Roadblocks on the Path of Achieving SDG 7: An Empirical Analysis of the Shift in India's Energy Import Dependency

[1]R U Megha & [2]Dr. Kalpana Sahoo

[1]PhD Scholar, [2]Assistant Professor
[1]Department of Economics,
[1]Rama Devi Women's University, Bhubaneswar, Odisha, India

Abstract: The attainment of Sustainable Development Goal 7 calls for balance between energy security and environmental sustainability. However, decarbonization, instead of promoting energy security by subsequently reducing dependence on petroleum imports, only shifts the dependence toward clean technology equipment and critical minerals, which are geographically concentrated. Thus, a new dependence is created, inevitably reintroducing the problems of energy security. The world's third-largest energy consumer, India also faces this dilemma of swapping its reliance on fossil fuels for reliance on clean energy without lowering its overall susceptibility to changes in global trade, thus jeopardizing energy security. despite previous research that has examined hydrocarbon supply risks and crucial mineral supply risks independently, longitudinal frameworks that integrate the evaluation of cumulative import vulnerabilities across both existing and evolving energy sources are still lacking, This study addresses this vacuum by empirically analyzing changes in India's vulnerability to external energy imports for both conventional fuel and renewables. The approach utilizes bilateral trade data to compare market concentration, as determined by the Herfindahl-Hirschman Index (HHI), and import partner diversity, as measured by the Shannon-Wiener Index (SWI), with the global Geopolitical Risk (GPR) Index. According to empirical evidence, the market focus for clean energy technologies and fossil fuels increased concurrently between 2021 and 2022, while the variety of trading partners gradually decreased. The findings show that increased geopolitical risks and increasing clean technology dependence cancel out the strategic security advantages gained by reducing fossil fuel dependency. Hence, India must promptly boost domestic upstream output, establish stockpiles of strategic minerals, and diversify its clean energy supply chains.

Keywords: *Energy Security, Energy Transition, SDG 7, Geopolitical Risk, Import Vulnerability*

1. INTRODUCTION

1.1 The Global Energy Security Imperative and SDG 7

Energy security continues to be a core requirement for national stability, economic competitiveness, and social welfare across the globe. Energy security, according to the United Nations Development Programme's broad definition, is the continual supply of various energy types in adequate amounts at reasonable pricing without negative economic or environmental consequences (Kruyt et al., 2009; Paravantis et al., 2018). This imperative is specifically stated in the United Nations Sustainable Development Goal 7 (SDG 7), which aims to "ensure access to affordable, dependable, sustainable, and modern energy for all," as part of the international development agenda.

SDG 7 can only be met by carefully weighing the three elements that make up the conventional energy security trilemma: environmental sustainability, supply security, and equity. Almost all earlier global efforts to secure energy supplies focused on protecting economies from price shocks, supply disruptions, and geopolitical cartels in global hydrocarbon markets (Berdysheva & Ikonnikova, 2021; Kharlamova et al., 2018; Pereira et al., 2024).

1.2 The Transition Paradox: Shifting Dependencies from Hydrocarbons to Minerals

Countries have expedited their shift toward renewable energy to satisfy the Paris Agreement's climate objectives and guard against the unpredictable trade in oil and gas. According to a prevailing notion in early energy strategy, switching from limited fossil fuels to naturally plentiful, non-exclusive resources—such as solar and wind—would automatically democratize energy systems, encourage strategic self-sufficiency, and lessen trade-based vulnerabilities (Krane & Idel, 2021; Stegen, 2018).

Yet, empirical evidence suggests a shifting paradox. Decarbonization doesn't end international trade reliance; instead, it shifts that reliance from hydrocarbon to essential mineral and technology supply chains (Filho & Santos, 2022; Hache, 2016; Paltsev, 2016). Compared to fossil fuel infrastructure, hardware for clean energy—such as solar photovoltaic (PV) modules, lithium-ion storage batteries, wind turbines, and electric vehicles—is far more mineral-intensive (Hund et al., 2023; McLellan et al., 2016). Therefore, the world's energy framework is changing from one that uses a lot of fuel to one that uses a lot of materials (Srivastava & Kumar, 2022).

Oil and gas reserves are far less geographically concentrated than critical mineral extraction, processing, and manufacturing facilities (e.g., lithium, cobalt, nickel, and rare earths) (Islam, Sohag, & Alam, 2022; Lee et al., 2024; Yu et al., 2023) (Islam, Sohag, & Alam, 2022; Lee et al., 2024; Yu et al., 2023). Geopolitical risk is redefined rather than eliminated by this structural rearrangement, which creates new economic vulnerabilities across global trade networks (Kilinc-Ata et al., 2023; Su et al., 2021).

1.3 India's Energy Position at the Crossroads

India is in a crucial but vulnerable situation in this changing global environment. India's historical expansion has been greatly dependent on fossil fuel imports, especially crude oil, liquefied natural gas (LNG), and thermal coal, as it is the world's third largest energy consumer (Sharma & Das, 2021; Shchedrov, 2022). For a long time, instability in the oil markets of the Middle East and international shipping lanes has posed risks to India's fiscal stability and trade balance (Kumar, 2023; Ma et al., 2012).

In response, India has pursued ambitious renewable energy deployment, highlighted by the National Solar Mission and aggressive capacity expansion targets (Behuria, 2020). Nevertheless, India's swift switch to clean energy has resulted in a new vulnerability in addition to reducing the intensity of its fossil fuels:

High import dependency on clean technology: Solar PV cells, lithium-ion units, and refined strategic minerals are still largely sourced internationally by India (Boraiaha & Chandan, 2022; Tagotra et al., 2024).

