

Geoeconomics of the transition to net-zero energy and industrial systems: A framework for analysis

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ABSTRACT

The unfolding transition to net-zero energy and industrial systems has a major impact on global value chains, the geoeconomic strategies of key players, and rules of engagement in the global economy. This research develops a novel conceptual framework for analyzing the geoeconomics of energy and industrial transformation, while delimiting it from geopolitics. The framework has three basic dimensions: a) resources, technology, and data; b) markets and networks; and c) rules of international economic interaction, which are negotiated by powerful players in the world economy. The discussion emphasizes the dual nature of the geoeconomics of energy and industrial transformation as a balancing act between securing autonomy and projecting geoeconomic influence. This sets it apart and makes it incompatible with more overt forms of geopolitical confrontation as witnessed between NATO countries and Russia. A transition to net-zero energy and industrial systems, the analysis concludes, hinges on the cooperation among countries and economic blocs. Managing this dilemma – competing to build an advantageous geoeconomic position while cooperating to ensure the broad participation of actors around the world – lies at the center of the geoeconomics of the transition to net-zero and is indispensable for advancing the United Nations' Sustainable Development Goal 7 (affordable and clean energy) and Sustainable Development Goal 13 (climate action) in ways that benefit a wider range of countries and not merely the most industrialized nations.

1. Introduction

The rise of China as a counterweight to the dominance of the US and its Western allies has placed geopolitics back on the global agenda. This geopolitical rivalry is leading to a fracturing of global institutions, like the World Trade Organization, which is seeing itself increasingly undermined by protectionist measures. This has been further exacerbated by the full-scale invasion of Ukraine by Russia in 2022. It not only represents an open – if not direct - confrontation between NATO countries and Russia, but it has further exposed the waning power of Western allies within the international system, as China and a number of countries from the Global South have chosen to remain neutral or even tacitly support Russia's unlawful annexation of Ukrainian territories.

The growing prominence of geopolitics in the face of the weakening liberal international order coincides with the looming climate crisis and the imperative to achieve net-zero emissions, which are increasingly

informing government and business strategies. By July 2024, some 150 countries collectively responsible for 88 % of the global emissions had proposed or adopted net-zero targets [1]. Oil and gas companies are diversifying their portfolios [2,3,4], and international financial institutions are increasingly reluctant to finance fossil fuels. In 2023, the share of renewable energy in global electricity production reached 30 % [5], and investment in clean energy technologies and infrastructure was nearly double the investment in fossil fuels [6].

Against this background, the geopoliticization of international relations is at odds with the collective action needed to accelerate decarbonization efforts, as exemplified by the international climate change negotiations under the UN Framework Convention on Climate Change (UNFCCC) and the related Sustainable Development Goals (SDGs): SDG 7 (Clean and Affordable Energy for All) and SDG 13 (Climate Action). At the same time, elements of the transition to net-zero energy and industrial systems may offer synergies with geopolitical goals, such as the greater degree of autonomy and resilience promised by harnessing

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List of abbreviations

AI	Artificial intelligence
CBAM	Carbon border adjustment mechanism
CCS	Carbon capture and storage
CCUS	Carbon capture, utilization and storage
ETS	Emission trading scheme
EU	European Union
GASSA	Global Arrangement on Sustainable Steel and Aluminum
GHG	Greenhouse gas
GPN	Global production networks
IR	International relations
IRENA	International Renewable Energy Agency
NATO	North Atlantic Treaty Organization
NZIA	Net-Zero Industry Act
OECD	Organization for Economic Cooperation and Development
OPEC	Organization of the Petroleum Exporting Countries
R&D	Research and development
SDG	Sustainable Development Goals
UNFCCC	United Nations Framework Convention on Climate Change
US	United States

domestic renewable energy potential rather than relying on fossil fuel imports. Moreover, technology leadership in the cleantech sector is increasingly perceived as an important source of strategic advantage, with leading economies vying for this status [7]. However, there remains a significant diversity among national strategies – especially as regards the contested role of nuclear energy, natural gas, or carbon capture, utilization and storage (CCUS) technologies. Ultimately, national economies seek to capitalize on their existing competitive advantages in the framework of the transition to net-zero.

