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Article

The Renewable Energy Transition: A New Geopolitical Game

Abstract: *The global transition to renewable energy is not simply a shift toward a sustainable future, but a fundamental geopolitical reconfiguration. This article analyzes how this transition, while promising a decentralized energy landscape, is paradoxically built upon a new and significant concentration of power. We argue that the geopolitics of energy is being redefined, shifting from a focus on fossil fuels to an intense competition for critical minerals (lithium, cobalt, and rare earths), manufacturing of clean energy technologies, and control over transnational super-grids. The extreme geographical concentration of mineral processing in nations like China creates significant strategic vulnerabilities for importing countries, prompting them to adopt proactive industrial policies such as onshoring and friend-shoring to enhance supply chain resilience. We further examine how the development of interconnected grids presents a dual reality of both enhanced energy security and potential new dependencies, with the increasing digitalization of these networks introducing new risks, particularly from cyber warfare. The ultimate prize in this new geopolitical game, we contend, is technological leadership. We analyze the distinct innovation models of the United States, China, and the European Union, differentiating between venture capital-driven innovation, state-directed techno-nationalism, and regulation-based standard-setting. The ability to control patents and establish global standards for energy technology will ultimately decide which nations lead the global energy order for the remainder of the century, demonstrating that the new energy game is a complex struggle where physical infrastructure, digital control, and great power ambition converge.*

Keywords: *Critical minerals; Energy transition; Geopolitics; Technological leadership; Rare earth elements (REEs); Super-grids*

Vittorio AMATO

Department of Political Sciences,
University of Naples Federico II,
Full Professor of Political and Economic Geography, Naples, Italy;
ORCID 0000-0003-4707-4034;
vitamato@unina.it

1. Introduction

The global energy transition to renewable sources, often envisioned as a path toward a more decentralized and sustainable geopolitical landscape, is in fact built on a new and significant geographical and geological concentration. The shift from fossil fuels to strategic technologies, such as lithium-ion batteries, permanent magnet generators for wind power, and high-efficiency solar panels, has generated unprecedented demand for non-combustible minerals. These materials are classified as "critical" due to their economic importance and the high supply risk associated with them (Hund et al., 2020).

In this context, it can be argued that energy geopolitics is not disappearing but is instead being redefined. The focus is shifting from the extraction and flow of hydrocarbons, which still maintain their strategic relevance, to intense competition over the extraction, processing, and production of mineral-based energy technologies. The supply chains for lithium, cobalt, and rare earth elements (REEs) are a prime example of this new dynamic, characterized by extreme geographical concentration, complex economic networks, and strategic vulnerabilities that are already influencing state policies and international alliances. This scenario sets the stage for an in-depth analysis of the interconnections among supply chains, network politics, and technological competition.

It is precisely this new complexity that requires a theoretical framework to understand the current global energy transition, moving beyond traditional geopolitics centered on fossil fuels and arriving at one that takes into account the simultaneous existence and interaction of both high- and low-emission energy systems. It is precisely to address these complex interactions of the current transformation that this work draws on the conceptual framework of Geopolitical Political Economy. This contemporary approach, developed by scholars such as Caroline Kuzemko and others, examines how the physical properties of energy systems, discursive formations of political power, the structure of markets, and technological innovations influence and co-produce each other, especially in the context of the global energy transition (Kuzemko et al., 2024).

By operationalizing this framework, this paper demonstrates that the new energy game is not a simple replacement of one resource dependency with another, but a complex, multi-scalar struggle over the material, spatial, and technological architecture of the 21st century.

2. Critical Minerals for the Green Revolution: Lithium, Cobalt, and Rare Earths

It is crucial to understand that a mineral's criticality is not an intrinsic property but rather a function of its economic importance and the vulnerability of its supply chain. Economic importance stems from the essential role the mineral plays in a specific technology for which there are no readily available substitutes. Supply risk, conversely, is assessed based on factors such as production concentration, governance issues in producing countries, and the efficiency of recycling infrastructure (Graedel et al., 2012). Based on these parameters, minerals like lithium, cobalt, and REEs score highly on both axes of this matrix, confirming their position as strategically crucial materials in the energy transition.