Geopolitical exposure: A big portion of these vital imports comes from focused markets, most notably China, with which India has fragile geopolitical ties and repeated trade disagreements (Islam et al., 2023a; Pandey, 2024; Srivastava, 2022).

Therefore, India is in danger of trading one type of import dependency for another (Kumar, 2023) as it works to lessen its reliance on international hydrocarbon markets.

1.4 Scope, Objectives, and Significance of This Study

Despite previous literature's analysis of fossil fuel trade security (Jang et al., 2014; Ma et al., 2012) or isolated critical mineral markets (Lee et al., 2024; Tagotra et al., 2024), there is a significant lack of integrated, longitudinal frameworks that empirically quantify the net energy security impact across traditional and emerging energy import baskets within a single national context over time.

By empirically assessing structural shifts in India's external energy import vulnerabilities between 2015 and 2024, this research bridges this gap in the literature. This article specifically constructs and analyzes two comparative import baskets:

Crude oil, Liquefied Natural Gas (LNG), and Coal comprise Basket A (Hydrocarbons).

Basket B Critical clean energy minerals, lithium-ion cells, and photovoltaic solar panels (both converted and non-converted) (Clean Energy Inputs).

This paper addresses two fundamental research questions by applying the Shannon-Wiener Index (SWI) and Herfindahl-Hirschman Index (HHI) (Curtis & McLellan, 2023) to market diversification and concentration indices and examining their interaction with the worldwide Geopolitical Risk Index (GPR): Between 2015 and 2024, how has the structural diversification and concentration of India's external energy import vulnerability changed across both clean and traditional energy supply chains? How much does the expanding clean energy industry add to geopolitical risk and import concentration, which counteracts the security benefits of lower fossil fuel imports?

It is critical to comprehend these structural changes to direct India's industrial policies, including Atmanirbhar Bharat (Self-Reliant India), PLI schemes (domestic manufacturing incentives), and strategic trade agreements. For lawmakers tackling decarbonization without jeopardizing national security, this research provides practical empirical insights by evaluating the trade-offs intrinsic to the energy transition.

2. Literature Review

2.1 Evolving Definitions and Quantification of Energy Security

The concept of energy security has progressed far beyond its initial emphasis on oil supply disruptions, embracing complex, multi-dimensional frameworks. According to Kruyt et al. (2009) and Paravantis et al. (2018), "the four As"—Availability, Accessibility, Affordability, and Acceptability—have always been the foundation of energy security. For most of the time, empirical evaluations of these variables in academic research and national policy are based on statistics pertaining to market concentration and trade variety (Jang et al., 2014; Ma et al., 2012). National and regional energy research frequently employs market concentration metrics, such as the Herfindahl-Hirschman Index (HHI) and diversity indices like the Shannon-Wiener Index (SWI), to gauge a nation's vulnerability to supply disruptions and market power imbalances from other nations, as well as its susceptibility to import (Curtis & McLellan, 2023; Jang et al., 2014). A dependency on geographically concentrated fossil fuel imports raises exposure to geopolitical conflicts and macroeconomic shocks, as shown by consistent drivers of energy security in European and global contexts (Kharlamova et al., 2018; Pereira et al., 2024).

2.2 The Shifting Geopolitical Paradigm: Hydrocarbons to Critical Minerals

In the past, cartels of crude oil, coal, and natural gas were the cause of geopolitical risks in the energy trade (Berdysheva & Ikonnikova, 2021; Ma et al., 2012). A preliminary corpus of literature contended that solar and wind are domestic resources that cannot be excluded, thus moving to renewable energy would consistently de-risk international energy trade (Krane & Idel, 2021; Stegen, 2018). Yet, current studies question this positive outlook, pointing to a developing transition dilemma: new supply chain dependencies are being created because renewable infrastructure is heavily dependent on manufactured hardware and critical minerals (Filho & Santos, 2022; Hache, 2016; Paltsev, 2016). Decarbonization changes the character of resource reliance rather than eliminating it:

Material Intensity: Compared to power plants powered by fossil fuels, clean energy equipment (such as electric motors, battery storage systems, and solar photovoltaic (PV) modules) needs far greater amounts of essential minerals (such as lithium, cobalt, nickel, and rare earth elements) for each unit of energy created (Hund et al., 2023; McLellan et al., 2016).

The processing, refining, and manufacturing stages of crucial minerals and clean technology hardware have a very high geographic concentration, which is frequently significantly greater than hydrocarbon extraction (Lee et al., 2024; Yu et al., 2023).

Cross-sectional and empirical research indicates that shifting to clean energy generates strategic mineral import requirements, introducing unique geopolitical and trade concerns (Islam, Sohag, & Alam, 2022; Islam, Sohag, Hammoudeh, et al., 2022; Kilinc-Ata et al., 2023; Su et al., 2021). Therefore, the mineral-energy nexus determines the courses for energy security (Srivastava & Kumar, 2022).

2.3 India's Energy Transition Paradox and Structural Vulnerabilities

India faces a two-sided structural weakness as a growing economy with increasing energy demand (Sharma & Das, 2021; Shchedrov, 2022). India's main energy security issue in the past was its heavy reliance on imports of coal and crude oil, which made its economy vulnerable to price fluctuations in the Middle East and international shipping bottlenecks (Kumar, 2023; Ma et al., 2012).

India implemented strong clean energy policies, like the National Solar Mission, to lessen its reliance on imported fuel (Behuria, 2020). However, expert assessments show that India's rapid renewable energy deployment has created fresh import dependency.

