$. This within-estimator is used to estimate the transformed regression model described in equation (10) through a pooled OLS estimation procedure.

3.3.5 Panel causality test

We employ the dynamic non-causality procedure devised by Dumitrescu & Hurlin [40] for heterogeneous panel data, including those with small data ranges.

This causality test provides distinct Z and W statistics, along with their corresponding p-values, which allow for a moderate detection of the causal associations among the variables.

The utilization of this test provides a robust approach to examining the potential causal relationships among the variables and thus helps to ensure the accuracy and comprehensiveness of the study's findings.

4. Results

The part of this study includes the findings derived from several analytical techniques, including descriptive analysis, CD test, panel unit-root inquiry, MM-QR technique, the Driscoll-Kraay standard errors procedure, and panel causality test.

4.1. Descriptive analysis findings

We commence our investigation by analysing descriptive statistics. Table 1 showcases the standard deviation of our variables, illustrating that the standard deviations are highly reflective for most of the study's indicators in the "between" option. This scenario exposes the panel squads-centric divergence in mineral importation and its utilization in wind power manufacture.

Additionally, we present Table 2, which illustrates the correlation matrix of the variables along with their corresponding significance levels (*p*-values). Our analysis reveals a strong positive correlation between *IWC* and *MI*, aligning with our *priori* expectations. Furthermore, we observe a positive correlation between IWC^2 and *MI*, which is consistent with our intuitive understanding of the relationship.

Table 1. **Descriptive statistics**

Variable		Mean	Std. Dev.	Min.	Max.	Obs.
MI	Overall	14.7302	0.7891	13.1181	16.1880	N = 130
	Between		0.7007	13.8837	15.6446	n = 5
	Within		0.4762	13.8116	15.3959	T = 26
IWC	Overall	1.5712	2.1157	–4.0745	5.6418	N = 130
	Between		1.4016	–0.1645	2.9041	n = 5
	Within		1.7006	–2.7795	5.3079	T = 26
IWC^2	Overall	6.9094	7.9022	0.0001	31.8308	N = 130
	Between		4.6692	1.07088	11.1174	n = 5
	Within		6.6980	–4.2046	27.6228	T = 26
COP	Overall	4.1739	0.8861	3.0179	5.8630	N = 130
	Between		0.0030	4.1726	4.1794	n = 5
	Within		0.8861	3.0124	5.8575	T = 26
EXR	Overall	4.6166	0.1193	4.2401	4.8673	N = 130
	Between		0.0581	4.5360	4.6987	n = 5
	Within		0.1073	4.3207	4.9123	T = 26
GDP	Overall	2.9026	3.6620	–5.6938	14.2308	N = 130
	Between		3.2951	0.6079	10.8697	n = 5
	Within		2.1572	–3.9634	8.4414	T = 26

Note: The descriptive analysis procedure computes the logarithmic form of the dataset.

Table 2. **Correlation matrix**

	MI	IWC	IWC^2	COP	EXR	GDP
MI	1.0000					
IWC	0.3981*** (0.0000)	1.0000				
IWC^2	0.1880** (0.0358)	0.7421*** (0.0000)				
COP	0.4653*** (0.0000)	0.7728*** (0.0000)	0.02850 (0.7524)	1.0000		
EXR	0.2083** (0.0198)	–0.2327*** (0.0090)	0.0647 (0.4732)	–0.1435 (0.1104)	1.0000	
GDP	0.0478 (0.5966)	–0.0583 (0.5183)	0.0411 (0.6486)	–0.1537* (0.0870)	0.0789 (0.3817)	1.0000

Note: *p*-values lie in first brackets. ***, ** and * are the significance levels at 1 %, 5 % and 10 %.

