Research Article

SUSTAINABLE POWER: TRANSFORMATIONS IN GLOBAL ENERGY SECURITY

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The evolving concept of energy security has shifted from a narrow focus on fossil fuel supplies to a broader framework that incorporates the stability of renewable energy systems and the infrastructure required to support them. As the climate crisis accelerates, the urgency of decarbonization has driven the expansion of renewable energy, yet this transition brings its own challenges. The need for resilient electricity grids, reliable energy storage, and a stable supply of critical minerals is now central to ensuring secure and sustainable energy. Additionally, geopolitical tensions are increasingly influencing energy strategies, requiring a balance between traditional and clean energy security concerns. The article highlights the complexities of navigating these competing demands and the strategies necessary to ensure a stable energy future in the face of geopolitical and environmental pressures.

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As Europe faced a winter energy crisis in 2022, triggered by the disruption of gas supplies due to Russia's invasion of Ukraine, energy security once again took center stage on the global agenda. Prices soared, and governments rushed to diversify energy sources. The crisis underscored the fragility of the current energy structure, but more importantly, it highlighted an urgent need for a clean transition and served as a powerful catalyst for accelerating the clean energy transition, which is expected to improve energy security.[1] Governments shifted their resources away from fossil fuels and redirected them towards clean energy investments. By 2023, global investments in clean energy are nearing two trillion dollars, almost double the amount spent on coal, oil, and gas.[2] Although the quick response and relatively mild winter helped mitigate the crisis, the clean energy transition required by the climate crisis,[3] along with rising geopolitical tensions worldwide, necessitates a fundamental shift in the approach to energy security.

Energy security, defined as the uninterrupted availability of energy at an affordable price[4] (IEA, 2014) has long been understood as the security of fossil fuels, namely oil and gas. Historically, energy security primarily meant ensuring access to these fossil fuels. The 1973 OPEC oil embargo was the event that first brought energy security to the forefront of the global agenda. A year later, in 1974, the International Energy Agency (IEA), which owns the definition, was founded in response to worries about disruptions in the supply of oil. However, with the growing urgency of the climate crisis and the fact that the most of carbon emissions worldwide comes from energy-related activities,[5] the concept is undergoing a significant transformation. In today's context, energy security is no longer solely about fossil fuels; it now includes ensuring stable renewable energy supplies. The increasing electrification of economies has made electricity security critical, requiring a stable supply, price stability, and resilient infrastructure. Critical minerals such as lithium, cobalt, and rare earth elements have become a top priority of energy security to decrease the dependence on traditional fossil fuels as these minerals are vital for clean energy technologies like electric vehicles (EVs) and photovoltaic (PV) systems. Also, rising

1) Anish Tailor, Andrea Pescatori, and Nicolas Van Zandweghe, "The Effects of Global Supply Shocks on Inflation in the US," IMF Working Paper, WP/24/006, January 2024.

2) International Energy Agency, "World Energy Outlook 2024," October 2024.

3) See, World Economic Forum, "Securing the Energy Transition," 2023, International Renewable Energy Agency (IRENA), "Global Energy Transformation: A Roadmap to 2050 (2019 Edition)", Abu Dhabi: IRENA, 2019, and Mustafa Tevfik Kartal et al., "Role of Energy Transition in Easing Energy Security Risk and Decreasing CO2 Emissions: Disaggregated Level Evidence from the USA by Quantile-Based Models," *Journal of Environmental Management*, Vol. 359, 2024.

4) International Energy Agency, "Energy Supply Security," 2014.

5) According to the IEA World Energy Outlook 2023 report, energy-related carbon dioxide (CO^2) emissions accounted for a significant portion of global emissions, reaching a record high of 37.4 billion tones in 2023. These emissions represented around 73-75 percent of total global CO^2 emissions, which mainly come from the burning of fossil fuels for electricity, transportation, and industrial activities.

geopolitical tensions, together with the urgent need to accelerate decarbonization to meet net zero targets, have brought nuclear energy back into focus as a key component of the carbon free energy mix. In short, energy security has evolved from a narrow focus on the protection of traditional fossil fuel supplies to a broader concept that now encompasses ensuring the sustainable progression of the clean energy transition.