India is highly dependent on international supply chains for processed critical minerals, lithium-ion battery cells, and solar PV parts, which are necessary for the deployment of green technology (Boraiaha & Chandan, 2022; Tagotra et al., 2024).

The concentration of these clean energy imports among a select number of trading partners, particularly China, poses supply risks during times of geopolitical conflict (Islam et al., 2023b; Pandey, 2024; Srivastava, 2022). Without necessarily lowering the overall external trade exposure (Kumar, 2023), scholars argue that India risks swapping one sort of external energy dependence (hydrocarbon fuels) for another (critical minerals and clean technology).

2.4 Identification of Literature Gap

Despite the literature's extensive insights into hydrocarbon market hazards (Jang et al., 2014; Ma et al., 2012) and important mineral supply chains (Lee et al., 2024; Tagotra et al., 2024), two major gaps still exist: (i) Separate evaluations of fossil fuel security and critical mineral security are made in the existing empirical literature, which also fails to consider how import vulnerabilities change in both areas over time. (ii) There are no integrated, longitudinal frameworks that quantify whether adopting clean energy really reduces a country's trade vulnerability or simply transfers exposure across concentrated import baskets in the presence of global geopolitical threats.

2.5 Conceptual and Theoretical Framework

This article develops a theoretical framework that compares the import exposure of traditional fossil fuels with that of emerging clean energy hardware to model the net energy security effect during the clean energy transition.

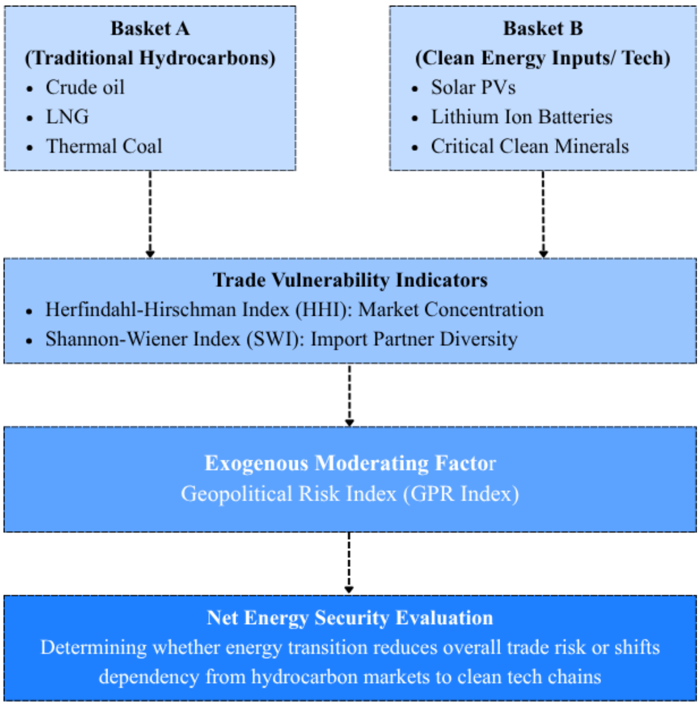

Figure 1: Conceptual Model
***Source**: Prepared by the author*

As assessed by the Geopolitical Risk Index (GPR), geopolitical tensions at the regional and global levels are exogenous shocks in this conceptual paradigm. Increased GPR exacerbate structural trade vulnerabilities when import concentration (HHI) is high and partner diversity (SWI) is low. This model compares the net change in India's external energy security during its transition to clean energy by contrasting the trajectories of Basket A and Basket B regarding GPR.

3. Methodology

3.1. Data and Variables:

The empirical analysis uses annual bilateral trade data spanning 2015 to 2024, sourced from the United Nations Commodity Trade Statistics Database (UN Comtrade). Import values are denominated in US Dollars ($) at free-on-board (FOB) or cost, insurance, and freight (CIF) values to capture total bilateral trade exposure. For Basket B items (SPVNP and SPVP), disaggregated trade classification codes under the Harmonized System (HS) were refined in national trade registries starting in 2022 to separate non-assembled PV units from fully integrated solar modules; hence, these disaggregated categories are tracked across the 2022–2024 window.

Table 1: Data Description

Symbol	Variable	Unit of Measurement	Data Source	Year
OIL	Oil Imports	Trade Value of Imports in US Dollars ($)	UN Comtrade	2015-24
LNG	Liquified Natural Gas Imports			
COAL	Coal Imports			
LI	Lithium-Ion Imports			
SPV_{NP}	Solar Photovoltaic (Not converted into panels)			2022-24
SPV_P	Solar Photovoltaic (Converted into panels)			

Source: Compiled by the author

3.2. Methods

3.2.1. Market Concentration: Herfindahl-Hirschman Index (HHI)

To quantify the market concentration of India's import origin countries for each commodity, this study adapts the traditional Herfindahl-Hirschman Index (HHI). Originally developed to measure market share concentration among competing firms within an industry, the HHI is widely applied in energy economics to evaluate trade reliance on dominant export nations (Jang et al., 2014; Ma et al., 2012). The HHI is defined as:

$$HHI = \sum s_i^2$$

Where,

i is the firm

s_i is the share of the firm in the market

For this study, we measure the share of imports from each country to India relative to the total imports of the goods

Hence, calculation being the same, modified the denotations for the current study to:

i is the country imported from

s_i is the share of the country in total imports of India

The calculated HHI value is scaled to 10,000 points):

Unconcentrated/Diversified Market (HHI < 1,500 points): Imports are distributed across numerous partner countries, minimizing supplier power.