Table 3. **Cross-sectional dependence (CD) and panel unit-root inquiries**

Variable	CD inquiry		Unit-root inquiry	
	Statistics	$\hat{p}$	CADF (Level)	CADF (First difference)
MI	14.95***	0.946	–2.001**	–3.886***
IWC	15.00***	0.948	–1.745**	–2.086**
IWC^2	5.04***	0.591	0.508	–3.096***
COP			7.774	–3.567***
EXR	1.75*	0.374	1.235	–2.237**
GDP	9.06***	0.573	0.566	–2.793***

Note: For the case of a global variable, specifically the COP, the CD and CADF inquiries are not suitable. As a result, we employ the ADF unit-root examination considering COP as the time-series property and finding its stationarity profile. The CD measurements and the average correlation ($\hat{p}$) among the cross-sections are presented in the 2nd and 3rd columns, respectively. Additionally, the CADF (Z[t-bar]) stats at the level $I(0)$ and the first-difference I(1) forms are displayed in the 4th and 5th columns, correspondingly.

Next, we move forward to investigate the Issue of CD in the panel squads at this juncture. The CD status plays a pivotal role in determining the appropriate model for the cross-sectional squads. The outcomes of the CD inquiry are displayed in Column 2 of Table 3. The CD inquiry procedure exhibits variables' level of significance at 1 %, signifying the existence of CD among the cross-sectional squads. It is worth noting that the *IWC* exhibits higher CD values, whereas the *EXR* displays lower values.

Given the Issue of CD observed among the panel squads, we employ the CADF procedure to check for stationarity. This test effectively handles concerns related to CD and slope homogeneity, resulting in a balanced outcome across the cross-sections. However, the CADF unit-root analysis reveals the integrating relationship between the variables, which is mixed in nature. As a result, due to the evidence of CD and the merged integrated order among the variables, it becomes necessary to utilize the MM-QR approach.

4.2. Main findings

This research measures the response of *MI* to *IWC* within the scope of *COP*, *EXR*, and *GDP* using the import-demand analysis procedure. We have opted for the MM-QR approach, which allows us to examine the specific discrepancies in location and scale while exploring the relationship between *MI* and *IWC* among the nations with the highest mineral consumption.

The hypothetical model under the framework of MM-QR approach used in our study includes

$$Q_{MI}\left(IWC, IWC^2, COP, EXR, GDP\right) = \\ = \alpha + X\left(IWC, IWC^2, COP, EXR, GDP\right)\beta + \\ + \sigma\left(\delta + Z\gamma\right)q\left(\tau\right).$$

In this model, we take into account cumulative *MI* as the regressed variable, *IWC* and *IWC*^{2} as the regressors, and *COP*, *EXR* and *GDP* as the control variables.

Table 4 depicts that *MI* has a monotonically positive response to the *IWC* in the 5 mineral-consuming nations. The result infers that the *IWC* significantly fosters the top mineral-consuming countries' *MI* demands in all quantiles from q10 to q90 due to having *IWC*'s positively significant coefficients emerged from the MM-QR regression approach (Figures 1 and 2).

Table 4. **Mineral importation and cleaner energy transformations**

Variables	Location	Scale	q10	q20	q30	q40
IWC	0.2062*** (0.0404)	0.0061 (0.0223)	0.1963*** (0.0482)	0.1992*** (0.0429)	0.2017*** (0.0403)	0.2037*** (0.0395)
IWC	–0.0517*** (0.0095)	–0.0100* (0.0052)	–0.0355*** (0.0113)	–0.0403*** (0.0101)	–0.0444*** (0.0095)	–0.0476*** (0.0094)
COP	0.4141*** (0.0841)	–0.0081*** (0.0465)	0.4272*** (0.1005)	0.4233*** (0.0895)	0.4200*** (0.0839)	0.4174*** (0.0823)
EXR	2.6588*** (.5180)	–0.1335*** (0.2862)	2.8743*** (0.6186)	2.8094*** (0.5512)	2.7551*** (0.5168)	2.7123*** (0.5074)
GDP	0.0304** (0.0137)	0.0278*** (0.0075)	0.0753*** (0.0163)	0.0618*** (0.0150)	0.0504*** (0.0140)	0.0415*** (0.0140)

