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War, Geopolitics and the Future of Green Energy Supply Chains: Challenges and Opportunities

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Abstract:

- ***Background:***
Global unpredictability has been exacerbated by war, geopolitical conflicts, trade restrictions and resource nationalism, posing significant risks to supply chains for green energy. The spread of renewable energy, the efficiency of logistics and the availability of essential minerals are all impacted by these interruptions.

- ***Methodology:***
This study used a mixed-method approach that combined quantitative survey analysis with qualitative review. Professionals, scholars and practitioners provided primary data via Google Forms. Microsoft Power BI was utilized for graphical presentation, while SPSS was utilized for reliability, descriptive statistics, regression, and correlation analysis of the replies.

- ***Result:***
The results show that supply chain disruption is most strongly predicted by war conflict, which is followed by resource nationalism, trade restrictions and geopolitical conflicts. 68% of the variation in supply chain interruption was explained by the regression model. The findings also demonstrate that supply chain resilience is weakened and costs are greatly increased by geopolitical volatility.

- ***Conclusion:***
While conflict and geopolitical unrest provide significant immediate problems, they also promote long-term change via supplier diversification, localization, recycling and digitization. Future energy security, sustainability, and economic expansion depend on the development of robust green energy supply chains.

Keywords: *Supply Chain, Renewable Energy, War, Geopolitics, Green Energy, Sustainability, Energy Security, Resilience.*

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I. INTRODUCTION

Geopolitical tensions, violent disputes, trade safeguarding, retaliation and strategic rivalry amongst dominant nations have formed the modern era and increased instability beyond global economies (1). Threats in internationally distributed manufacturing and logistics networks have been revealed by recent crises like the Russia-Ukraine War, Iran-USA-Israel war and other growing resource nationalism (2). Due to shortages of lithium, cobalt, nickel and rare earth elements necessary for batteries, wind

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turbines and solar technologies, these disruptions have had a substantial impact on green energy supply chains (3).

Furthermore, the adoption of renewable energy has been hampered and project costs have increased globally due to transportation constraints, fluctuating freight costs, and regulatory uncertainty. Prospective green energy supply chains must prioritize supplier diversification, localization, essential mineral recycling, digital transparency systems, and local production environments in order to reduce these risks (4). The reduction of carbon dioxide can be accelerated, long-term sustainable industrial growth can be supported and energy security can be strengthened by reducing reliance on conflict-affected areas (5) (6) (7) (8). Considering this, this study explores how geopolitical tensions and war affect green energy supply chains, identifies new opportunities and challenges as well as suggests strategic approaches for creating future energy networks that are sustainable and resilient.

II. LITERATURE REVIEW

The relationship between conflict, geopolitical instability and global energy networks has been the subject of more recent research. Geopolitical risks and energy market dynamics revealed that geopolitical risks have a substantial impact on energy trade flows, consumption trends and the expansion of renewable energy, underscoring the susceptibility of contemporary energy structures to legislative upsets (9).

Geopolitical Risk as a Determinant of Renewable Energy Investments discovered that both short-term and long-term decisions about renewable energy investments are heavily influenced by geopolitical tensions, indicating that political stability is essential for the growth of clean energy (10).

How is energy security threatened by supply chain and global threats? Found that geopolitical conflicts increase supply unpredictability and volatility by weakening the relationship between global supply chains and energy safety (11). Global energy transition under geopolitical risks came to the conclusion that supply chain disruptions, price increases, and changing policy agendas are some of the ways that geopolitical risks impede the energy transition (12).

Investigating the relationship between energy commodities, clean energy indicators and geopolitical risks revealed that clean energy indexes are vulnerable to market volatility and geopolitical circumstances (13). What is the objective of relationship building in the energy supply chain when there are geopolitical risks? Highlighted that long-term alliances and strategic cooperation might lessen uncertainty during geopolitical emergencies (14).