This work develops a novel conceptual framework for better understanding the parallel trends of geopoliticization and decarbonization and how they interact. It frames the transition to net-zero as a process that is primarily subject to *geo-economic* competition, contrasting this to the more overt nature of geopolitical confrontation. The analysis begins by disentangling the oft-overlapping concepts of geopolitics and geo-economics in pursuit of greater theoretical clarity. The next step is the development of an analytical framework for the *geo-economics* of the transition to net-zero energy and industrial systems. This places a special emphasis on the emerging transition process, instead of focusing primarily on likely outcomes within a future net-zero world, a focus of much of the existing literature. The framework is applied to provide a structured review of the key elements of geo-economic competition within the unfolding transition to net-zero, followed by a discussion of potential trade-offs. The article's findings are summarized in the conclusion.

2. From geopolitics to geo-economics

2.1. Geopolitics and the role of energy

Classical geopolitics accords central importance to geographic factors – including location, territory, resource endowment, and population – to the ways in which nation states exercise and project power. According to one definition, geopolitics is “the influence of geography on the power of states and international affairs, emphasizing the strategic importance of natural resources, their location, and transportation routes” [8, p. 4]. The geopolitical analysis of (fossil) energy conceptualizes such geographic factors as “the distribution of centres of supply

and demand” and highlights their role in influencing “state and non-state actions to ensure adequate, affordable and reliable supply of energy.” [9] The traditional geopolitics of energy thus includes the ability to wield power through control of energy resources and transit routes to coerce other actors [10]. It is often buttressed by military power and security arrangements with a territorial dimension [11,12].

The unfolding global energy transition is challenging the dominant role of hydrocarbons – and therefore, of fossil fuel exporters - by putting an emphasis on renewable energy, which, unlike oil and gas, can be harnessed in any country. The geopolitical ramifications of this process have been the focus of a rapidly growing body of research (e.g. [13,14, 15,16]), largely focusing on the future decarbonized world of 2050 or beyond. This literature tends to describe renewable energy as more conducive to international security and peace compared to fossil fuels [17,18], albeit with the important exceptions related to the competition over critical raw materials [19,20,21,22], as well as cybersecurity risks. More recent studies have painted a more nuanced picture [23], for instance, with regard to renewable energy technology trade conflicts [24]. Herranz-Surrallés discusses an emerging process of *geopoliticization*, where the “energy transition is seen through the lenses of international hierarchies and global-power rivalries” [25, p. 1891]. The complex dynamics of the ongoing transition are also analyzed by Blondeel et al. [26], who specifically focus on energy system transformation as a twofold process, combining ‘high-carbon’ energy transitions (i.e. phasing out hydrocarbon consumption) and ‘low-carbon’ energy transitions (deployment of renewable energy and other low-carbon technologies). This points to the growing importance of net-zero technologies and industries in the global economy, increasingly subject to competition among major powers for leadership in this area [7,27].

2.2. The rise of geo-economics

Despite this growing attention to the geopolitical and geo-economic dimensions of the energy transition, there has been little theoretical discussion of how the concepts differ in their relationship to the unfolding transition. While the concept of geopolitics emerged in the first part of the 20th century, followed by discussions of energy as an arena and tool of geopolitics at the turn of the century [28,29], the term *geo-economics* was coined by Luttwak in 1990 following the end of the Cold War. The growing interconnectedness of the global economy had led to a rise of interest in states’ use of economic tools (rather than ideology and military power) for geostrategic purposes. Despite this shift, Luttwak argued, the adversarial and zero-sum type of thinking in international relations remained unchanged [30]. Today, the far-reaching impact of global value chains, the deepening integration of trade links and financial markets (which amplifies the impact of economic tools) and the emergence of China with its active use of state-owned enterprises for geostrategic purposes [31] explain the sustained interest in *geo-economics* [32].

Yet what is understood under “*geo-economics*” remains contested [33]. Wigell [34] defines *geo-economics* as “the geostrategic use of political power by economic means”, whereas Blackwill and Harris [35] speak of “the use of economic instruments to promote and defend national interests and to produce beneficial geopolitical results; and the effects of other nations’ economic actions on a country’s geopolitical goals.” Grevi argues that *geo-economics* “encompasses both the conversion of economic assets into political influence and the mobilisation of political power to achieve economic goals through a mix of competition and cooperation” [36, p. 28]. Moraes and Wigell emphasize the centrality of the pursuit of autonomy in *geo-economic* strategies, either by “trying to enforce dependencies on others” or by reducing one’s own dependencies [37]. The search for autonomy has been reinforced by the growing salience of the security risks of connectivity and interdependence (by contrast, liberal internationalism considers greater interconnectedness as a factor contributing to peace).