Table 4. **Mineral importation and cleaner energy transformations (the end)**

Variables	q50	q60	q70	q80	q90
IWC	0.2052*** (0.0398)	0.2081*** (0.0424)	0.2103*** (0.0460)	0.2137*** (0.0533)	0.2170*** (0.0620)
IWC	–0.0502*** (0.0094)	–0.0548*** (0.0100)	–0.0585*** (0.0109)	–0.0640*** (0.0126)	–0.0694*** (0.0145)
COP	0.4153*** (0.0830)	0.4115*** (0.0883)	0.4086*** (0.0958)	0.4041*** (0.1109)	0.3997*** (0.1292)
EXR	2.6788*** (0.5112)	2.6169*** (0.5441)	2.5680*** (0.5902)	2.4951*** (0.6835)	2.4228*** (0.7952)
GDP	0.0345** (0.0139)	0.0216 (0.0149)	0.0114 (0.0162)	–0.0037 (0.0187)	–0.0188 (0.0209768)

Note: Standard errors lie in first brackets. *** p<0.01, ** p<0.05, * p<0.1

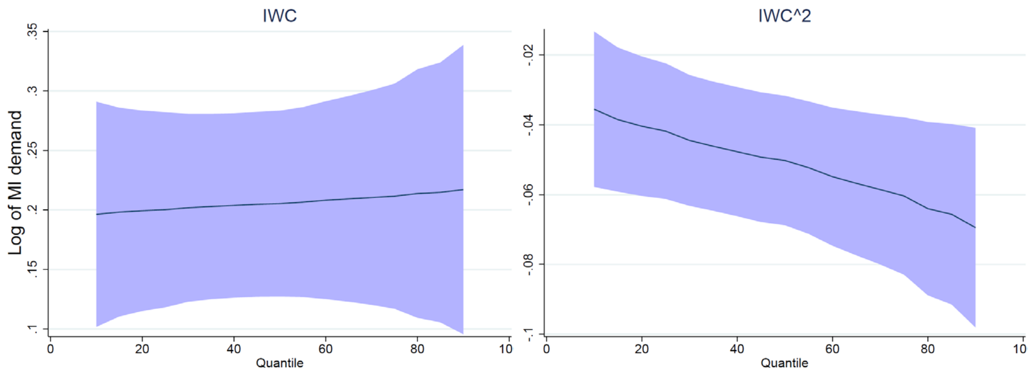

Figure 1. Reply of *MI* demand to *IWC* and *IWC*^{2}

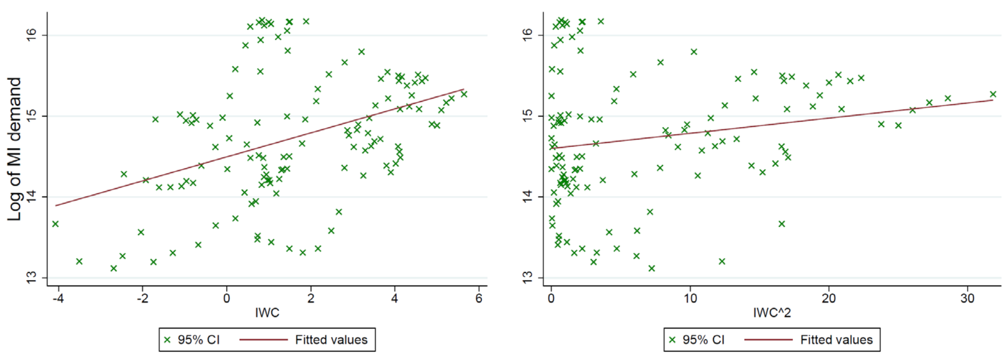

Figure 2. Fitted values of *MI* demand to *IWC* and *IWC*^{2}

These favourable and substantial coefficients of the wind power at all-time horizons (quantiles) also signify that *IWC*, which plays a crucial role in worldwide cleaner energy metamorphosis, relies on minerals. This contributes to the growing demand for mineral goods imports.