Lithium represents the cornerstone of the electrification revolution, as it's the fundamental element in the cathodes of nearly all lithium-ion batteries that power electric vehicles (EVs) and grid-scale energy storage systems. Cobalt, equally crucial for cathodes, ensures thermal stability and increases energy density.

Rare earth elements (REEs), particularly neodymium, praseodymium, dysprosium, and terbium, are indispensable for the high-strength permanent magnets used in direct-drive wind turbines and high-end EV motors, offering a performance advantage that's difficult to replicate with electromagnets (IEA, 2021). The lack of readily available and scalable substitutes for these minerals in the short and medium term creates a structural dependence for importing nations, reminiscent of the 20th-century oil dependencies, albeit with much more complex and opaque supply chains.

The production and processing of these critical minerals show a significantly higher degree of geographical concentration than that of oil or gas. In 2022, the Democratic Republic of Congo (DRC) supplied over 70% of the world's cobalt production, with a significant portion coming from artisanal and small-scale mining, a sector known for human rights violations and governance challenges (Sovacool, 2019). Simultaneously, China dominates the global processing sector, refining approximately 65% of the world's cobalt, 60% of its lithium, and nearly 90% of its rare earth elements (USGS, 2023).

This dominance is no accident; it is the result of a long-term strategic industrial policy. Following its "Going Out" strategy in the early 2000s, Chinese companies have acquired stakes in key mining assets abroad (such as the Tenke Fungurume cobalt mine in the DRC) and have invested massively in domestic processing capacity and technology, creating a powerful monopsony. The control over the midstream processing stage, where raw ore is transformed into refined chemicals and metals, represents a strategic chokepoint that gives Beijing considerable market power and potential geopolitical leverage. This situation has already triggered reactions reminiscent of the so-called "petrostates." Indonesia, for example, a major nickel producer, has banned the export of raw ore to force foreign investment to localize processing plants within its territory, a clear example of resource nationalism applied to the green economy (Lee et al., 2020).

This extreme concentration generates profound vulnerabilities for importing nations, such as the European Union and the United States. Supply risks are multidimensional and include not only political instability or strategic manipulation but also environmental, social, and governance challenges that can disrupt supplies and create reputational risks. The cobalt supply chain from the DRC is a prime example, associated with issues of child labor, unsafe working conditions, and corruption (Kara, 2018). In the case of rare earths, China's use of export quotas in 2010, following a dispute with Japan, caused a price surge, serving as a severe warning about the potential for weaponization of supply (Wübbeke, 2013).

Furthermore, the ecological footprint of extraction and processing, particularly for REEs that generate large volumes of toxic and radioactive waste, represents a significant challenge to the sustainability narrative of the energy transition. Such vulnerabilities are prompting consuming nations to re-evaluate their strategic dependencies and diversify supply chains.

In response to these increasing challenges, the geopolitics of critical minerals is increasingly configured as a strategic "chess game," focused on securing access and building resilience. National strategies are articulated along several axes of action to address this scenario. First, there is an intensification of diplomatic initiatives and alliances aimed at catalyzing public and private investment in responsible global supply chains. The Mineral Security Partnership (MSP), led by the United States, is a clear example, explicitly framing mineral security as a matter of national security and aligning with strategic partners (White House, 2022).

Second, there is the implementation of domestic and onshoring policies. Regulations like the U.S. Inflation Reduction Act use substantial financial incentives to stimulate domestic extraction, processing, and recycling. For example, this legislation explicitly links tax credits for electric vehicles to mineral sourcing requirements from the United States or its trade allies (Congress.gov, 2022). Finally, a third crucial axis of action is technological innovation, with significant funding allocated to research into new battery chemistries that reduce or eliminate cobalt (such as lithium iron phosphate batteries) and the development of rare-earth-free motors (Ziegler & Trancik, 2021).