Moderately Concentrated Market (1,500 points < HHI < 2,500 points): Exposure is concentrated across a moderate cluster of exporters.

Highly Concentrated Market (HHI > 2,500 points): Imports rely heavily on a dominant supplier or oligopoly, indicating high exposure to supply interruptions or geopolitical leverage (Curtis & McLellan, 2023).

3.2.2. Shannon-Wiener Index (SWI) – Measures diversification of trade

Even though the HHI squares market shares and consequently under-represents the distribution profile across small trade partners, it nevertheless emphasizes the market power of large providers. To balance this metric, this study uses the Shannon-Wiener Index (SWI), sometimes known as the Shannon Entropy Index, to evaluate the evenness and trade partner richness (Curtis & McLellan, 2023; Kruyt et al., 2009). The SWI is calculated as

$$SWI = -\sum (p_i \times \ln p_i)$$

Where,

p_i is each species' proportion

For this study, we measure the share of imports from each country to India relative to the total imports of the goods

Hence, calculation being the same, modified the denotations for the current study to:

p_i is each country's proportion in the total imports in India

Greater trade diversification is indicated by greater SWI Values, where import shares are uniformly spread among a large network of foreign partners. In the domestic economy, high diversity protects against supply shocks from any single trading partner (Jang et al., 2014). In contrast, reduced trade diversity is indicated by lower SWI Values, where imports are dependent on a tiny number of major source countries, making them more susceptible to bilateral disputes or localized disruptions (Curtis & McLellan, 2023).

3.3. Exogenous Moderating Factor: Geopolitical Risk (GPR) Index

The structural trade exposure is assessed using import concentration (HHI) and minimal trade diversity (SWI), but the actual risk for importing countries is influenced by geopolitical stability throughout international supply networks. The Geopolitical Risk Index (GPR) developed by Caldara and Iacoviello is used to factor in this gap..

GPR is a new based index that is calculated from the frequency of certain terms appearing in a basket of selected highly influential newspapers that related to geopolitical unrest from across the globe. It is a suitable measure for the increasing trade vulnerability arising due to geopolitical tensions among economies. AN increase in global or regional GPR increases structural import risks when trade diversity (SWI) is low and trade concentration (HHI) is structurally high (Islam et al., 2023b; Su et al., 2021).

By comparing these trade metrics across Basket A and Basket B with the GPR timeline, we can assess whether India's clean energy transition reduces total supply weaknesses or shifts trade exposure into mineral supply chains that are vulnerable to geopolitical tension (Kumar, 2023; Srivastava & Kumar, 2022).

4. Results

4.1. Market Concentration Dynamics: Herfindahl-Hirschman Index

Figure 2 illustrates the temporal trajectory of the Herfindahl-Hirschman Index (HHI) across both Basket A (hydrocarbons) and Basket B (clean energy inputs and technology) from 2015 to 2024.

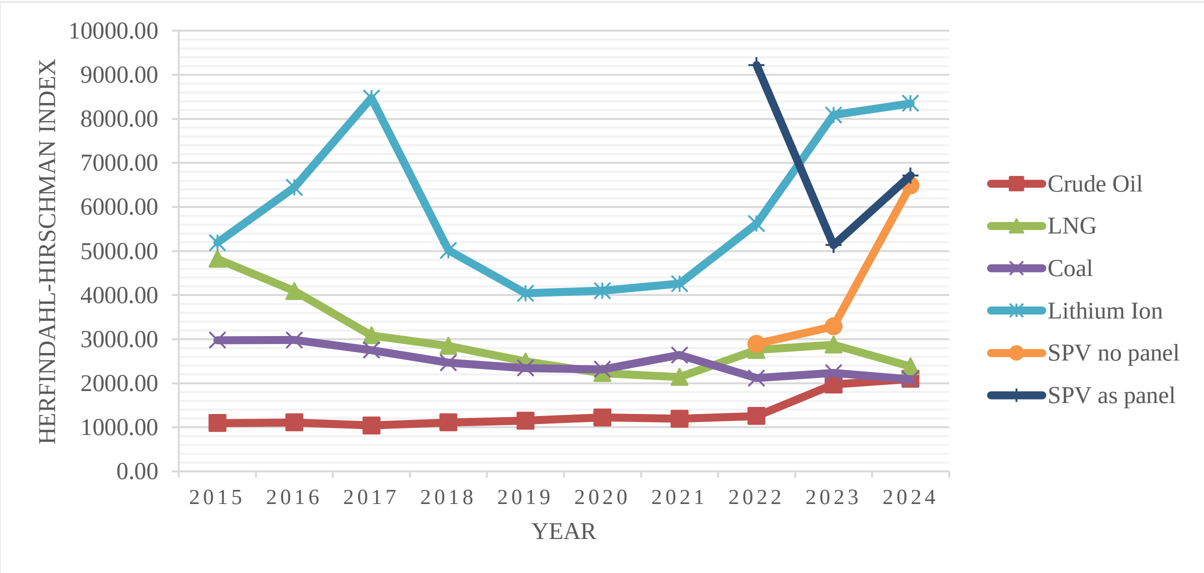

Figure 2: Herfindahl-Hirschman Index
***Source**: Calculated and illustrated by author*

Before 2021, the HHI patterns for traditional fossil fuels (Oil, LNG, Coal) showed slight variations, demonstrating India's continued attempts to modify its sourcing agreements with suppliers in the Middle East, Africa, and the surrounding region. However, following the 2021–22 period, there is a noticeable rise in the HHI for both Basket A and Basket B. In Basket A, realignments in worldwide crude oil and coal acquisition routes following post-pandemic demand recoveries and regional conflict disturbances have led to an increase in market concentration. In Basket B, market concentration for clean energy hardware, namely solar PV components (Solar PVP and Solar PVNP) and lithium-ion accumulators (LI), continues to be extremely high, and the concentration profile has become steeper after 2021–22.