Our findings in Table 4 also unveil that the mineral import demand (*MI*) encounters a monotonic reverse move at all-time horizons while expanding the volume of wind energy generation using quadric form in the study's model. Furthermore, it indicates that the response of *MI* to the quadric form of installed wind capacity (*IWC*^{2}) is significantly negative all over the quantiles (q10-q90) from the perspectives of the largest mineral-consuming nations (Figures 1 and 2).

This situation implies that mineral resources' responsiveness does not cover up but surpasses the massive wind generation. Therefore, it has negatively affected mineral-based wind energy production.

Our finding (Table 4) also establishes that the response of *MI* to the copper price (*COP*) is monotonic and conducive all over the quantiles (q10-q90) due to its significantly positive coefficients. This finding indicates that the importation of mineral commodities consistently rises in tandem with the supply of mineral commodities in the market, primarily driven by the rapid expansion of wind energy generation.

In addition, the result concerning *EXR* shows a positive response of *MI* to *EXR* in entire timespans (q10-q90). The positive consequence of *EXR* on *MI* requirement may be rational from the standpoints of these economies' higher rate of local currencies.

Finally, we find that the *MI* demand monotonically and positively responds to the economic growth (*GDP*) from q10 to q50, and this factor remains inconsequential during the residual quantiles, e. g., q60-q90. Our result implies that *GDP* elevates mineral import (*MI*) demand up to a specific level.

However, after the threshold level, the *GDP* growth becomes elusive to promote *MI* demands in these mineral importing countries. The reason behind the monotonically positive impact of GDP growth on MI demand in these countries is their focus on harnessing the full income potentials for clean energy production, particularly wind energy. Besides, income growth values' exponential rate promotes a commodity's import growth for a certain level (threshold level).

4.3. Robustness checked by the DKSE technique

To examine the robust results, we employ the DKSE procedure, which is an adapted version of the previously developed estimator of the standard non-parametric covariance matrix. This estimator is specifically designed for analysing time-series data and assessing both cross-sectional and time-based dependence. Importantly, the DKSE procedure yields compelling findings that address the Issue of cross-sectional dependence [47].

Our estimated findings in Table 5 divulge that our main proposition, viz., the positive reply of *MI* to *IWC* and the quadric form of *IWC* (IWC^2), is explored using this alternate estimation technique, namely Driscoll-Kraay standard errors technique.

Table 5. **Results derived from the DKSE procedure**

Variables	Coefficient	Drisc/Kraay Std. Error	t	*p*-value
IWC	0.2062**	0.0445	4.63	0.010
IWC^2	–0.0517***	0.0100	–5.14	0.007
COP	0.4141***	0.0853	4.85	0.008
EXR	2.6588***	0.2680	9.92	0.001
GDP	0.0304**	0.0109	2.77	0.050
R^2		0.4296		
Root MSE		0.6084		
Obs.		125		

Note: *** and ** denotes the 1 % and 5 % significance levels.

This finding coincides with the results obtained from the MM-QR approach. Besides, we also explore the positive coefficients of the copper price (*COP*), the exchange rate (*EXR*) and economic growth (*GDP*) that are entirely coherent with the finding from the MM-QR technique.

Overall, the Driscoll-Kraay standard errors estimation procedure establishes our core assumption concerning the beneficial feedback of *MI* to *IWC* and *IWC2* in from the perspectives of the largest 5 mineral-consuming nations.

4.4. Panel causality test's findings

In order to obtain more robust findings, we utilize a dynamic panel causality analysis technique developed by Dumitrescu & Hurlin [40]. This causality test offers the advantage of providing an unbiased measurement while taking into account the heterogeneous properties of the panel data.

Table 6 presents the W-stat and Z-stat, which illustrate the Granger causality for all variables in relation to MI.

The investigated results show a bidirectional causal association between *MI* and *IWC* and the quadratic form of *IWC* (*IWC*2) across the sample nations. Besides, the unidirectional causality lies between the mineral imports (*MI*) and exchange rate (*EXR*), and the bidirectional causality exists between the *MI* and the economic growth (*GDP*).