In summary, the competition for these minerals is not just a race for resources but a fundamental struggle for the industrial and technological architecture of the 21st-century energy system. Control over these supply chains confers not only an economic advantage but also the power to set standards, influence the pace and geography of the energy transition, and exert significant diplomatic influence. Leadership in the patents and technologies that will define this new era will be inextricably linked to secure, resilient, and ethically managed access to the mineral resources on which it is based.

3. Solar and Wind Supply Chains: Between Concentration and Vulnerability

The transition to renewable energy promises a future of decentralized power generation and greater independence. However, the industrial reality of producing the technologies that make this transition possible, particularly photovoltaic panels and wind turbines, presents a paradox. Rather than a dispersed and resilient global network, their supply chains are marked by a deep geographical concentration and strategic dependencies that generate new vulnerabilities and re-establish old geopolitical patterns.

Building upon the concept of critical mineral dominance, it is clear that control over the midstream and downstream segments of renewable technology production, specifically polysilicon purification, cell manufacturing, and turbine assembly, has become a central arena of geopolitical competition. This concentration creates strategic chokepoints that states can leverage, compelling consumer nations to adopt strategies of friend-shoring, industrial policy, and innovation to secure their energy future.

An exemplary case of profound industrial concentration is the global solar photovoltaic supply chain. Although the raw material, polysilicon, is accessible from several nations, including the United States and Germany, its purification has been almost entirely absorbed by China. Thanks to massive state investments, economies of scale, and competitive energy costs, China now holds over 80% of the world's polysilicon production capacity and more than 95% of the production of key components like ingots, wafers, and cells (IEA, 2022). This dominance is not solely explained by cost competitiveness but is the result of a long-term strategy of vertical integration that has allowed Chinese companies to control every phase of production, from raw material to the finished module, creating an ecosystem that Western competitors find extremely difficult to challenge.

This concentration generates multiple levels of vulnerability for importing nations. Firstly, the solar industry is extremely sensitive to political shifts and production disruptions in China, as demonstrated by the period from 2020-2021 when the forced closure of some polysilicon plants in the Xinjiang region, due to energy consumption policies and forced labor concerns, caused a significant increase in global module prices, delaying solar projects worldwide (BloombergNEF, 2021). This event highlighted how geopolitical and political risks in such a concentrated region can immediately create shockwaves across the entire global energy transition. The second vulnerability lies in the geopolitical leverage that Chinese dominance affords Beijing. While a total embargo on solar exports is unlikely due to the enormous economic importance of the sector for China itself, more subtle coercive tools are available. Such tools include delays in issuing export licenses, customs audits, or the prioritization of supplies to allied nations, with the potential to slow the energy transition of geopolitical competitors. Finally, the third vulnerability is related to forced labor concerns. A significant portion of polysilicon production is concentrated in Xinjiang, where documented accusations of human rights abuses against Uyghur minorities have emerged. This has created a serious ethical and compliance dilemma for Western countries, leading to the adoption of regulations like the U.S. Uyghur Forced Labor Prevention Act, which effectively bans imports from the region (Congress.gov, 2021). This scenario imposes a difficult trade-off between the pace of decarbonization and adherence to ethical standards, complicating procurement strategies.