The changing dynamics of energy security in light of the clean energy transition will be examined in this article. It will look at how energy security has changed from being centered on fossil fuels to emphasizing reliable renewable energy sources, price stability, electrical security through reliable supply, and the infrastructure required to support growing electrification. The role of energy efficiency in reducing demand and enhancing system resilience will also be touched upon. Additionally, the article will delve into the geopolitical risks associated with critical mineral supply chains, the role of nuclear energy in the decarbonization process, and the rising importance of securing resilient energy systems in the context of climate resilience. Finally, it will assess the necessary investments and policies required to modernize energy infrastructure, diversify supply chains, and ensure long-term energy security in a rapidly changing global environment.

Historical Context: The Evolution of Energy Security

Energy security has long been a significant issue for countries, traditionally centered on ensuring a stable and affordable supply of fossil fuels, particularly oil and gas. In this sense, the 1973 OPEC oil embargo was a turning point since it elevated the idea of energy security to the top of international political and economic agendas.[6] The economic shock that followed the dramatic cut in oil supply brought to light the vulnerability of countries that rely on imported oil, underscoring the necessity of diversifying energy sources and securing dependable supply lines. In response, the International Energy Agency (IEA) was established in 1974 to mitigate such risks by coordinating efforts to safeguard oil supplies and stabilize energy markets.

Energy security has long been closely linked to the geopolitics of gas and oil, with trade disputes, sanctions, and conflicts frequently causing interruptions in global energy flows. The necessity of protecting conventional fossil fuel sources is further highlighted by the ongoing geopolitical tensions in a number of areas, including the Middle East, Russia-Ukraine, and portions of Africa. Even while the shift to renewable energy is accelerating, oil continues to play a significant role in the world's energy mix, particularly in industries that are more difficult to decarbonize quickly, such heavy industry and transportation. For many countries, securing oil supplies,

6) Matthew Hagerty, "Europe's Energy Dependence and Lessons Learned from 1973." FactSet, 1 April 2022. https://insight.factset.com/europes-energy-dependence-and-lessons-learned-from-1973

primarily via strategic reserves and safeguarded trading routes, remains a top priority.

In the meantime, natural gas has maintained its significance as an essential transitional energy source, enabling the move towards cleaner energy systems and providing a lower-carbon substitute for coal and oil.[7] Natural gas offers the backup required to handle intermittency problems as renewable energy sources like wind and solar continue to grow, guaranteeing a steady and dependable power supply. Geopolitical dynamics, however, also affect natural gas supply chains, as seen in the 2022 European energy crisis, which underscored the Europe's dependence on Russian gas. This crisis emphasized the need for diversified supply sources and further investments in liquefied natural gas (LNG) infrastructure to bolster energy security during the transition period.[8]

Even if the energy landscape is moving toward renewables, the world is still heavily dependent on oil and gas, especially natural gas. The geopolitical risks related to these commodities continue to influence energy security policies, even though their importance diminishes. As countries accelerate their decarbonization efforts to meet net zero targets, managing the transition in a way that balances both renewable and traditional energy security will be essential in the coming decades.[9]

Electricity Security in the Age of Renewable Energy Expansion

The capacity for renewable energy has grown remarkably in recent years. Over 500 gigawatts of new renewable capacity were added globally in 2023, a 50 percent increase, with solar photovoltaics accounting for three-quarters of these additions. This is the fastest growth rate for renewables in over two decades.[10] Renewable energy investments have surged dramatically, reflecting the global push to decarbonize and enhance energy security. Clean energy investment is expected to double fossil fuel investments in 2024, with key areas like solar PV and wind accounting for a significant portion of this growth. Falling costs, the drop in prices of solar PV over the last decade, and strong government support have driven this shift.[11] Achieving both energy security and net zero goals is possible only through investments in renewable energy, as fossil fuel production conflicts with sustainability efforts.[12]

However, the increased reliance on renewable energy sources comes with new

7) International Monetary Fund, "World Economic Outlook, October 2022: Countering the Cost-of-Living Crisis," Washington, DC: IMF, Vol. 2022, No. 10, October 2022, Chapter 3, p. 53-85.