Table 6. **Results from panel causality test**

Hypotheses	W-stats	Z-stats	*p*-values.	Outcomes	Conclusion
IWC→MI	10.1679	9.1320	0.0000	Yes	Bilateral causation
MI→IWC	8.1459	6.8713	0.0000	Yes	
IWC^2→MI	4.5158	2.8127	0.0049	Yes	Bilateral causation
MI→IWC^2	9.2343	8.0882	0.0000	Yes	
MI→COP	3.6142	1.8047	0.0711	Yes	Unilateral causation
EXR→MI	4.4613	2.7518	0.0059	Yes	Unilateral causation
GDP→MI	8.7399	7.5355	0.0000	Yes	Bilateral causation
MI→GDP	4.4527	2.7423	0.0061	Yes	

Accordingly, our findings are robust and aligned with the MM-QR and Driscoll-Kraay standard error techniques.

5. Discussion

The findings of this study provide empirical evidence of a positive relationship between mineral goods imports and wind power installation in major mineral commodity-consuming countries.

These findings highlight the significant utilization of critical mineral goods by these nations in the manufacturing process of cleaner power. Specifically, wind power serves two primary purposes: offshore and onshore. The maintenance of offshore wind plants heavily relies on rare earth minerals, particularly permanent magnets used in generator operations. As wind generator technologies continue to advance, the growing trend in wind power installation further underscores the importance of these mineral commodities as essential raw materials [41].

As one of the top mineral-importing countries, the situation of the US is particularly striking when it comes to producing renewable electricity from wind sources. Over the past three decades, the US has witnessed a significant increase in wind electricity production through the use of wind technologies. The adoption of advanced technologies has led to a reduction in wind-based electricity production costs. According to a report by the EIA[1], "Total annual U.S. electricity generation from wind energy increased from about 6 billion kilowatt-hours (kWh) in 2000 to about 380 billion kWh in 2021."

Similarly, China has emerged as the leader in wind installation capacity worldwide. In 2020, developers constructed approximately 100GW of wind farms in China, which is enough to power roughly three times the number of houses in the UK. Additionally, there was a nearly 60 %

[1] https://www.eia.gov/energyexplained/wind/electricity-generation-from-wind.php

increase in wind installation capacity in China in 2021[1].

Crucially, in Japan, wind power currently contributes a modest percentage to the overall electricity industry. The onshore wind capacity in Japan is projected to be 144 gigawatts, while the offshore wind capacity is estimated to be 608 GW. As of 2020, the country's total installed wind power capacity was 4.2 GW. In comparison to other countries, the government's objectives for wind power development in 2018 were relatively modest, aiming for 1.7 percent of the total electricity production. However, in December 2020, Japan's authorities announced plans to develop up to 45 GW of offshore energy from wind sources by 2040[2].

The wind energy industry holds paramount importance in Germany's energy revolution, as it continues to account for the highest share of domestic power production in 2021. Germany stands as Europe's largest wind energy market, boasting an installed capacity of nearly 63 GW. Repowering constituted 13 % of new onshore installations in 2021, contributing to approximately 23 % (net) of Germany's total electricity output.

Likewise, the Netherlands heavily relies on wind energy as a significant renewable energy source. Consequently, the central government has made the decision to increase the number of onshore wind farms. By the end of 2015, at least 2,525 onshore wind turbines generated 3,000 megawatts of power, equivalent to approximately 5 % of the Netherlands' overall energy requirements. In line with the Energy Agreement for Sustainable Growth report, the country achieved its target of producing 6,000 MW of onshore wind energy in 2020. Currently, the Netherlands aims to install between 1,000 and 1,500 new onshore wind turbines, considering that an average wind turbine has a capacity of 2 to 3 MW[3].

Furthermore, to meet climate targets and reduce reliance on Russian gas, the Netherlands plans to significantly increase offshore wind plant construction in the coming years, aiming to triple the anticipated capacity by 2030[4].

The overall explosive growth rate of wind energy generation in the top five mineral-consuming nations significantly increases the demand for minerals used in the manufacturing and maintenance of wind technologies. The findings of our study, which demonstrate a positive and significant association between mineral commodities' importation and wind power generation in these major mineral-consuming economies, align with the studies conducted by Islam et al. [1, 34], Giurco et al. [42], Islam et al. [6, 27], and Buchholz & Brandenburg [43].