The wind power supply chain shows less concentration than the solar one, particularly in the production of turbines and towers, where European players like Vestas and Siemens Gamesa and Chinese manufacturers like Goldwind and Envision hold significant global market shares. However, critical dependencies persist. As previously mentioned, the permanent magnets used in the most efficient direct-drive generators depend on rare earth elements, whose processing is almost entirely dominated by China. Additionally, the production of key components such as blades and nacelles has also undergone significant consolidation in China to meet both the domestic market and growing export demand. These dynamics make the wind sector vulnerable on two fronts. Firstly, there is a "hidden" dependency on components, as while a wind turbine may be assembled in Europe or the U.S., its performance-critical elements, namely the magnets, remain tied to the fragile China-centric REE supply chain. This creates a structural vulnerability within an otherwise more diversified production base. Secondly, the sector is exposed to logistical bottlenecks. Unlike solar panels, wind turbine components (blades, towers, nacelles) are massive and require specialized transport and port infrastructure. This generates logistical vulnerabilities where disruptions in global maritime transport, or geopolitical tensions in major sea lanes, can cause severe delays and cost increases for projects (Global Wind Energy Council, 2022).

In response to these highlighted vulnerabilities, the United States and the European Union are adopting aggressive strategies aimed at reconfiguring renewable energy supply chains, in close correlation with technological competition. One of the main responses is the adoption of a protectionist-style industrial policy. The U.S. Inflation Reduction Act is the most emblematic example, offering substantial tax credits for the domestic production of solar components, wind turbines, and batteries. This legislation is not merely a climate policy but represents a clear industrial and security strategy aimed at bringing production back home (onshoring) and reducing dependence on a single foreign source (Sargent, 2022). The European Union has responded with its own Green Deal Industrial Plan, an initiative designed to simplify regulations and allocate funds to strengthen its clean technology manufacturing base.

Another crucial strategy is friend-shoring and the development of strategic alliances. Recognizing that complete self-sufficiency is neither efficient nor immediately achievable, the U.S. and E.U. aim to build alternative supply chains with allied and geopolitically reliable nations. This approach translates into partnerships with countries like India, Vietnam, and South Korea for solar panel assembly, and with Canada and Australia for the processing of critical minerals (The White House, 2022). The goal is to create a parallel and more resilient network that reduces strategic exposure to China.

Finally, technological diversification serves as a tool to mitigate specific dependencies. Research and development are being intensified on alternative technologies that can bypass critical chokepoints in the chain. In the wind sector, this means developing REE-free turbines using externally excited synchronous motors. In solar, alternative photovoltaic technologies are being promoted, such as cadmium telluride thin-film panels, which rely on a less concentrated supply chain (NREL, 2023).

In essence the configuration and control of solar and wind supply chains are not simple commercial matters but fundamental determinants of energy security in a world moving toward decarbonization. The ability to produce and distribute renewable technologies on a large scale and in a timely manner is now a central element of national power. This production scenario will directly influence the feasibility of the interconnected super-grids discussed later, as nations will be hesitant to increase energy interdependence if the technology supporting it comes from a strategic competitor. The success of the reshoring, friend-shoring, and technological diversification strategies cited here will ultimately decide who leads the next phase of the energy transition and who remains vulnerable to the concentration of power in the age of renewable energy, a central theme of the concluding analysis on technological leadership.

4. The Geopolitics of Grids: Super-Grids and Energy Interdependence

The transition to renewable energy systems, powered by the minerals and technologies analyzed thus far, necessitates a radical rethinking of energy infrastructure itself. Unlike hydrocarbon-based systems, which rely on fungible raw materials transported along flexible routes, renewable energy is often generated intermittently and far from demand centers. This reality brings to the forefront an ancient geopolitical question: who controls the cables? The development of transnational electricity grids, particularly the ambitious “super-grids,” thus represents a new frontier of energy geopolitics. This dynamic is characterized by an inherent tension between the promise of greater security through interdependence and the risk of new vulnerabilities and strategic dependencies. The architecture of these future grids will be the main arena where technological competition for the establishment of standards and leadership will manifest, determining the flow of energy and influence in the 21st century.