Both research questions about the development and overall effect of India's external energy vulnerability are directly addressed by these empirical findings. The data shows that India's external energy structure has simultaneous market concentration across both traditional fossil fuels and emerging green technology inputs, rather than a steady de-escalation of trade concentration as clean energy adoption increases. The economy is vulnerable still by the shift toward clean energy owing to market power asymmetries.

Imports in Basket B are still largely concentrated among a select group of major manufacturing countries (mostly China). Because of this, the structural benefits anticipated from moving away from fossil fuel imports are consistently negated by high supplier concentration in clean energy technology supply chains.

4.2. Trade Partner Diversification: Shannon-Wiener Index

Figure 3 depicts the Shannon-Wiener Index (SWI) trajectories, capturing the richness and evenness of India's trade partner distribution across both energy baskets from 2015 to 2024.

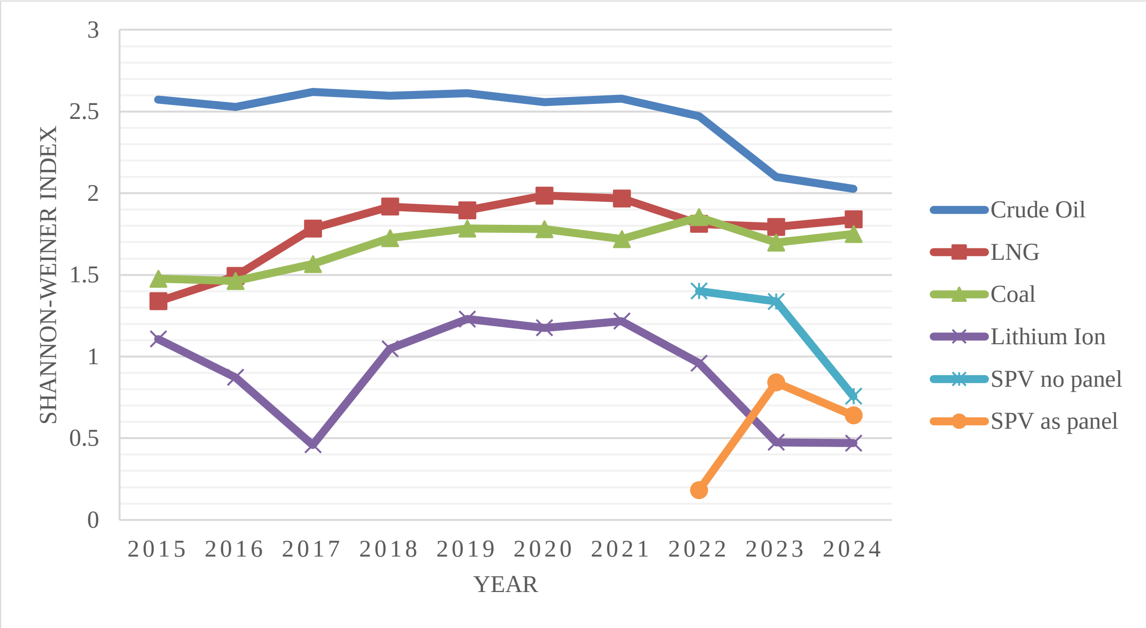

Figure 3: Shannon-Wiener Index
Source*: Calculated and illustrated by author*

The SWI findings assess how evenly commerce is distributed across partner nations, providing a crucial structural counterweight to the HHI measurements. For large energy commodities in both Basket A and Basket B, the SWI shows a constant downward tendency following 2021–22, according to the longitudinal window. A declining SWI verifies that India's energy imports are growing less diverse and more dependent on a small network of export countries. The poor and deteriorating SWI in Basket B in particular shows that battery components (LI) and solar PV modules (SPVP) are imported from a small number of trade partners, with very little trade volumes coming from other secondary markets. The empirical downward shift in SWI offers crucial data for responding to the study's research questions. The structural loss in trade resilience shown by the decrease in SWI after 2021–22 suggests that India's trade profile has narrowed rather than expanded its network of import partners during the energy shift.

While energy transition theory predicts that adopting renewables would increase self-reliance and supply resilience, India's green growth is currently reliant on an asymmetrical, non-diversified import pipeline, as evidenced by the corresponding decline in SWI across clean technology imports. The clean energy supply chain is particularly vulnerable to trade bottlenecks and supply shocks from a single source due to this shortage of supplier diversity.

4.3. Interaction with Global Volatility: Geopolitical Risk Index

Figure 4 entails the trajectory of GPR Index over from 2015 to 2025. It demonstrates a continuous and sharp upward trend post-2020–21. This is an indication of heightened global geopolitical friction, territorial disputes, and trade realignments.