In our findings, we have also observed a negative relationship between assumed expansion of clean power production and the import demands of critical mineral goods. There are several rationales behind this observation.

Firstly, these countries may lack the necessary preparation, target determination, and capacities to effectively utilize mineral resources for a significant portion of wind energy production. Additionally, bottlenecks related to mineral mining and extraction can hinder the exploitation of the full potential of these mineral resources, as they are often concentrated in specific regions. Furthermore, people and governance in mineral-producing countries may not be inclined to export mineral resources to other nations.

[1] https://www.theguardian.com/business/2021/mar/10/china-leads-world-increase-wind-power-capacity-windfarms

[2] https://www.reuters.com/article/us-japan-windpower-idUSKBN28P0C6

[3] https://www.government.nl/topics/renewable-energy/wind-energy-on-land

[4] https://www.reuters.com/business/environment/netherlands-ramps-up-plan-doubling-offshore-wind-capacity-by-2030–2022–03–18/

Secondly, mineral trade-related extremism can contribute to the negative consequence of utilizing mineral resources in the production process of wind energy, which ultimately affects mineral-importing countries.

Considering these factors, mineral-importing countries are required to sensibly utilize mineral resources in the production of renewable energy, particularly wind energy. Moreover, the clean energy transitions driven by mineral resources in these countries are fundamentally shaped by the state policies adopted to address challenges arising from various socio-economic, political, and cultural factors.

The negative response or bottlenecks in mineral import and exploitation relevant to cleaner energy generation align with previous studies conducted by Bazilian [18], International Energy Agency[1], Mudakkar et al. [44], De Ridder [45], Hu et al. [46], Nassani et al. [23], and Hanai [16].

The study's finding also establish the beneficial influence of copper prices on mineral importation that denies the Marshal's price/demand-centric theorem regarding the import-demand analysis. Marshallian view depicts that the importing commodities' own price may adversely influence the commodities demanded [32].

More specifically, global market dynamics and supply chain interdependencies may also play a role in shaping the relationship between copper prices and mineral imports. Changes in global copper prices can reflect shifts in global demand and supply conditions, affecting the overall availability and cost of mineral commodities. These fluctuations can influence the decision-making process of mineral-importing countries, leading to adjustments in their import demands in response to changing copper prices.

Our findings explore the positive consequence of exchange rates on the requirement for mineral imports, which can be rationalized from the standpoint of these economies having a higher rate of local currencies. This finding also indicates that a stronger local currency can serve as an indicator of higher export earnings. When a country's exports perform well, it generates a surplus of foreign currency, contributing to the strengthening of the local currency. This surplus of foreign currency can then be utilized to finance mineral imports. The positive relationship between exchange rates and mineral imports can be seen as a reflection of the availability of foreign currency reserves that can be allocated towards the importation of mineral commodities.

The final findings of this study provide valuable insights into the relationship between economic development and the expansion of mineral goods imports in major mineral commodities-importing nations. The results highlight the beneficial impact of economic development on the overall growth of imports, particularly in the context of mineral commodities. The findings suggest that higher levels of economic development often coincide with increased industrialization and infrastructure development. These activities require significant quantities of mineral resources, further driving the demand for mineral goods imports.

As a result, the specific level of income growth plays an expediting role in spurring the growth of mineral goods imports, aligning with the needs and demands of the mineral goods-consuming nations.

6. Conclusion and policy implications

The utilization of minerals is highly prevalent in the production of clean energy, particularly in the domain of wind power. Despite the inherent variability and unpredictability of mineral markets, the focus on minerals as a cornerstone in clean ener-

[1] https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

gy generation has proven instrumental in driving their significant demand.