A purely national and decentralized energy model often proves impractical due to the geographical discrepancy between the potential of renewable sources and population density. Solar energy produced in deserts, wind power generated offshore, and hydroelectric power from mountainous regions all require transmission over vast distances to power cities and industries. This scenario creates a strong incentive for cross-border grid interconnection. Super-grids, which are large, high-voltage grids connecting heterogeneous national networks, are promoted as a solution to the intermittency of renewable sources. By pooling production over a wide geographical area, they can balance supply and demand: when the sun isn’t shining in one country, the wind might be blowing in another (Van der Vleuten & Lagendijk, 2010). Proponents of this approach believe it fosters peace and cooperation, creating a “geography of peace” where the mutual benefits of energy trade make conflicts prohibitively costly, echoing the functionalist theories of integration (Deutsch et al., 1957).

However, this optimistic vision obscures a more complex geopolitical reality. Interdependence is not synonymous with symmetry; it can generate relationships of vulnerability and leverage. A state that becomes a net exporter of electricity gains significant economic and strategic influence over its import-dependent neighbors. This dynamic, transforms electricity from a purely domestic commodity into a tool of foreign policy, similar to natural gas, but with a potential for influence.

The global push for super-grids is not developing in a neutral context but is deeply intertwined with great power competition. Two main models are emerging. The first is the Chinese model, which views grids as a tool of economic statecraft. China's vision, promoted primarily through the Belt and Road Initiative, involves exporting its electricity grid technologies and standards. State-owned companies like the State Grid Corporation of China have invested massively and acquired stakes in national grid operators in countries such as Portugal, Australia, the Philippines, and Brazil (Wilson, 2019). This strategy has multiple objectives: creating profitable markets for Chinese technology, expanding Beijing's economic and political influence, and allowing China to shape technical standards abroad. Control over another country's grid infrastructure is a profound form of strategic leverage, providing potential access to data and, in a confrontational scenario, serving as a vector for cyberattacks. This strategy directly leverages China's manufacturing dominance to achieve geopolitical ends.

The second is the transnational model, exemplified by the approaches of the EU and the United States. The European electricity grid is already one of the most integrated in the world, a project driven by a supranational political entity. Nevertheless, it continues to face geopolitical tensions. Projects like the North Sea Wind Power Hub, a proposed artificial island to connect enormous offshore wind farms to several North European countries, require resolving complex issues of cost-sharing, jurisdiction, and market design. Furthermore, the EU's dependence on Russian gas led to a belated awareness of the risks of energy interdependence with an adversarial power, prompting a more cautious approach to grid connections with non-member states. The United States, with its fragmented regional grid structure, focuses primarily on modernizing its own national grid to integrate renewables, while its international ambitions are limited to North American integration with Canada and Mexico, which in turn requires managing sovereignty issues.

The geopolitics of grids is further complicated by their increasing digitalization. The modern power grid is a cyber-physical system, relying on sophisticated software and communication networks for its operation. This creates a new area of vulnerability. Grids are primary targets for cyberattacks by state and non-state actors. A successful cyberattack could cause widespread blackouts, paralyzing a nation's economy and security apparatus. This risk makes countries extremely cautious about authorizing the use of equipment or software from geopolitical rivals, particularly China, in their critical grid infrastructure. Consequently, the United States and its allies have explicitly banned the use of Chinese-made transformers and telecommunications equipment from companies like Huawei in their power grids (U.S. Department of Energy, 2020).

Another crucial aspect is the battle over standard-setting. The rules governing the operation of grids and their digital systems are themselves a source of power. Dominance in setting international technical standards for grid interoperability, smart grid technologies, and cybersecurity protocols confers long-term economic and strategic advantages. The entity that establishes de facto standards shapes the market in its own image, entrenching its technology and influence for decades. This context can create a security dilemma. A state's investment in another's grid, intended for mutual economic benefit, may be perceived by a third party as a strategic threat, triggering countermeasures and potentially igniting a cycle of techno-nationalist decoupling. The dream of a global, interconnected renewable grid thus clashes with the reality of a world that is fragmenting into competing technological spheres of influence.

