Geopolitics and Green Transition Trilogy in the EU: Industrial Strategy, Critical Minerals, and Innovation

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Abstract

The European Union is decarbonising its energy sector amidst a changing geopolitical context. This article focuses on the nexus of three inter-related policy pillars; industrial strategy-critical materials-innovation. We investigate the elements of this 'policy trilogy' and present some recommendations.

1. Introduction

The European Union's (EU) decarbonisation and Green Deal policies sit within a changing geopolitical energy context and can be characterised as a 'trilogy' comprising (i) industrial strategy, (ii) critical materials, and (iii) innovation. The energy 'trilemma' (security, sustainability and affordability) conventionally faced by policymakers now need to be pursued within the context of this emerging 'trilogy' (Figure 1). Both the trilemma and the trilogy demonstrate features of public goods, meaning that markets alone are unlikely to deliver the efficient amount and right balance of each of their components. For example, competitive pressures and lack of access to critical materials may incentivise firms to innovate, but industrial strategy may not necessarily support firms that have the greatest potential for efficiency and innovation.

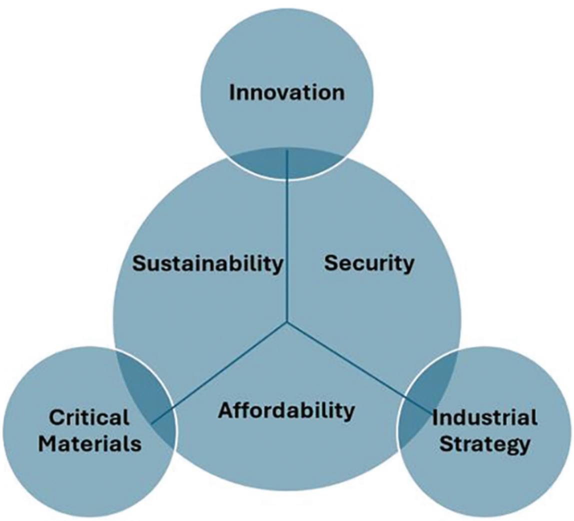

Figure 1: Energy Trilemma within Trilogy Framework. Source: Authors.

At the same time, industrial strategy may be able to initially support the most promising firms, which may lead them to become complacent and reduce their incentives for further innovations or for the efficient procurement, allocation and use of critical and other materials. In this case, firms supported by the industrial strategy may instead focus on increasing their dominant market power. Such consequences are detrimental to the energy Trilemma.

Thus, optimising the trilogy will require carefully thought-out policy interventions, which may be sub-optimal from a narrow economic efficiency point of view in the sense that market values capture only part of full economic (or social) values. However, deviations from efficiency occur frequently in economic policy making and guided by higher-level geopolitical and security considerations.

The new geopolitical context can weaken some established multilateral trading blocs, leading to the use of less formal and more unilateral diplomatic and trade measures (Hegde, Wouters, & Raina, 2021). This trend may have implications for global trading in critical minerals, energy (fossil and clean fuels and electricity), infrastructure equipment, and in the development of new technologies as seen in the EU's renewed focus on industrial competitiveness. As new competing geopolitically motivated trade blocs emerge, more may follow, leading to segmentation of global trade markets that have historically been based on the economic principles of comparative and competitive advantages among countries, and the associated supply chains, thus constraining innovation.

EU industrial strategy, innovation and raw materials also influence the pursuit of the three dimensions of the original energy trilemma. For example, securing critical minerals within the EU through deep-sea mining could risk the affordability of end-products, and might impact sustainability of the marine environment and biodiversity if not pursued in a reasonable and sustainable manner; a better alternative would be to pursue procurement through global trade based on economic sustainability, rather than geopolitics.