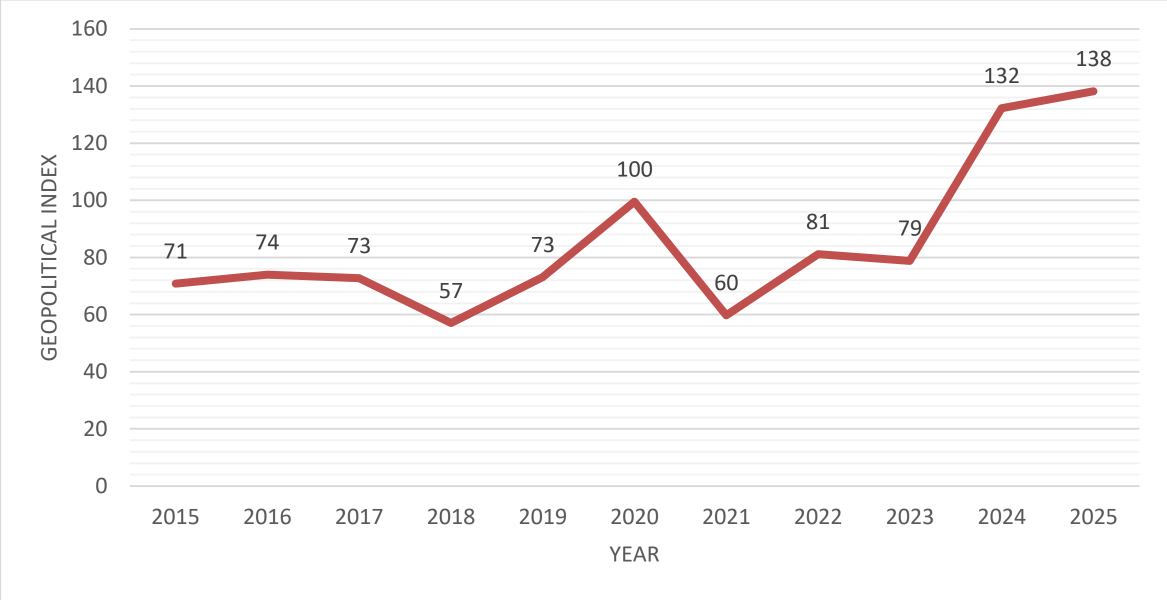

Figure 4: Geopolitical Risk Index

Source*: Data from https://www.matteoiacoviello.com/gpr.htm and illustrated by author*

Integrating the empirical findings from Figures 2, 3, and 4 shows that India's trade vulnerability profile has increased post-2021–22, with growing geopolitical concerns globally directly overlapping with declining trade diversification and rising market concentration.

The main question posed in this research paper is definitively answered by this artificial conversation. When answering Research Question 1, the data demonstrates that from 2015 to 2024, India's external energy vulnerability evolved from a single-front exposure (fossil fuel market volatility) to a dual-front structural exposure across fossil and clean energy inputs. In response to Research Question 2, the empirical correlation between rising geopolitical risk (GPR) and increasing clean technology import concentration (HHI_B) shows that the clean energy industry introduces new import dependencies that counteract gains from decreased reliance on fossil fuels. The areas of active bilateral tension coincide with Basket B's dependencies (e.g., China for solar PV and battery inputs), India's green transition is highly exposed to geopolitical shocks outside of its control, effectively exchanging strategic clean-tech vulnerabilities for traditional hydrocarbon vulnerabilities.

5. Conclusion

The assumption that switching to clean energy provides affordable, dependable, and sustainable electricity while protecting national sovereignty serves as the foundation for the quest of United Nations Sustainable Development Goal 7 (SDG 7) (Kruyt et al., 2009; Paravantis et al., 2018). Initial discussions about energy transitions argued that replacing scarce fossil fuels with non-excludable resources such as solar and wind would naturally eliminate trade-based weaknesses (Krane & Idel, 2021; Stegen, 2018). Nonetheless, the empirical results of this study show that decarbonization does not eradicate external dependencies; instead, it moves the locus of vulnerability from fuel-intensive supply chains to material- and technology-intensive supply chains (Filho & Santos, 2022; Srivastava & Kumar, 2022). A structural realigning of India's energy trade architecture is shown by the longitudinal data from 2015 to 2024. After 2021–22, India saw a decline in trade partner diversification and a concurrent increase in market concentration for both legacy hydrocarbons (Basket A) and clean technology inputs (Basket B). These trends reveal that India's external energy security profile has become increasingly compounded and vulnerable to exogenous supply shocks (Islam et al., 2023c; Su et al., 2021) when compared to the dramatic increase in global geopolitical concerns after 2020–2021.

According to the empirical evidence, hydrocarbon exposure has shifted from being one-front to being compound and two-front. Due to price volatility and the dangers of maritime interruption, importing crude oil, natural gas, and thermal coal from geographically concentrated Middle Eastern markets has historically posed the biggest energy security challenge for India (Kumar, 2023; Ma et al., 2012). However, the longitudinal research shows that market concentration, as assessed by the Herfindahl-Hirschman Index (HHI), has increased in both Basket A (legacy fossil fuels) and Basket B (clean energy inputs and technology) since 2021–2022. Similarly, the Shannon-Wiener Index (SWI) for both product baskets during the same period indicates a structural decline in the variety of trade partners (Curtis & McLellan, 2023). Instead of diversifying its worldwide supplier network as it moves toward renewable energy, India's foreign trade profile has grown more concentrated among a small number of exporting nations. This empirical evidence suggests that India's total external import vulnerability has not decreased between 2015 and 2024. Instead, it was structuralized over two different pipelines, making the local economy vulnerable to simultaneous supply concentration risks in both fossil fuels and green technology hardware.