8) Vlado Vivoda, "LN Import Diversification and Energy Security in Asia." *Energy Policy* 129 (June): 967– 74.

9) Anna-Alexandra Marhold, Towards a 'security-centred' energy transition: balancing the European Union's ambitions and geopolitical realities, *Journal of International Economic Law*, Volume 26, Issue 4, December 2023, p. 756–769.

10) International Energy Agency (IEA), "Renewables 2023: Analysis and Forecast to 2028", Paris, 2023.

11) International Energy Agency (IEA), "World Energy Investment 2024", Paris, 2024.

12) Serhan Cevik, "Climate Change and Energy Security: The Dilemma or Opportunity of the Century?" IMF. 9 September 2022.

challenges, particularly around electricity security. Unlike fossil fuels, renewables like wind and solar are intermittent, meaning they depend on weather conditions, which can fluctuate seasonally and even daily. This intermittency can lead to periods where there is either excess electricity or a shortage, putting strain on electricity grids. Additionally, IEA projects that electricity demand will increase six times faster than total energy demand until.[13] Therefore, grid infrastructure needs to be upgraded to handle the growing proportion of renewable energy sources and provide a steady electricity supply.

Electricity storage is also directly linked with this issue. The intermittency of renewable energy sources makes storage systems essential to deal with fluctuations in supply and demand. To this end, investment in battery storage is projected to exceed 50 billion dollars in 2024,[14] but more is needed to ensure that grids can handle the variability of renewable electricity. Upgrading grids and investing in storage systems are keys to managing these challenges and keeping electricity affordable for taxpayers.

Challenges in Critical Mineral Supply Chains for the Clean Energy Transition

As the world moves further into the age of electricity,[15] driven by the rapid expansion of EVs, solar PVs and other clean technologies, the demand for critical minerals has surged. Minerals such as lithium, cobalt, nickel, and rare earth elements are fundamental to the manufacturing of batteries, electric motors, and other key components necessary for renewable energy systems and the broader electrification of economies. These minerals are critical for ensuring the stability and performance of technologies that are at the heart of the clean energy transition.

A critical challenge facing the energy security is the mismatch between the supply of critical minerals and the ambitious climate targets set by governments worldwide. As demand for minerals like lithium, cobalt, and nickel continues to surge, which is driven by the rapid expansion of EVs, energy storage systems, and renewable energy technologies, there are growing concerns that the current supply chains may not be able to keep up. The long lead times required for developing new mining projects, coupled with the significant investment needed to scale production, pose a major challenge to meeting the rising demand for critical minerals. If supply and production cannot meet this demand, the prices of these essential materials will rise significantly, making the clean energy transition more costly and difficult to achieve. Renewable energy reduces dependency on fossil fuels, thereby enhancing energy

13) International Energy Agency (IEA), "World Energy Outlook 2024," Paris, October 2024.

14) International Energy Agency (IEA, “Electricity Grids and Secure Energy Transitions, Paris, 2023.

15) International Energy Agency (IEA), "World Energy Outlook 2024," Paris, October 2024.

security. However, any disruptions in the supply chains of critical minerals could affect the deployment of technologies like EVs and solar PVs and reverse these gains by increasing reliance on fossil fuels, which would be highly detrimental to global energy security efforts as the rate of electrification in the building and transportation industries mostly determines how quickly oil may be phased out.[16]

The second, and more significant, concern for the clean energy transition is the lack of diversity in critical mineral supply chains. Mining and processing of such minerals are geographically concentrated in a few countries, particularly China. China controls over 70 percent of the global production of rare earth elements and has a similarly dominant position in the refining of lithium and cobalt, essential for EV batteries and other renewable energy technologies. Also, China's dominant role in mineral refining—nearly 90 percent of refined rare earths and 50-70 percent of lithium and cobalt processing—means that any disruptions, whether due to trade restrictions or political conflict, could cause severe bottlenecks in the global supply of these materials.[17] Naturally, reliance on a single country for such a crucial segment of the supply chain poses significant risks to energy security, especially as geopolitical tensions rise.