Given this context, this article addresses two major questions. First, how could an EU strategy adapt to recent geopolitical changes? We consider the period

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starting with the Russian invasion of Ukraine in 2022 followed by increasing global instabilities and trade tensions, aggravated by import tariffs implemented in the United Sates (US) since early 2025.[1] And second, what are the resulting implications for industrial competitiveness, decarbonisation of the economy, and efficient 'green' energy supply chains? This article considers issues and options relating to the three pillars of the trilogy, in relation to the energy trilemma framework, through a lens of economic and policy analysis.

2. Industrial strategy and competitiveness

In February 2023, the European Commission introduced 'A Green Deal Industrial Plan for the Net-Zero Age'[2], accompanied by measures for strengthening Europe's net-zero technology products manufacturing ecosystem (Net Zero Industry Act), a framework for ensuring secure and sustainable supply of critical raw materials for energy, and a reform of electricity market design.

The Draghi Report in 2024 analysed the competitiveness of EU industry and strategy (European Commission, 2024a). It highlighted the market price of electricity in the EU higher than those of China, and the US, with a combination of the generation mix, resource endowments, technology costs and political economy at times favouring technologies with higher economic costs. In 2024, coal formed the highest share of the electricity generation mix in China (58.4%), in the US it was natural gas (42.6%), and in the EU it was renewable energy sources (RES), 48.7% (IEA, 2025a).

Global installed capacity of RES has been increasing every year (IRENA, 2024). In 2024, RES made up almost three-quarters of the overall increase in global power generation (IEA, 2025a). Access to low-cost new energy technologies will be an important factor in global industrial competitiveness (European Commission, 2025).

Global value chains of trade, partnerships, and research and innovation (R&I) could promote overall global competitiveness and net global welfare gains. For instance, in 2020, mobile phone manufacturing for a global major company involved suppliers in 43 countries across six continents (Ross, 2020). Similarly, it has been suggested that international cooperation between the US, EU, and China could bring forward the point at which electric vehicles (EVs) reach market cost parity with internal combustion engine (ICE) vehicles (Lam & Mecure, 2022). Simulations show that global supply chains for solar panels resulted in faster learning and lower global market prices than fully domestically supplied markets (Helveston, He, & Davidson, 2022).

On the other hand, in a scenario where the global market for critical energy equipment is segmented into trading blocs, there may be a global net welfare loss as supply and value chains will be rearranged according to geopolitically-driven industrial strategy priorities. In this scenario, the EU trading bloc would be a sizable proportion of the global market, though not the largest. For instance, by 2050, projections show India's electricity generation will exceed that of the EU, and China's renewable electricity generation will be about four times that of the EU (IEA, 2024). While some blocs will win, others will lose, to varying extents, resulting in widening equity gaps across the globe, and potentially leading to instabilities.

The energy crisis after the Russia-Ukraine war has widened the economic boundaries between the energy and the public sectors as considerable resources have been required to support consumers and the green transition. The magnitude of required investments combined with new uncertainty about the progress

Table 1: Policy recommendations - Industrial Strategy and Competitiveness

Policy recommendation	Potential benefits
Develop demand-side electrification, green fuels, and energy efficiency activities.	• Lower energy costs • Stimulate employment in new economic activities[3] • Reduce uncertainty in expanding manufacturing capacity and 'anticipatory investments' • Stimulate upstream investments in the value chain[4] • Increase bankability of new projects • Improve competitiveness as suppliers compete for market share
Where specific EU energy equipment lags other trade blocks on quality and cost, leverage the scale of the EU market to promote foreign direct investments in energy equipment manufacture – for instance, joint ventures (JVs), to promote technology transfer and risk sharing in EU markets.	• Reduce the market and technology risk of investments for foreign investors in introducing new energy equipment and technology transfer in EU market • Take advantage of the experience of other regions in energy equipment manufacture[5]
Improve regulatory predictabilities and reduce uncertainties to promote anticipatory investments in electricity networks and other infrastructures.	• Reduce time to commission new investments, which reduces uncertainty and financing risks[6] • Lower and more predictable network costs for new economic activities.
Develop demand-side flexibility solutions, including storage.	• Lower RES curtailment during surplus production[7] • Smooth peak electricity prices[8] • More efficient use of electricity networks • Deferred or cost saving of redundant grid construction and upgrades, higher system resilience, resource adequacy and lower GHG emissions[9] • Consumer electricity bills and costs savings[10]
Prioritize projects that require minimum financial support in relation to required total investment.	• Take better advantage of nearing commercial viability technologies • Improve efficiency and efficacy of public financial support such as Connecting Europe Facility (CEF)