Ultimately the development of super-grids is not merely a technical exercise but a deeply political process that will define the geopolitical landscape of the energy transition. The choices regarding interconnection – with whom, under what standards, and using what technology – will create new patterns of alliance and dependence. These physical grids will determine which regions can effectively exploit their renewable potential and which will remain limited. The vulnerabilities inherent in the concentrated supply chains for minerals and manufacturing are ultimately managed and mitigated through the architecture of the grid. Moreover, the race to develop and export the next generation of grid control technologies, smart inverters, and cybersecurity solutions represents a crucial battlefield for technological leadership. Therefore, the geopolitics of grids represents the ultimate manifestation of the new energy game, where physical infrastructure, digital control, and great power ambition converge to shape the flow of power in all its aspects.

5. Technological Leadership and the Race for Patents and Dominance (U.S. vs. China vs. EU)

The transition to a renewable energy system is not only a competition for physical resources, such as critical minerals, production capacity, or infrastructure, but is, ultimately, a battle for the intellectual property and innovation that define the future of energy technology. Technological leadership, measured and exercised through the dominance of patents, the power to set standards, and control over next-generation technologies, therefore represents the most valuable prize in the new geopolitical game. This leadership is the culmination of the struggles over supply chains and minerals and will determine who reaps the vast economic benefits and wields the strategic influence inherent in designing the global energy architecture of the 21st century, including the super-grids. The competition is primarily a three-way contest, opposing the U.S. innovation model driven by venture capital, China's state-directed techno-nationalism, and the European approach based on setting regulatory standards.

In the high-knowledge economy of clean energy, patents are a crucial form of power. They represent a temporary monopoly on a specific technology, giving the holder the ability to collect royalties, block competitors, and control the direction of technological development. Patent portfolios are, therefore, a key indicator of a nation's innovative capacity and its potential to dominate future markets. An analysis of patent filings reveals a dramatic shift in the global landscape. While the U.S. and EU once led in renewable energy innovation, China has staged a stunning comeback. In the early 2020s, China was filing more patents than any other country in several key sectors, including solar photovoltaic technologies, battery storage, and wind power (IRENA, 2021). This success was not accidental but the result of a long-term, comprehensive strategy. The Chinese approach to technological leadership is a central element of its industrial policy, articulated in plans such as "Made in China 2025." The state provides massive subsidies for research and development, directs its vast complex of academies and state-owned enterprises toward strategic priorities, and often conditions market access on technology transfer, forcing foreign companies to share their intellectual property with Chinese partners (Kennedy, 2015). This has allowed China not only to produce technologies but also to progressively innovate and acquire the intellectual property behind them, climbing the value chain from imitation to invention.

The three main geopolitical blocs are pursuing distinctly different innovation models to achieve technological dominance, each with its own strengths and vulnerabilities. The U.S. model leverages its cutting-edge university system, robust venture capital markets, and an entrepreneurial culture that promotes risk-taking. Its strength lies in disruptive and fundamental innovation – the creation of entirely new technologies rather than the incremental improvement of existing ones. This approach has generated breakthroughs in areas such as next-generation battery chemistries and solar cell materials (Sivaram, 2018). However, its historical vulnerability lies in the ability to "scale up", or to transform laboratory prototypes into commercially viable and mass-produced products. This has often led the U.S. to invent a technology, only to see it manufactured and dominated by others, particularly China. The Inflation Reduction Act is a direct attempt to overcome this weakness by providing massive incentives for domestic production.

The Chinese model, as already noted, is state-planned and state-directed, focusing on volume, scale, and systemic integration. Its advantage lies in the ability to mobilize vast resources toward a single objective, to rapidly refine existing technologies to reduce costs, and to integrate innovation along the entire supply chain, from raw ore to the finished product and the grid connection. This has made China a global leader in the production and deployment of current-generation technologies. Its vulnerability, conversely, lies in a relative lack of truly revolutionary innovations and a persistent dependence on foreign expertise in key areas, such as the design of advanced semiconductors for energy management systems.