In response to China's dominant position in critical mineral supply chains, the United States and the European Union have implemented significant policy measures to strengthen energy security and promote the clean energy transition. These efforts aim to reduce dependence on foreign sources of critical minerals, which are crucial for electric vehicles, renewable energy systems, and other green technologies. The Inflation Reduction Act (IRA) seeks to encourage domestic production of critical minerals and secure partnerships with allied nations, to ensure that the transition to clean energy is not vulnerable to supply chain disruptions. Similarly, the EU has initated the European Green Deal initiative and adopted its Critical Raw Materials Act (CRMA) to diversify supply sources, increase recycling, and boost domestic production. The key object is to position Europe as a more resilient player in the global race for clean technology dominance by reducing reliance on non-member countries.

The strategic focus of these policies is not just to secure materials but also to safeguard energy security. By fostering domestic supply chains and reducing reliance on a single dominant supplier like China, both the U.S. and the EU aim to protect their economies from geopolitical risks and market fluctuations. These policy responses highlight the intersection of green technology development and global energy dynamics, where controlling critical minerals has become a matter of strategic importance. The IRA and EU Green Deal signal a clear shift towards ensuring that clean energy expansion

16) Tailor et al. (2024).

17) International Energy Agency, "Global Critical Minerals Outlook 2024", Paris, 2024.

does not come at the cost of national security, while also fostering technological independence and resilient energy structure.

Key Policy Strategies: Energy Efficiency and Nuclear Energy

Looking at other policy options to boost energy security, energy efficiency also protects its historical significance for governments to bolster energy security. By reducing the amount of energy required to power homes, industries, and transportation, energy efficiency measures alleviate pressure on energy supply chains and decrease overall energy consumption. This, in turn, reduces a country's dependence on both fossil fuels and imported energy sources. Investments in more efficient buildings, appliances, and industrial processes can significantly lower energy demand, allowing nations to meet climate goals without increasing dependence to non-domestic suppliers. In parallel, efforts to inform the public about reducing demand have gained significant importance, especially for energy importers as it has been witnessed in the EU following the Russia-Ukraine war. For many countries, energy efficiency continue to be seen as the fastest and most cost-effective way to enhance energy security, providing long-term benefits while supporting the clean energy transition.

In a way that would have been unexpected 10 years ago, nuclear energy has re-emerged in governments' policy portfolios as a critical component of the global strategy to secure a carbon-free energy mix and ensure energy security as it serves both ends simultaneously. Nuclear power offers a stable and large-scale domestic alternative as geopolitical tensions, fossil fuel volatility, and the need for reliable low-carbon energy sources continue to shape energy policy. While countries like Germany have phased out nuclear energy, others, such as France, have extended the operational lifetimes of their nuclear reactors to meet their climate targets and energy needs. Notably, the recent launch of the Olkiluoto 3 (OL3) nuclear reactor in Finland has shown the benefits of nuclear power, leading up to a seventy-five percent reduction in electricity prices,[18] indicating that nuclear option is also significant to cope with soaring energy bills. Therefore, for developing nations, like Türkiye, nuclear energy remains a crucial element in achieving long-term energy security,[19] providing a stable power supply while reducing reliance on fossil fuel imports. Additionally, the development of SMRs may even open new opportunities for developing countries by providing a scalable and cost-effective solution for clean energy, despite that lack of know-how for such countries creates new forms of dependence. Still, their modular design, lower upfront costs, and faster construction times make them commercially

18) John Benny, "Nuclear Power Helps Bring Down Electricity Prices by 75% in Finland," The National News, May 2023, https://www.thenationalnews.com/business/energy/2023/05/14/nuclear-power-helps-bring-down-electricity-prices-by-RE-in-finland

19) Sohbet Karbuz and Barış Şanlı, "On Formulating a New Energy Strategy for Turkey." *Insight Turkey*, Vol. 12, No. 3, 2010, p. 89–105.

viable, offering flexibility and easier integration into smaller power grids compared to traditional large-scale reactors, making them viable options for developing countries.