of green transition portends careful thinking around 'anticipatory investments' for regulators and industry. In addition, EU integration projects present a 'cross border cost allocation (CBCA)' dimension that requires special instruments (Sen et al., 2024).

The support for consumers and the green transition needs to be strategically designed as support to energy prices may undermine progress. For example, subsidies on retail tariffs should be refocused on encouraging demand-side flexibility and efficiency, which could enable the green transition in addition to reducing electricity bills. This effect was seen in the UK after the energy crisis precipitated by Russia's invasion, with an increase in demand flexibility services provided by companies to consumers. In the EU, high electricity and gas prices and new incentives in the aftermath of the invasion drove rapid growth in solar PV installation. However, outside of three largest markets (Germany, Italy and Spain), annual PV additions declined in over 15 member states in 2024, as lower energy prices and reduced policy support slowed growth (IEA, 2025b).

3. Innovation

The formation of competing trading blocs could segment and rearrange established industrial energy supply chains. This trend could also affect the scale of R&I networks, and some collaborations may give way to competition among former collaborators. Multinational companies with research centres around the world may be forced to reorganise their innovation activities. This trend may reduce the global rate of innovation in terms of learning-by-research and the diversity of complementary attributes. The economic cost of foregone innovation for global decarbonisation can be substantial, as trading blocs aim to innovate independently.

The economies of the EU are diverse and establishing new R&I infrastructures could be an opportunity to create high value-added jobs and innovations that deliver solutions specific to the EU, laying the foundations for future 'green' growth. As global geopolitical conditions improve, EU technologies could be marketable to other countries, as the EU is regarded as a global leader in promoting sustainability and the 'green' economy.

Increasing the utilisation of existing technologies and promoting the commercialisation of technologies that are nearly at maturity could optimise funding costs, especially with a stronger focus on market mechanisms. For instance, while next generation of inverter-based resources (IBRs) for RES can enable stable operations of highly decarbonised grids, the potential to leverage existing conventional and advanced IBRs is overlooked. Most power systems do not yet require new advanced IBRs to support the grid, often using existing IBRs as legacy units, even though some systems have the technical capability to deliver services and be marketed (EPRI, 2025). Another example is long duration energy storage (LDES), which is yet to be fully commercialised at low cost. [11] The utilisation and support of existing and near-market innovations with high technology readiness levels (TRLs) are as important as supporting emerging technologies.

Table 2: Policy recommendations - Innovation

Policy recommendation	Potential benefits
Increase investment levels in R&I and consider new models of organising and funding R&I in the EU	• Increases the scale of R&I capacity and scale which is important for energy but is beyond the reach of smaller utilities[12]
Measure and benchmark performance of regulatory incentives for innovation in the grid	• Incentivises network companies to become innovation facilitators, effectively channelling regulatory incentives to suppliers, service providers and research institutions that traditionally show higher patenting activity[13]
Prioritise 'market pull' and learning-by-doing R&I for existing and near-market technologies to achieve cost reduction	• More efficient allocation of public funds for technology promotion[14]
Prioritise 'technology push' and learning-by-research R&I to support emerging technologies	• Helps technologies progress faster from the 'emerging' to 'evolving stage'[15]
Widen the use of regulatory sandbox to trial non-mature solutions related to equipment for grid and RES	• More efficient regulatory developments. • Less uncertainty when revising and updating regulation[16]

Furthermore, designs of new support mechanisms for R&I would benefit from thorough evaluations of the organization, efficiency and efficacy of existing and past R&I support. Such evaluations would include a full cycle, such as proposal, selection, implementation, monitoring, reporting and verification, etc. to help improve outcomes for the new R&I programs.