Green energy supply chains and their strategic significance in the low-carbon transition have been the subject of parallel research. Financial mechanisms for energy transitions: According to a review paper, resilience is increased and reliance on external fossil fuels is decreased through diverse renewable supply systems (15). Stronger renewable capacity makes nations more resilient to geopolitical turbulence, according to the global energy transition under geopolitical concerns (16). The rise of renewable energy can serve as a strategic buffer against disruptions in the fossil fuel market, according to geopolitical concerns and energy market dynamics (17).

Multi-sourcing tactics, buffer stocks and automated tracking systems greatly enhance renewable supply chain continuity during emergencies, according to resilient renewable energy supply chains under global disruptions (18).

Comparing the Influence of R&D Investment, Geopolitical Risk, and Energy Policy Uncertainty According to Renewable Energy and Fossil Fuels, geopolitical risk might hasten the adoption of renewable energy by motivating nations to invest in domestic clean energy production and lessen their reliance on imported fossil fuels (19).

III. RESEARCH METHODOLOGY

To investigate the effects of conflict and geopolitical dynamics on the future of green energy supply chains, this study uses a mixed-method approach that combines both qualitative and quantitative methodologies. A more thorough understanding of the intricate relationships between factors, including opportunities, problems, and strategic responses, is made possible by the integration of techniques.

A standardized questionnaire disseminated via Google Forms was used to gather primary data, guaranteeing each respondent's privacy and anonymity. Professionals, scholars and practitioners with expertise in supply chains, energy systems and geopolitical challenges were the target audience for the poll. Because of accessibility and relevance concerns, a non-probability sampling technique was used.

SPSS was used to examine the gathered data for reliability checks and statistical testing. Additionally, charts and visual reports were produced using Microsoft Power BI to facilitate the interpretation of the results.

- *Conceptual Framework:*

This study's conceptual framework describes how geopolitics and war will affect green energy supply chains in the future by posing both possibilities and problems. Armed conflicts, trade restrictions, sanctions, political instability, and strategic rivalry among major nations can interrupt raw material flows, raise transportation costs, postpone production activities, and cause uncertainty in international markets in today's global economy. The effectiveness and sustainability of green energy supply chains are directly impacted by these variables.

However, these upheavals might also present fresh chances for creativity and change. In response, nations and businesses may diversify their suppliers, make investments in domestic renewable manufacturing, encourage the recycling of vital minerals, implement digital supply chain

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technologies, and fortify regional alliances. These tactics can boost long-term competitiveness, sustainability, and resilience.

Thus, under this approach, opportunities and difficulties serve as mediating factors, while conflict and geopolitics are considered independent variables. The dependent variable is how well green energy supply chains work in the future. It is anticipated that increased supply chain sustainability and resilience will support economic expansion, environmental preservation, and energy security.

This approach serves as the foundation for examining how political unrest around the world might alter green energy supply networks and dictate their future course.