The European Union's path to leadership is distinct, relying less on pure invention or mass production and more on its ability to shape the global rules of the game through regulation and standard-setting. By establishing strict environmental, efficiency, and recycling standards, the EU effectively defines the parameters for what is considered an acceptable clean technology in the global market (Falkner, 2016). This "Brussels Effect" compels foreign manufacturers to conform to European norms to access its large and affluent market. Its main challenge is the fragmentation of capital markets and the difficulty of scaling up companies to compete with Chinese and American giants.

The ultimate expression of technological leadership is manifested in the power to set international standards. The entity that defines the technical standards for interoperability (e.g., how batteries communicate with grids, how electric vehicles connect to charging stations, and how different national super-grids connect to each other) will entrench its technology for decades, generating enormous network effects and considerable market power. This represents the new frontier of competition: the "Internet of Energy." In this scenario, China is actively promoting its own standards internationally through the Belt and Road Initiative, while the European Union is leveraging its regulatory power to impose de facto global standards. The United States, for its part, is capitalizing on its technology industry to establish software and communication protocols for smart grids (Schmidt & Huenteler, 2016). The winner of this standards war will not only dominate exports but will gain a significant strategic advantage, as future energy systems will be built to its specifications, thereby creating a deep and lasting technological interdependence.

In short, the race for technological leadership is the keystone of the geopolitics of the energy transition. Control over patents and standards allows a nation to overcome the vulnerabilities tied to dependence on physical resources and production concentration, enabling it to design the energy grids of the future on its own terms. For the United States, leadership is a matter of economic and national security. For China, it represents the path out of the "middle-income trap" and the route to achieving great power status. For the EU, it is a battle to maintain its relevance and uphold its values-based regulatory order. The outcome of this three-way competition will not only decide who profits from the sale of solar panels or batteries but will establish which vision of governance, security, and innovation defines the global energy order for the rest of the century.

6. Conclusions

The global energy transition is not merely a technical or environmental shift, but a profound geopolitical transformation. This new era reconfigures the dynamics of power, competition, and vulnerability, moving the focus from a fossil fuel-based system to one centered on critical minerals, technology supply chains, and interconnected grids. The struggle for control over these elements is not just about securing resources; it is fundamentally about shaping the industrial and technological architecture of the 21st-century energy system.

The extreme geographical concentration of critical mineral extraction and processing, as well as the deep industrial consolidation of solar and wind technology manufacturing, has created new strategic chokepoints. This reality challenges the narrative of a decentralized, democratized energy future and instead reveals a system defined by profound dependencies. Nations are now navigating a complex landscape of supply risks, ethical dilemmas, and geopolitical leverage, necessitating strategies like friend-shoring, reshoring, and technological diversification to build resilience.

Ultimately, the apex of this new geopolitical game lies in the competition for technological leadership. The control of intellectual property, particularly through patents and the ability to set global technical standards, enables a nation to transcend the vulnerabilities inherent in physical resource dependencies. The development of transnational super-grids, while promising to mitigate the intermittency of renewables through greater interconnection, is also a deeply political process. The architecture of these digital and physical networks (which standards are adopted, what technology is used, and who controls the data flows) will determine the distribution of power and influence for decades to come.

In conclusion, the energy transition is a multifaceted struggle for dominance over critical minerals, manufacturing capacity, and technological standards. The outcome of this competition (which pits the state-directed model of China against the market-driven innovation of the United States and the standards-based approach of the European Union) will determine not only who reaps the economic benefits but also which vision of governance and security will define the global energy order for the remainder of the century.

Conflicts of interest

The author declares no conflict of interest.

About the author

Vittorio AMATO is a Full Professor of Political and Economic Geography within the Department of Political Sciences at the University of Naples Federico II. He also holds a lectureship in Geopolitics at the Italian Air Force Academy. Following a six-year tenure as Director of the Department of Political Sciences, he currently serves as the Coordinator of the PhD program in "Public Policies of Cohesion and Convergence in Europe" at the University of Naples Federico II.

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