The measures outlined under the industrial strategy pillar can leverage the scale of the EU market for R&I. A larger EU market with inward international investment in energy equipment manufacturing and standardisation could increase the incentive to invest in R&I. This increase could in turn raise the potential for cost reduction through learning-by-doing. Similarly, the development of the demand-side for green technologies and fuels can be supported by R&I through learning-by-research (market-pull) measures (Jamasb, 2007). Finally, bridging policies and financial support can align the demand and supply sides and reduce the likelihood of losing emerging technologies in the 'valley of death' (Gbadegeshin, et al., 2022).

4. Critical Materials

Geopolitical competition over scarce critical materials that can help deliver a global public good (i.e., climate change) to achieve narrow industrial policy objectives, is unlikely to lead to the optimal use of these resources. From a global welfare maximising and climate change perspective, collaborative approaches are preferable and deliver better outcomes than uncontrolled competition among trade blocs. Therefore, collaborative multilateral solutions based on a fair distribution of the value-added emanating from these minerals among exporting and importing countries would be likely to deliver more sustainable outcomes and need to be considered.[17]

Many critical energy minerals are concentrated in a small number of countries.[18] In the absence of exporter-importer collaboratives, a possible outcome is the formation of Organization of the Petroleum Exporting Countries-like exporting blocks for different minerals (Ghorbani, et al., 2024). An example is the formation of BRICS+6 in relation to critical minerals (Vivoda, Matthews, & McGregor, 2024). However, past attempts of metal producer clubs had not been sustainable or successful, such as Intergovernmental. Council of Copper Exporting Countries, Association of Iron Ore Exporting Countries and Primary Tungsten Association.

Ongoing technological changes and policies on recycling and waste minimisation affect the demand for the types and amounts of critical minerals and could limit the growth of the critical minerals market. Unlike crude oil, critical minerals are highly heterogeneous, making cartelisation or monopolisation strategies unsustainable. High market concentration poses risk of supply shortfalls and the exporting countries' dependence on mineral export revenues. Furthermore, as of 2025, 55% of strategic minerals are under some form of export restrictions, half of which are produced as by-products, limiting the flexibility of their supply and amplifying supply risks (IEA, 2025b).

EU Industrial policies such as the European Critical Raw Materials Act, secure supply chains innovation (extracting, processing, recycling) and set a limit of 65% of EU's annual needs of each strategic raw material at stages of processing coming from a single third country. From the economic efficiency point of view, competition allowing exit and entry and diversification could achieve continuing technological change and cost reduction more effectively than cartelisation of the supply and demand sides. Innovative policy tools can be explored, such as standards and regulations; for example, EU battery passports could support the sustainability of a battery throughout its lifecycle. Innovative market mechanisms are also emerging, such as London Metal Exchange (LME) exploring the potential for producing sustainable metal premia for LME-approved brands. For example, LME aims to monetise positive externalities of critical minerals with 'low-carbon' nickel.

Further research into sustainable exploration, alongside the development of circular economy strategies in key end-use sectors, such as RES and EVs, may also generate substantial national and global returns. R&I and commercialisation of technologies using fewer (or no) critical minerals could also be prioritised. For example, sodium-ion batteries could be explored as a potentially cheaper alternative to lithium iron phosphate (LFP) due to the latter's high cost, uneven geographic distribution, and environmentally damaging extraction process. Sodium-ion cathodes rely on a new supply chain for sodium instead of lithium, which is predominantly sourced from soda ash. Europe is among the major producers, with 20% of global production, driven by Türkiye producing almost 80% of this production from natural soda ash.