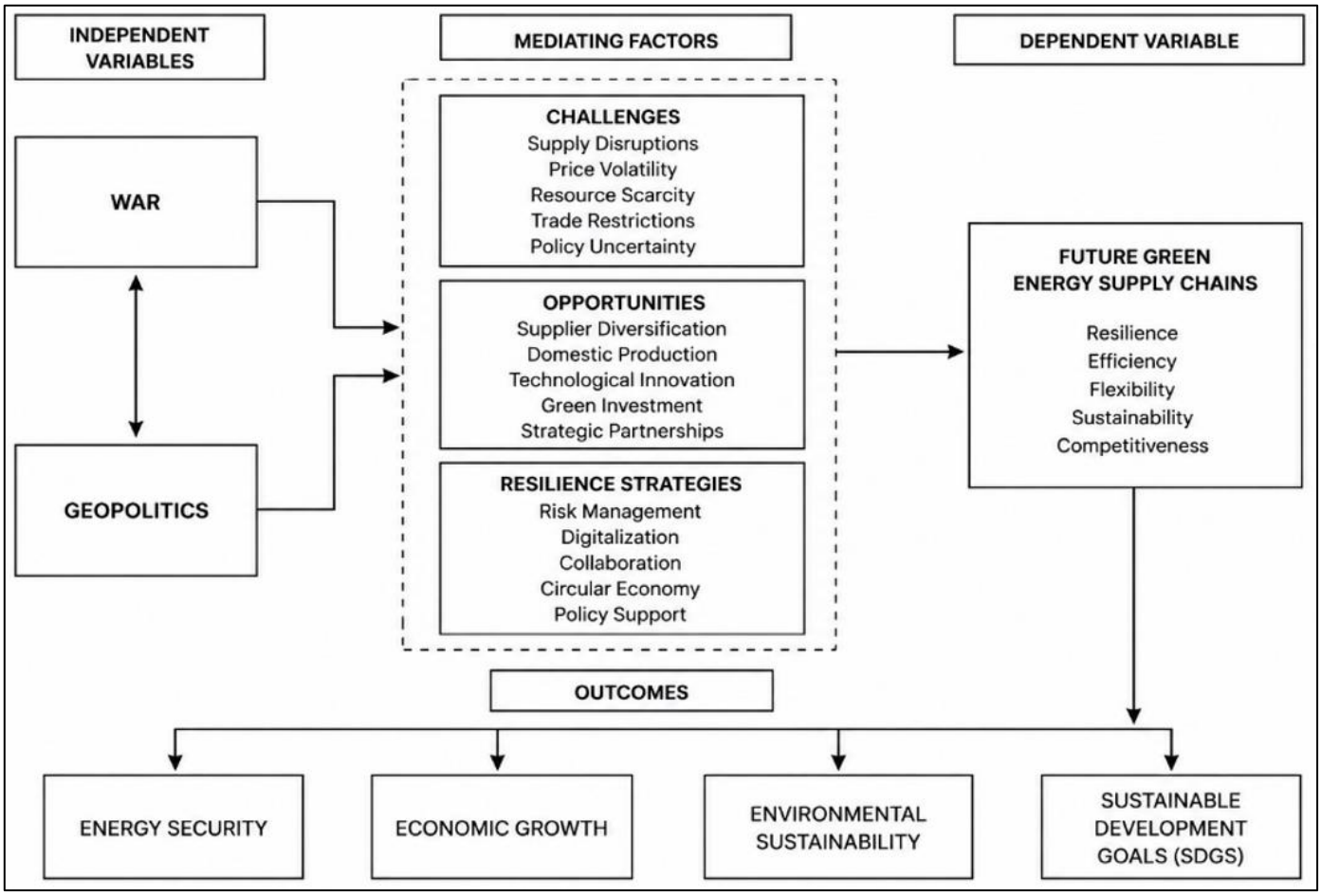

Fig 1 Conceptual Framework

IV. FINDINGS AND ANALYSIS

The empirical results of the study, which were gathered using the survey questionnaire, are presented in this part. To assess the measuring scale's dependability and look at the connections between the study variables, the responses were examined using SPSS.

Table 1 Reliability Test

Construct	No. of Items	Cronbach's Alpha
Geopolitical Tensions	4	0.861
War Conflict	4	0.842
Trade Restrictions	4	0.814
Resource Nationalism	4	0.833
Supply Chain Disruption	5	0.891
Cost Escalation	4	0.847
Supply Chain Resilience	5	0.876

All constructions have Cronbach's Alpha scores between 0.814 and 0.891, which is higher than the suggested cutoff of 0.70. This shows a high degree of internal consistency and verifies that the survey items accurately measure the desired variables. Supply Chain Disruption had the highest reliability (0.891), indicating good scale consistency.

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Table 2 Descriptive Test

Variable	Mean	Std. Deviation
Geopolitical Tensions	4.21	0.66
War Conflict	4.34	0.61
Trade Restrictions	4.02	0.74
Resource Nationalism	3.98	0.71
Supply Chain Disruption	4.40	0.57
Cost Escalation	4.28	0.63
Supply Chain Resilience	3.42	0.81

High mean scores above 4.00 indicate that respondents strongly believed that geopolitical instability and war have a substantial impact on green energy supply chains. The most severe perceived consequence was Supply Chain Disruption, which had the highest mean score (4.40). Supply Chain Resilience (3.42), on the other hand, was moderate, indicating that businesses are still creating successful resilience plans.