The synthesized model also demonstrates the existence of an acute energy transition paradox (Filho & Santos, 2022). The idea that deploying wind and solar energy intrinsically improves strategic self-reliance by shielding nations from limited hydrocarbon markets is a fundamental tenet of renewable energy policy (Krane & Idel, 2021; Stegen, 2018). However, the methodical alignment between the growing market concentration in clean technology inputs (HHI_B) and the consistent post-2020–21 increase in the worldwide Geopolitical Risk (GPR) Index shows that these hypothetical gains are systematically countered by high import dependencies in clean hardware supply chains (Islam et al., 2023c; Su et al., 2021). India's green transition is quite vulnerable to geopolitical conflicts and two-sided trade bottlenecks because the country is still heavily reliant on a small group of major manufacturing partners—especially China—for crucial decarbonization inputs such as solar photovoltaic cells and lithium-ion battery accumulators (Boraiaha & Chandan, 2022; Tagotra et al., 2024). Consequently, the empirical results prove that while clean energy expansion successfully curtails fossil fuel import growth, it effectively exchanges traditional hydrocarbon market vulnerabilities for strategic clean-technology dependencies, leaving India's net energy security heavily exposed to exogenous geopolitical shocks (Kumar, 2023; Paltsev, 2016).

India needs to actively diversify its technology and mineral sourcing through trade deals with non-dominant suppliers in Southeast Asia and Latin America to lessen the significant import concentration that has been seen in supply chains for clean energy. Policymakers should establish official strategic mineral alliances with countries like Australia and Chile, while simultaneously investing in domestic mineral processing capacities to lessen their reliance on single-origin exporters. At the same time, shielding the local economy from growing geopolitical conflict necessitates the establishment of strong strategic reserves for critical minerals and fossil fuels to mitigate against abrupt supply shocks. The government needs to speed up the use of biofuels and domestic renewable energy sources to further decrease hydrocarbon imports and lessen reliance on them in the conventional energy sector. Finally, industrial strategies under Atmanirbhar Bharat must concentrate on high-value upstream manufacturing, such as cell chemistry and solar wafer production, with the backing of international partnerships that facilitate the transfer of advanced technology and capital investment.

When interpreting the empirical results of this study, several data-related and methodological limits should be considered. First, because of the restricted availability of current international trade data, the choice of commodities inside Basket A and Basket B is limited. As a result, the empirical models are unable to identify every sub-component of secondary transition minerals or developing green technology. Secondly, the lack of data granularity caused by the dependence on national-level bilateral trade statistics limits the ability to perform firm-level supply chain studies for targeted micro-economic insights. Third, from an econometric point of view, formal structural break analysis is not included in the present analytical framework, which is necessary to strengthen the methodology and statistically pinpoint the precise timing of regime changes in import concentration. Finally, the study depends only on quantitative measurements, ignoring the thorough qualitative information that may be gathered by examining specific bilateral relationships. These limits create a well-defined agenda for more research at the intersection of the energy transition and trade security. As international trade databases' disaggregated reporting for specialist transition materials improves, future research should broaden the basket of products for both hydrocarbon and clean energy categories. Researchers should also work to enhance the specificity of their data so they may conduct studies on supply chains at the firm level and gain more focused knowledge on how endogenous supply shocks affect domestic businesses. Geopolitical crises must be formally structurally broken analyzed in future research to scientifically verify the timing and endurance of changes in trade concentration. Lastly, future research would benefit from adopting an integrated methodology that rigorously analyzes particular bilateral links, integrating qualitative insights with quantitative data to present a more comprehensive view of national energy resilience.

References

[1] Behuria, P. (2020). The politics of late late development in renewable energy sectors: Dependency and contradictory tensions in India’s National Solar Mission. *World Development*, *126*, 104726. https://doi.org/10.1016/j.worlddev.2019.104726

[2] Berdysheva, S., & Ikonnikova, S. (2021). The Energy Transition and Shifts in Fossil Fuel Use: The Study of International Energy Trade and Energy Security Dynamics. *Energies*, *14*(17), 5396. https://doi.org/10.3390/en14175396

[3] Boraiaha, C. K., & Chandan, R. (2022). The Future of the Clean-Energy Minerals in India: Issues and Challenges Out to 2050. *The Indian Economic Journal*, *70*(1), 190–199. https://doi.org/10.1177/00194662211063548

[4] Curtis, A., & McLellan, B. (2023). Framework for Assessment of the Economic Vulnerability of Energy-Resource-Exporting Countries. *Resources*, *12*(2), 27. https://doi.org/10.3390/resources12020027

[5] Filho, V. G., & Santos, T. (2022). Energy Security Transition: Clean energy, critical minerals, and new dependencies. *Ambiente & Sociedade*, *25*, e01791. https://doi.org/10.1590/1809-4422asoc20210179r1vu2022l4oa

[6] Hache, E. (2016). The geopolitics of renewables: Does more energy security come with more energy dependencies? *Revue Internationale et Stratégique*, *N° 101*(1), 36–46. https://doi.org/10.3917/ris.101.0036

[7] Hund, K., La Porta, D., Fabregas, T. P., Laing, T., & Drexhage, J. (2023). *Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition*. World Bank. https://doi.org/10.1596/40002

[8] Islam, Md. M., Sohag, K., & Alam, Md. M. (2022). Mineral import demand and clean energy transitions in the top mineral-importing countries. *Resources Policy*, *78*, 102893. https://doi.org/10.1016/j.resourpol.2022.102893

[9] Islam, Md. M., Sohag, K., Hammoudeh, S., Mariev, O., & Samargandi, N. (2022). Minerals import demands and clean energy transitions: A disaggregated analysis. *Energy Economics*, *113*, 106205. https://doi.org/10.1016/j.eneco.2022.106205

[10] Islam, Md. M., Sohag, K., & Mariev, O. (2023). Geopolitical risks and mineral-driven renewable energy generation in China: A decomposed analysis. *Resources Policy*, *80*, 103229. https://doi.org/10.1016/j.resourpol.2022.103229