Through our analysis, we seek to investigate the dynamic relationship between *MI* and cleaner energy transformation parameters, specifically the wind installation capacity (*IWC*), in conjunction with several other explanatory variables, e. g., *COP*, *EXR*, and *GDP* growth. To achieve this, we apply rigorous econometric techniques to uniquely examine the import-demand function analysis within the leading 5 mineral-consuming nations.

Our study provides some persuasive results.

First, we establish our primary hypothesis by finding mineral import's monotonic long-run positive responsiveness to the installation of wind power capability. This is obvious in the case of these mineral goods consuming nations owing to their appalling use of mineral resources as raw materials in the operation of wind energy technologies and their production.

Secondly, the own price of mineral goods does not hold the Marshallian price-quantity theorem in influencing the requirements of mineral commodities.

Thirdly, the exchange rate positively increases the *MI* demands for these economies. The strength of the currencies of these mineral importing economies directs to the significant influence of exchange rates on the mineral import demands. Furthermore, the cumulative proportionate alteration in import unit values plays a crucial role in detecting the influence of exchange rate fluctuations on *MI* demands.

Finally, economic growth appears to have a monotonic positive influence on mineral import (*MI*) from q1 to q5. After this threshold level, the income growth factor shows inconsequential throughout the remaining quantiles (q6-q9). This result indicates that these economies utilize the *GDP*'s potential in promoting *MI* growth, but GDP's exponential rate upholds *MI* growth for a certain level (threshold level).

Our findings are robust across the alternate estimation parameters, namely the DKSE technique and the Dumitrescu-Hurlin panel causality test.

The outcomes of our comprehensive investigation carry substantial theoretical and practical implications for the formulation and implementation of policies. Our findings indicate that a strategic utilization of minerals in the development of renewable energy holds the potential to facilitate a transition towards a decarbonized or net-zero emissions trajectory for mineral-importing nations.

However, it is imperative for decision-makers in these economies to address the critical Issue of a recycling framework for minerals. Without a well-defined plan for recycling, these nations will be unable to achieve the fundamental objective of a circular economy.

By implementing appropriate policies, the exploitation of minerals can yield significant profitability, enabling policymakers to capitalize on the income growth potential that renewable energy sources offer while simultaneously steering their energy infrastructures away from non-renewable sources.

Furthermore, the collective efforts of these nations to ensure that global average warming remains below the ambitious target of 1.5 °C, as set by world leaders at COP26, can be further bolstered by actively avoiding the use of non-renewable energy sources through a concerted and deliberate approach.

The governments of major economies that rely heavily on mineral imports must conscientiously acknowledge the growing necessity for minerals as they seek to pursue more sustainable forms of energy. According to the World Bank's (2020) forecast, the demand for minerals in renewable energy technologies is anticipated to surge by more than

500 % by 2050. This staggering depiction of mineral demand may spur various nations to ramp up their mineral imports to reinforce their capacity for producing clean energy. In light of this, it is crucial for the governments of these nations to establish sensible mineral import policies that enable them to sustain mineral goods importation to facilitate the responsible use of renewable equipment, namely wind turbines, wind generators, and wind cells.

Theoretical and empirical implications arise from the analysis of exogenous shocks and the bargaining power of mineral-importing nations in relation to mineral prices. Understanding and being mindful of these exogenous shocks, such as oil price fluctuations, exchange rate fluctuations, economic recessions, and unstable global financial conditions, among others, is crucial for mineral-importing nations. This knowledge can inform policy decisions and strategies to mitigate the adverse impacts of these shocks on mineral prices and ensure the stability and affordability of mineral imports.

The concept of bargaining power becomes an essential factor in the context of attaining favorable mineral pricing and furthering mineral imports. The ability of mineral-importing nations to negotiate favorable terms and conditions can influence the availability and cost of mineral commodities.

This highlights the importance of strengthening the bargaining power of these nations through strategic alliances, trade agreements, and sustainable resource management practices. Understanding the dynamics of bargaining power can guide policymakers in formulating effective strategies to secure access to critical minerals at competitive prices.