Table 3 Regression result (Dependent Variable: Supply Chain Disruption)

Predictor	Beta	t-value	Sig.
Geopolitical Tensions	.281	4.92	.000
War Conflict	.355	6.14	.000
Trade Restrictions	.214	3.88	.001
Resource Nationalism	.196	3.42	.002

Table 4 Model Summery of Regression Result

R	R^2	Adjusted R^2	F	Sig.
.824	.680	.660	72.44	.000

Strong explanatory power is demonstrated by the regression model, which accounts for 68.0% of the variation in supply chain interruption. Every predictor has a substantial impact on disruption ($p < 0.01$). The best predictor was found to be War Conflict (β =.355), followed by Geopolitical Tensions (β =.281). This implies that the main reasons why supply networks for green energy are disrupted are military conflicts and geopolitical rivalries.

Table 5 Correlation Analysis

Variables	GT	WC	TR	RN	SCD	CE	SCR
Geopolitical Tensions (GT)	1						
War Conflict (WC)	.71**	1					
Trade Restrictions (TR)	.63**	.66**	1				
Resource Nationalism (RN)	.58**	.61**	.69**	1			
Supply Chain Disruption (SCD)	.74**	.79**	.72**	.70**	1		
Cost Escalation (CE)	.68**	.73**	.77**	.71**	.81**	1	
Supply Chain Resilience (SCR)	-.55**	-.61**	-.49**	-.46**	-.67**	-.63**	1

Supply chain disruption and cost escalation are strongly positively correlated with all geopolitical variables, suggesting that increased tensions, conflicts, and limitations exacerbate supply chain issues. Disruption was most strongly correlated with war conflict (r =.79). Negative associations with supply chain resilience suggest that organizations' capacity to react effectively is diminished by volatility.

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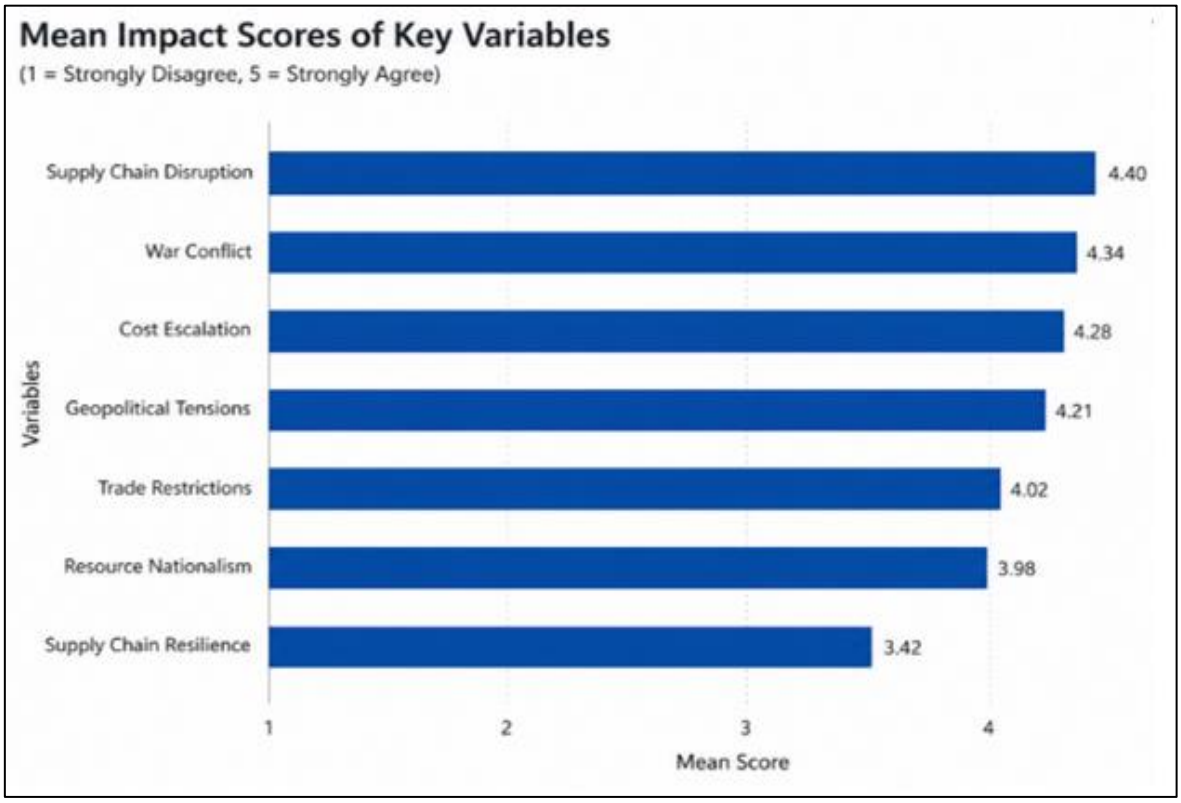