Table 3: Policy Recommendations – Critical Materials

Policy recommendation	Potential benefits
Promote research into modern and sustainable exploration, extraction, and use of raw materials in Europe (e.g. sustainable critical minerals and circular economy strategies)	• Generate substantial national and global returns • Lower risk on the currency exchange rate from imports • Improves security of supply[19]
Support R&I and commercialisation of technologies requiring less critical minerals or finding alternatives	• Lower dependence on critical materials • Less market power for agents that possess dominant critical raw materials
Innovation in circular economy and recycling critical minerals	• Improves security of supply[20] • Reduce dependence on materials from abroad
Consider bloc-to-bloc coordination or trade and investment agreement[21]	• Sharing of technical know-how for collaborative competitions that enables access to critical raw materials and innovations[22]
Implement technical and sustainability standards and regulations for critical raw materials value chain	• Improve competitiveness and sustainability of the European industry related to critical raw materials[23]

5. Conclusion

As the EU continues to decarbonise, recent changes in the geopolitical context imply that it will need to adapt the three pillars or 'trilogy' of its policy (industrial strategy, innovation, and critical minerals) to fit the new geopolitical context and ensure an efficient amount and right balance of each among them. To continue with the path of decarbonization, it is necessary to have access to critical materials but also implement efficient and effective R&I to strengthen EU competitiveness. Such access and R&I become more challenging since the global geopolitical changes are reconfiguring historical alliances and redefining new global supply chains.

The implementation of recommended policies in this article must be agile to mitigate the risk of increasing vulnerabilities to geopolitical shocks and/or fragmentations. The implementation inevitably requires political leadership to set a clear, viable and pragmatic roadmap at EU level. Moreover, EU must strive to set new global strategic alliances to guarantee access to critical materials, innovation and capital. A successful policy would strengthen exports of high-value-added technology, which would also improve Europe's economic development and could maintain EU as a global leader of green transition that the other regions could learn and benefit from.

As a next step, we recommend conducting specific studies and estimates to design the details of the policy recommendations into strategic roadmap and action plan.

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Notes

[1] Up to the time of drafting this article as of May 2025.

[2] European Commission (2023) eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023DC0062

[3] Tamba et al. (2022)

[4] IEA (2023)

[5] ACER & CEER (2024).

[6] ACER & CEER (2024).

[7] PXiSE (2024).

[8] Jamasb, Nepal, & Davi-Arderius (2024).

[9] PXiSE (2021); Hledik & Peters (2023); Deloitte (2024); PXiSE (2024); Anaya & Pollitt (2021); Anaya & Pollitt (2022).

[10] Asmus & Kelly (2021); PXiSE (2021).

[11] The Long Duration Energy Storage Council. https://www.ldescouncil.com/

[12] Jamasb, Llorca, Meeus, & Schittekatte (2023)

[13] Ribeiro & Jamasb (2025).

[14] Jamasb (2007).

[15] Jamasb (2007).

[16] Schittekatte, Meeus, Jamasb, & Llorca (2021)

[17] The solutions would need to be within the bounds of ownership and regulation of natural resources within national boundaries.

[18] For example, Brazil produces 98% of the world's active niobium reserve; global cobalt reserves are concentrated in the Democratic Republic of Congo (DRC); Argentina, Bolivia, and Chile, known as the "lithium triangle", together hold half of the world's lithium reserves; Indonesia controls over 20% of the world's nickel reserves; Mozambique controls more than half of the global graphite reserves; Russia has nearly half of global palladium deposits; and China holds reserves of rare earth oxides, and 34% of the world's copper reserves (Foreign Affairs Committee, 2023; Romani, Comincioli, & Vergalli, 2024).

[19] Maisel, Neef, Marscheider-Weidemann, & Nissen (2023)

[20] Lotric, Sekavcnik, Kustrin, & Mori (2021)

[21] European Comission (2024b)

[22] Vivoda (2023)

[23] CEN-CENELEC (2023)