Diesen discusses the concept of “asymmetric dependence,” which

makes it possible for the “more powerful and less dependent state to set favorable conditions for economic cooperation and to extract political concessions from the more dependent state” [38, p. 568]. In a similar vein, Farrell and Newman [39] speak of “weaponized interdependence.” They demonstrate that complex systems tend to produce “asymmetric network structures”, where some nodes (e.g. powerful states) function as hubs and boast many more connections than others. This position enables them to “weaponize” interdependence, i.e. use their privileged status to coerce others. Control over important hubs allows states to leverage network interdependencies and impose costs on others.

2.3. Distinguishing between geopolitics and geoeconomics

The boundaries between geopolitics and geoeconomics are often blurred, which complicates their conceptual delineation. Both focus on nation states and their actions to project power beyond their borders. Since political power and economic power are intimately tied, geopolitical considerations often result in the deployment of typical geoeconomic instruments, such as sanctions or investment controls. Coelho Jaeger and Pereira Brites [40] argue that geoeconomics is merely a subset of classical geopolitics as applied to “international economic relations.” By contrast, Blackwill and Harris [41] draw the following distinction: geopolitics is “about how a state exercises power over territory”, whereas geoeconomics explains “how a state builds and exercises power by reference to economic factors rather than geographic ones.” In turn, Wigell and Vihma contrast the operational logics of geopolitical and geoeconomic power projections - “confrontation” versus “selective accommodation” – and emphasize that they provoke different counter-reactions on the recipients’ side [42, p. 605].

This work argues that unlike geopolitics, which is more concerned with actively projecting power, geoeconomics has a more dual nature. On the one hand, it can be inward-oriented, focusing on increasing the resilience of one’s own economy in the global competition, reducing reliance on imports, protecting jobs at home, and containing external influence within the domestic economy (i.e. reducing one’s asymmetrical dependency on others). At the same time, it also involves building geoeconomic power by shaping the global economic system or other national or regional economies in order to exert influence over strategic elements of relevant markets and networks. This includes, for instance, activities aimed at positioning domestic industrial clusters as important hubs within global production networks (i.e. increasing others’ strategic dependency on oneself) [43]. An important nuance is that excessively assertive demonstrations of geoeconomic power – e.g. in the attempts to leverage or “weaponize” interdependence to gain strategic advantage – can be counterproductive, leading the recipients to invest resources and effort in seeking greater independence (similarly to what Roberts et al. [44] call a ‘use-it-and-lose-it’ quality of interdependence). Finding the right balance between autonomy and connectedness is thus a delicate act.

Drawing on the existing literature ([42]), seven dimensions for distinguishing geopolitics from geoeconomics can be identified (see Table 1): nature of competition; main arenas for wielding power; dominant forms of power; dominant mode of wielding power; main sources of power; channels for exerting and maintaining power; and the role of natural resources and physical infrastructure. The caveat is that reflecting the complex nature of interstate relations, this delineation can never be fully clear-cut. Governments can and often do combine geopolitical and geoeconomic logics and strategies; the table thus may be viewed as an attempt to identify the opposite ends of the spectrum of geostrategic action.

While both geopolitics and geoeconomics may influence a country’s foreign economic policy simultaneously, their focal points are different. The geopolitical approach is predicated on the use of hard economic power and is grounded in coercion – with the result that it heightens threat perception in the object of geopolitical action [42]. Geoeconomic action, on the contrary, takes place on a wider spectrum and may

Table 1
Differences between geopolitics and geoeconomics.

Dimension	Geopolitics	Geoeconomics
Nature of competition	Political	Economic
Main arena for wielding power	Global political system and related security/territorial regime	Interdependent, global economic system and related regulatory regime
Dominant forms of power	Military power, hard economic power (“sticks”), political power (ideology)	A spectrum of economic power from hard to soft; from “sticks” (sanctions) to “carrots” (soft economic power in the form of preferential trade and investment agreements and the like), market power, regulatory power
Dominant mode of wielding power	Coercion	Cooptation and selective accommodation
Main sources of power	Leadership in military-industrial complex	Industrial and technology leadership
Channels for exerting and maintaining power	Control over physical infrastructure and natural resources, including land/territory, promotion of political ideology	Influence and control over markets, networks and tangible and intangible flows in the economy
Role of natural resources and physical infrastructure	Control over and access to natural resources and related infrastructure is secured politically and militarily and represents a source of conflict	Access to natural resources and influence over their flows is secured through mutually beneficial yet potentially asymmetrical economic relationships and represents the basis for securing economic power

involve both negative and positive inducements. The former may range from sanctions to investment or export controls, while the latter may include investment agreements, industrial and technology cooperation, development finance, multilateral institution-building, and regulatory diplomacy.