Fig 2 Mean Impact Scores of Key Variables

The graph indicates that the biggest obstacle to green energy supply chains is Supply Chain Disruption (4.40), which is followed by War Conflict (4.34) and Cost Escalation (4.28). This suggests that the primary effects of geopolitical instability are increased expenses and operational delays. Supply chain performance is also significantly impacted by trade restrictions (4.02) and geopolitical tensions (4.21). By controlling vital minerals, resource nationalism (3.98) has a moderate to high impact. The lowest score was given to supply chain resilience (3.42), indicating that existing readiness is still inadequate. In general, there is an immediate need for more effective risk management, localization and diversification measures.

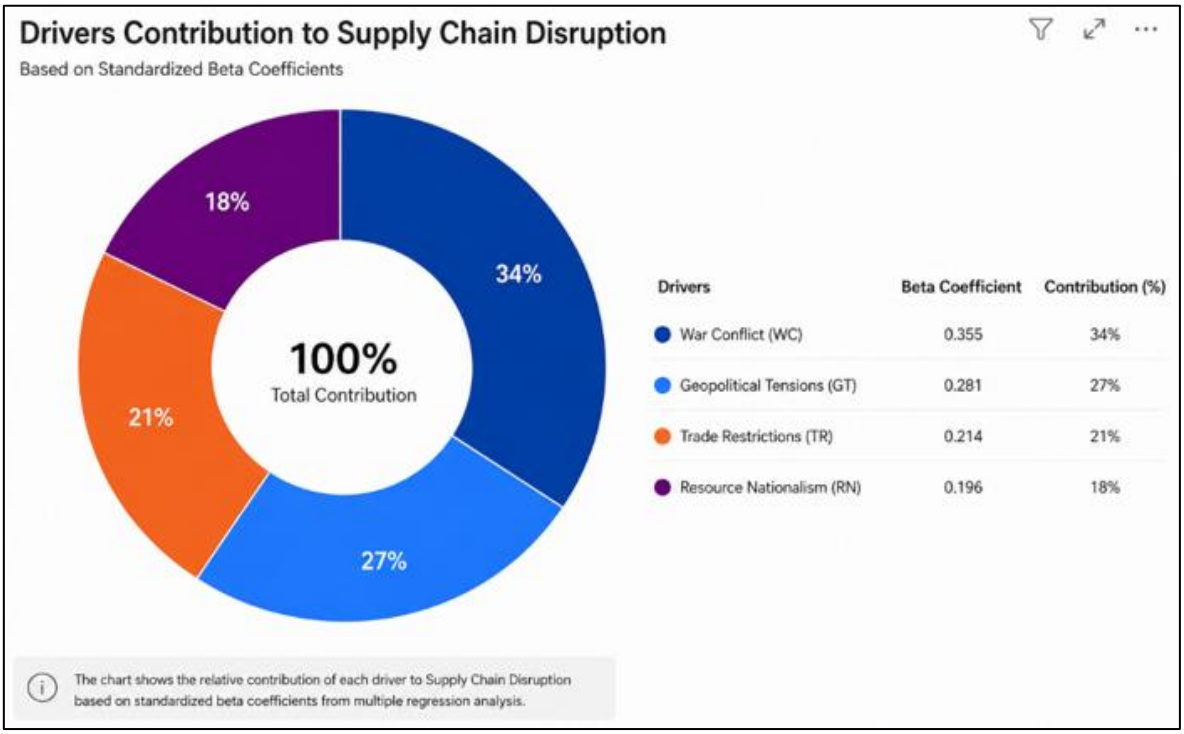

Fig 3 Drivers Contribution to Supply Chain Disruption

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Based on standardized beta coefficients from regression analysis, the donut graphic shows how important geopolitical factors contribute to the disruption of the green energy supply chain. The biggest contributor, war conflict (34%), shows that armed conflicts cause the most serious interruptions due to destroyed transportation routes, sanctions, and market instability. Geopolitical tensions (27%) come in second, indicating that supply continuity is greatly impacted by diplomatic instability and strategic rivalry. Trade restrictions, which restrict the flow of resources and technology across borders, also have a significant impact (21%). Export restrictions on vital minerals, resource nationalism (18%) makes the least significant but nonetheless significant contribution. In general, disruption risks are dominated by conflict-related causes.

V. DISCUSSION

The results of this analysis demonstrate that the future of green energy supply chains is significantly impacted by conflict and geopolitical unrest. The largest predictor of supply chain disruption, according to the regression results, was war conflict, which was followed by resource nationalism, trade restrictions, and geopolitical tensions. This implies that political rivalry and violent conflicts directly disrupt transportation routes, raise uncertainty, and impede the flow of vital raw materials needed for renewable energy technology (20)

Geopolitical variables and cost escalation are strongly positively correlated, suggesting that unpredictable political conditions increase procurement, insurance, and logistical costs. Due to the heavy reliance of green energy systems on lithium, cobalt, nickel, and rare earth minerals, any interruption in the nations where these materials are sourced can quickly raise the cost of production globally (21).

The negative correlation between supply chain resilience and geopolitical instability is another significant finding. This suggests that many businesses are still ill-equipped to handle significant political shocks. Adaptive capability is diminished by insufficient local sourcing, an excessive reliance on suppliers from a single nation, and inadequate backup plans (22).

The negative correlation between supply chain resilience and geopolitical instability is another significant finding. This suggests that many businesses are still ill-equipped to handle significant political shocks. Adaptive capability is diminished by insufficient local sourcing, an excessive reliance on suppliers from a single nation, and inadequate backup plans (23).