Moreover, the pursuit of decisive renewable energy productivity within the framework of global sustainability necessitates the leveraging of crucial mineral goods by the largest mineral-consuming nations. The production of clean energy, facilitated by the utilization of minerals, holds substantial potential to make a significant contribution towards achieving a carbon-neutral planet by the twenty-first century.

This highlights the importance of prioritizing the development and deployment of renewable energy technologies that rely on minerals, while also considering the environmental and social implications associated with their extraction and processing. Overall, the production of clean energy facilitated by minerals holds substantial potential to make a significant contribution towards the attainment of a carbon-neutral planet by the twenty-first century.

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INFORMATION ABOUT AUTHOR

Md. Monirul Islam

Researcher, School of Economics and Management, Ural Federal University named after the first President of Russia B. N. Yeltsin, Yekaterinburg, Russia (620002, Yekaterinburg, Mira street, 19); Associate Professor, Bangladesh Institute of Governance and Management, University of Dhaka, Dhaka, Bangladesh (E-33, Sher-E-Bangla Nagar, Agargaon, Dhaka — 1207); ORCID https://orcid.org/0000-0002-9818-1676 e-mail: monirul.islam@bigm.edu.bd

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Межстрановое исследование спроса на импорт полезных ископаемых и ветроэнергетики: эмпирические данные ведущих импортеров полезных ископаемых

Мд. Монирул Ислам

Уральский федеральный университет имени первого Президента России Б. Н. Ельцина, г. Екатеринбург, Россия

Университет Дакки, г. Дакка, Бангладеш

monirul.islam@bigm.edu.bd

Аннотация. Актуальность данного исследования связана с использованием минеральных продуктов в качестве важнейших промышленных ресурсов для производства оборудования для возобновляемых источников энергии, что вызвало рост спроса и цен на основные полезные ископаемые. Цель исследования — изучить функцию импорт-спрос на металлические минеральные товары с применением метода квантилей через моменты (MM-QR) с учетом потенциальной неоднородности по выборке пяти ведущих стран — потребителей полезных ископаемых (стран-импортеров). Набор данных, охватывающий период с 1996 по 2021 г., анализируется для проверки гипотезы о влиянии ветроэнергетических мощностей на потребности в импорте полезных ископаемых с учетом цен на минеральные товары, обменных курсов и роста доходов. Мы наблюдаем монотонную благоприятную реакцию импорта полезных ископаемых на ветрогенерацию по всем квантилям. Однако при рассмотрении квадратичной формы производства ветровой энергии спрос на импорт полезных ископаемых демонстрирует монотонную обратную тенденцию по мере увеличения размеров ветрогенерации. Полученные результаты свидетельствуют о неожиданном выявлении монотонного положительного влияния цен на медь на импортный спрос на полезные ископаемые, что противоречит теореме Маршалла о ценах. И наоборот, реакция импорта полезных ископаемых на валютные курсы остается стабильно положительной без модуляции. Кроме того, мы наблюдаем немонотонную связь между фактором дохода и импортом полезных ископаемых, что указывает на то, что реакция импорта полезных ископаемых на экономический рост остается положительной до тех пор, пока не будет достигнут определенный порог, за которым она имеет тенденцию к стабилизации. Теоретическая и практическая значимость этих выводов заключается в стимулировании торговли минеральными товарами для достижения цели перехода к чистой энергии для декарбонизации глобальной окружающей среды.

Ключевые слова: импорт полезных ископаемых; установленная мощность ветра; подход MM-QR; пять ведущих стран-импортеров полезных ископаемых.

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ИНФОРМАЦИЯ ОБ АВТОРЕ

Ислам Мд. Монирул

Исследователь Института экономики и управления Института экономики и управления Уральского федерального университета имени первого Президента России Б. Н. Ельцина, г. Екатеринбург, Россия (620002, г. Екатеринбург, ул. Мира, 19); доцент Бангладешского института управления и менеджмента Университета Дакки, г. Дакка, Бангладеш (E-33, Sher-E-Bangla Nagar, Agargaon, Dhaka — 1207); ORCID: https://orcid.org/0000-0002-9818-1676
e-mail: monirul.islam@bigm.edu.bd

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