Concluding Remarks

The concept of energy security has significantly expanded in recent years, evolving from its traditional focus on the uninterrupted availability of oil and gas to a broader framework that includes the stability of clean energy systems and the critical infrastructure needed to support electrification. In a world where geopolitical tensions have intensified, the diversification of oil and gas supply sources and ensuring reliable energy routes are still keeping its importance, but at the same time, it highlights the weaknesses of the current energy structure and emphasizes the need of prioritizing clean and reliable energy to ensure energy security. This shift reflects both the historical reliance on fossil fuels, even though today this has less importance, for energy security and the new challenges arising from the transition to clean energy.

At the same time, the climate crisis and the urgency of decarbonization have driven the rapid expansion of renewable energy capacity. While renewables help reduce the reliance on imported fossil fuels,[20] they introduce new challenges. First, the intermittency and seasonality of renewable energy sources like wind and solar require robust grid infrastructure, with significant investments needed to upgrade power grids to handle fluctuations. Second, the need for effective energy storage systems has become critical in balancing supply and demand, making the development of sustainable infrastructure essential to ensuring a stable energy supply.

Furthermore, the age of electricity has brought about the rapid electrification of transportation and industry, making the deployment of technologies like EVs and PVs crucial for reducing fossil fuel dependence. However, the rising demand for such technologies has also increased the need for critical minerals like lithium, cobalt, and rare earth elements. Unfortunately, the mismatch between supply and demand, together with the geopolitical dominance of China over these minerals created significant risks for energy security. Investments in diversifying supply sources and increasing production are urgently needed to close this gap.

In response to these challenges, governments around the world have begun to prioritize policies that address both energy security and the smooth transition to a green economy. The US IRA and the EU Green Deal represent significant initiatives to strengthen supply chains, boost clean energy investments, and ensure long-term energy resilience. Governments also benefit from other options of energy security policies portfolio. For instance, energy efficiency remains a key policy tool for

20) Fazıl Gökgöz and Mustafa Taylan Güvercin, "Energy Security and Renewable Energy Efficiency in EU," *Renewable and Sustainable Energy Reviews*, Vol. 96 (2018), p. 226-239.

reducing overall demand and easing pressure on energy supply networks. At the same time, nuclear energy, particularly with the development of Small Modular Reactors (SMRs), has re-emerged as a viable option for achieving a carbon-free energy mix, offering reliable, large-scale energy that can enhance energy security while supporting decarbonization efforts.

Looking ahead, the future of global energy security will depend on a careful balance between traditional energy sources and clean energy systems, with a strong focus on critical minerals, infrastructure development, and policy reform. Governments must continue to address the vulnerabilities exposed by the concentessential concentration ofl supply chains while accelerating investments in renewable technologies and grid infrastructure. The path to a smooth green transition will require sustained political will, international cooperation, and the strategic mobilization of public and private investments. The coming years will determine whether the global energy system can meet net-zero goals without compromising security.

However, the future of geopolitical tensions will also play a crucial role in shaping global energy security. Whether energy remains a competitive battleground or becomes an area for international cooperation in the pursuit of climate goals will determine the trajectory of global security dynamics. As seen in recent years, energy resources and supply chains could continue to be used as leverage in geopolitical conflicts, or nations might choose to prioritize collaborative efforts to achieve decarbonization and secure the clean energy transition. Unfortunately, the current global landscape, with rising tensions and fractured international relations, suggests that cooperation may be difficult to achieve in the near term, casting uncertainty over the future of energy security.