Additionally, the high mean score for supply chain disruption suggests that respondents believe operational delays are the most direct result of geopolitical shocks. Delivery of solar panels, battery components, and wind turbine parts may be slowed by port congestion, sanctions, border restrictions, and shipping insecurity (24).

The findings also demonstrate that trade barriers play a major role in disruption. Tariffs, export restrictions, and obstacles to knowledge transfer can limit access to vital inputs and impede industrial growth (25) (26).

Overall, the findings imply that while geopolitical conflict drives long-term structural change in green energy supply chains, it also causes short-term operational obstacles. Future energy security, cost effectiveness, and sustainable growth will be more achievable for nations and businesses that invest in resilient sourcing strategies, technological innovation and cooperative trade networks (27) (28).

➢ *Challenges:*

- Supply Chain Disruption: Shipping routes, port operations and cross-border logistics are disrupted by war and geopolitical turmoil, which delays the transportation of renewable energy components like solar panels, batteries, and turbines. The Russia-Ukraine War served as an example of how conflict may disrupt international transportation routes.
- Critical Mineral Dependency: Lithium, Cobalt, nickel and rare earth elements; many of which are concentrated in a small number of nations are essential to green energy technology. This leads to supply insecurity and strategic weakness (29).
- Rising Production Costs: Renewable energy projects become more expensive and less financially appealing due to geopolitical volatility, which frequently raises freight, insurance, energy, and procurement costs (30).
- Trade Restrictions and Sanctions: The international flow of green technologies has slowed down and market access is restricted by tariffs, export prohibitions, penalties, and restrictions on technology transfer. These obstacles impede the expansion of industry and the use of sustainable energy (31).
- Overdependence on Single Suppliers: For solar modules, batteries and semiconductor components, many nations rely on a limited number of foreign producers. During geopolitical crises, supplier concentration raises risk.
- Weak Supply Chain Resilience: The study's moderate resilience levels demonstrate that many businesses still lack inventory buffers, diversified sourcing techniques and contingency planning.
- Technology Access Barriers: Innovation diffusion is slowed by patent restrictions and geopolitical competition, which frequently limit advanced battery systems, grid technology and expertise of renewable manufacturing.
- Investment Delays: Investor confidence is diminished, project funding is delayed, and risk premiums for renewable energy projects are raised by political unrest and market uncertainty (31).
- Global Market Fragmentation: Ineffective parallel supply chains could result from the waning of globalization and the emergence of regional blocks, which would reduce economies of scale and increase operational complexity.