[11] Jang, Y.-C., Bang, K.-Y., Lee, K.-Y., & Kim, K. N. (2014). Analysis of energy security by the diversity indices: A case study of South Korea. *Journal of Energy Engineering*, *23*(2), 93–101. https://doi.org/10.5855/ENERGY.2014.23.2.093

[12] Kharlamova, G., Stavytskyy, A., & Chernyak, O. (2018). Analysis of Energy Security Provision in the European Countries. In R. Orăștean, C. Ogrean, & S. C. Mărginean (Eds.), *Innovative Business Development—A Global Perspective* (pp. 111–131). Springer International Publishing. https://doi.org/10.1007/978-3-030-01878-8_10

[13] Kilinc-Ata, N., Alshami, M., & Munir, K. (2023). How do strategic mineral resources affect clean energy transition? Cross-sectional autoregressive distributed lag (CS-ARDL) approach. *Mineral Economics*, *36*(4), 643–654. https://doi.org/10.1007/s13563-023-00373-3

[14] Krane, J., & Idel, R. (2021). More transitions, less risk: How renewable energy reduces risks from mining, trade and political dependence. *Energy Research & Social Science*, *82*, 102311. https://doi.org/10.1016/j.erss.2021.102311

[15] Kruyt, B., Van Vuuren, D. P., De Vries, H. J. M., & Groenenberg, H. (2009). Indicators for energy security. *Energy Policy*, *37*(6), 2166–2181. https://doi.org/10.1016/j.enpol.2009.02.006

[16] Kumar, N. (2023). Transition to electric economy from hydrocarbons: Let us not trade one energy dependence with another insecurity. *Third International Meeting for Applied Geoscience & Energy Expanded Abstracts*, 1705–1709. https://doi.org/10.1190/image2023-3907484.1

[17] Lee, R., Ahuja, J., & Čavoški, A. (2024). The Geopolitics of Access to Critical Minerals Necessary to Support Energy Transition. *Global Energy Law and Sustainability*, *5*(2), 163–181. https://doi.org/10.3366/gels.2024.0122

[18] Ma, P., Jiang, H., & Hong, Y. (2012). Geographic Concentration of Korean Oil Imports and the Implications. *Advanced Materials Research*, *608–609*, 1506–1510. https://doi.org/10.4028/www.scientific.net/AMR.608-609.1506

[19] McLellan, B., Yamasue, E., Tezuka, T., Corder, G., Golev, A., & Giurco, D. (2016). Critical Minerals and Energy–Impacts and Limitations of Moving to Unconventional Resources. *Resources*, *5*(2), 19. https://doi.org/10.3390/resources5020019

[20] Paltsev, S. (2016). The complicated geopolitics of renewable energy. *Bulletin of the Atomic Scientists*, *72*(6), 390–395. https://doi.org/10.1080/00963402.2016.1240476

[21] Pandey, V. (2024). Geopolitics of Energy Transition: The Role of Renewables in Shaping Power Dynamics. *International Journal of Science and Research (IJSR)*, *13*(11), 1453–1455. https://doi.org/10.21275/SR241121153044

[22] Paravantis, J. A., Kontoulis, N., Ballis, A., Tsirigotis, D., & Dourmas, V. (2018). A Geopolitical Review of Definitions, Dimensions and Indicators of Energy Security. *2018 9th International Conference on Information, Intelligence, Systems and Applications (IISA)*, 1–8. https://doi.org/10.1109/IISA.2018.8633676

[23] Pereira, M. B., Robaina, M., & Silva, S. (2024). Energy security in the European Union – Main Determinants. *2024 20th International Conference on the European Energy Market (EEM)*, 1–6. https://doi.org/10.1109/EEM60825.2024.10608952

[24] Sharma, M., & Das, S. (2021). Energy and Resource Security: Some Insights. *Energy Economics Letters*, *8*(2), 145–155. https://doi.org/10.18488/journal.82.2021.82.145.155

[25] Shchedrov, I. (2022). Energy transition in India: Challenges and prospects. *Asia and Africa Today*, (9), 20. https://doi.org/10.31857/S032150750020528-2

[26] Srivastava, N. (2022). Trade in Critical Minerals: Revisiting the Legal Regime in Times of Energy Transition. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.4255549

[27] Srivastava, N., & Kumar, A. (2022). Minerals and energy interface in energy transition pathways: A systematic and comprehensive review. *Journal of Cleaner Production*, *376*, 134354. https://doi.org/10.1016/j.jclepro.2022.134354

[28] Stegen, K. S. (2018). Redrawing the Geopolitical Map: International Relations and Renewable Energies. In D. Scholten (Ed.), *The Geopolitics of Renewables* (Vol. 61, pp. 75–95). Springer International Publishing. https://doi.org/10.1007/978-3-319-67855-9_3

[29] Su, C.-W., Khan, K., Umar, M., & Zhang, W. (2021). Does renewable energy redefine geopolitical risks? *Energy Policy*, *158*, 112566. https://doi.org/10.1016/j.enpol.2021.112566

[30] Tagotra, N., Srivastava, N., Sharma, A., & Gowthami, T. S. (2024). Critical Minerals for India's Clean Energy Transition. *World Resources Institute*. https://doi.org/10.46830/wriwp.23.00063

[31] Yu, D., Wenhui, X., Anser, M. K., Nassani, A. A., Imran, M., Zaman, K., & Haffar, M. (2023). Navigating the global mineral market: A study of resource wealth and the energy transition. *Resources Policy*, *82*, 103500. https://doi.org/10.1016/j.resourpol.2023.103500