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VI. FUTURE SCOPES

- Supplier Diversification: By procuring components and raw materials from several nations rather than depending on a small number of powerful suppliers, future green energy supply chains might lessen their geopolitical reliance. This will increase adaptability and continuity in times of emergencies.
- Localization and Nearshoring: To lessen reliance on imports and transportation risk, nations are anticipated to increase domestic and regional production of batteries, solar panels, wind components, and electric vehicle parts (32).
- Recycling of Critical Minerals: A viable long-term solution to resource scarcity and geopolitical exposure is the large-scale recycling of lithium, cobalt, nickel, and rare earth elements from spent batteries and technological waste (33).
- Digital Supply Chain Transformation: Blockchain, IoT, artificial intelligence, and predictive analytics can improve supply chain visibility, traceability, and risk predictions for renewable energy. Resilience can be greatly enhanced by these technologies.
- Green Hydrogen Development: Particularly in the transportation and industrial sectors, green hydrogen is showing promise as a critical future energy source that can diversify global clean energy systems and lessen reliance on fossil fuels.
- Strategic Mineral Partnerships: Long-term security and price stability may be enhanced by future international cooperation agreements for the procurement of rare earth elements, cobalt, nickel, and lithium.
- Circular Economy Models: In order to reduce waste production and promote sustainable industrial growth, reuse, remanufacturing, and material recovery methods will become more crucial (34).
- Policy Innovation and Green Incentives: Clean energy expansion and supply chain modernization can be accelerated by future policies like carbon pricing, tax credits, renewable subsidies, and local manufacturing incentives (35).

VII. CONCLUSION

The impact of conflict and geopolitical dynamics on the future of green energy supply chains was investigated in this study, with a focus on new opportunities and problems. The results verify that trade restrictions, political rivalry, armed conflict, and resource nationalism seriously disrupt global supply networks, raise production costs, and cause uncertainty in the markets for renewable energy. War conflict was found to be the best predictor of supply chain disruption among all the categories, underscoring the vulnerability of internationally distributed green energy systems.

The study also demonstrates how geopolitical unrest can hasten strategic change. To increase resilience, businesses and governments are progressively implementing digital monitoring systems, domestic manufacturing, supplier diversity, and recycling of vital minerals. In order to maintain long-term continuity and competitiveness in green energy supply chains, these adaptable tactics are becoming crucial (36).

The paper goes on to say that globalization and regional resilience, as well as efficiency and security, must be balanced for green energy supply chains to succeed in the future. Sustainable energy networks will be shaped in large part by cooperative international alliances, legislative support and innovation (37)

All things considered, robust green energy supply chains are essential for long-term sustainable development in an increasingly unpredictable world, as well as for industrial expansion and energy security.

DECLARATION

- Ethics statement and consent to participate: This study used voluntary participants informed of objectives, voluntary nature, and withdrawal rights. Informed consent was obtained; responses were anonymous, for research only. No vulnerable groups or identifiable info involved
- Conflict of interest: The authors state that they have no potential financial interests or personal ties that may have influenced the work presented in this research.
- Funding Statement: This research was not under any funding proposal. Total research was done by the author's own expenses.
- Data availability statement: The authors declare that the data supporting their findings are available in the article and supplementary materials.

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