Drawing on this delineation, this work defines geoeconomics as the field of study concerned with the engagement of governments in exerting influence – or building the capacities to do so - by shaping international markets, trade flows and related global production networks (see Wigell [34] for a similar conceptualization). Geoeconomics involves active competition between states or groups of states aimed at securing a dominant (i.e. influential) and at the same time resilient position within an interdependent global economic system. This involves promoting institutions and structures that favor domestic technology and industrial leadership, while avoiding or minimizing asymmetric dependencies and vulnerabilities.

Even though the boundary between geopolitics and geoeconomics is fluid, the transition to net-zero energy and industrial systems operates within an arena that is characterized primarily by geoeconomic competition rather than by the classic geopolitical competition. As physical resources lose in relative importance, the importance of securing trade routes and maintaining strategic security alliances with exporters of energy commodities does not feature prominently in the transition to net-zero. Instead, this transition is characterized by a large degree of uncertainty regarding a future carbon-neutral energy system. Hence, in the current phase of transition, competition between major economic powers is centered on defining the future trajectory of energy system development while securing technological and industrial leadership. State intervention is not primarily required for projecting political power but for the purpose of providing coordination and guidance and for reducing uncertainty and risk. Analytically, this has to be separated from a broader trend of increased geopolitical rivalry and open conflict between the major powers, as evidenced by Russia’s full-scale invasion of Ukraine and its weaponization of energy resources in its confrontation with the West.

3. An analytical framework for the geoeconomics of the transition to net-zero

Having distinguished classical geopolitics from geoeconomics, the following section proposes and then applies an analytical framework to help illustrate the nature of competition within the transition to net-zero. This builds and expands on an emerging discussion on the *sources* of geoeconomic power. Blackwill and Harris refer to geoeconomic “endowments” [45, pp. 87–91], while Diesen speaks of “levers” of geoeconomic power [46, p. 569]. The former encompass the ability to control outbound investment; domestic market features in terms of size, control and asymmetries vis-à-vis rivals; and influence of commodity and resource flows. The latter include control over strategic industries, transportation corridors and mechanisms for economic cooperation. Neither provides a clearly defined rationale for singling out these specific aspects of geoeconomic power, nor do they conceptualize how they differ in nature.

In order to frame the following discussion of the geoeconomics of the transition to net-zero energy and industrial systems, this paper provides an overview of those elements of geoeconomic power that are of particular importance within the transition process. Moreover, it adds an additional conceptual layer by clarifying the differing nature of each element. We distinguish between three interconnected dimensions of geoeconomic power (see Fig. 1):

- Resources, technology, and data
- Markets and networks
- Rules of international economic interaction.

Resources, technology and data represent the basis for economic value creation, and, hence, control over these resources represents the most basic form of geoeconomic power. In the context of the net-zero transition, shifts in geoeconomic power are linked to the changing role of energy-related natural resources and technology as a result of decarbonization processes. It also includes data related to the functioning of a changing energy and industrial system as well as the impacts of (old and new) technologies on greenhouse gas emissions (GHG). Secondly, markets and networks – the main emphasis in the approaches presented by both Diesen and Blackwill & Harris - represent the key arenas in which these different types of resources are produced and exchanged. They include both tangible and intangible networks that connect economic actors and facilitate economic exchanges in the economy. Influence over markets and networks provides leverage points for exerting geoeconomic power by, in the latter case, enabling or constraining access to resources, technologies and data, and, in the former, by providing access to opportunities for economic value

creation. Like the resources themselves, these elements of the energy and industrial system are subject to processes of change and renewal, which may facilitate shifts in geoeconomic power. Finally, the transition to a net-zero energy and industrial system offers a window of opportunity for governments to influence the development of the aforementioned elements through various instruments. Most notably, by shaping new rules of international economic interaction (or, slightly more narrowly, economic cooperation) governments can shape the changing terms of economic exchanges within an emerging net-zero energy and industrial system. Such rules determine which products and services are accepted by the market based on their impacts on CO₂ emissions and other sustainability-related dimensions. They include a wide array of governance mechanisms and regulatory interventions, ranging from climate clubs [47], measures to prevent carbon leakage, sustainable finance taxonomies, product standards, certification procedures, and life cycle assessment methodologies for calculating the CO₂ footprint [33, p. 97]. While other economic instruments, most notably control over finance and investment, may represent formidable tools for exerting geoeconomic influence, including in the development of net-zero technologies and infrastructure, they are not unique to the transition to a net-zero economy, and they are not changing as a result of it and are not considered here. The following subsections provide a more detailed explanation of each dimension highlighted.

3.1. Resources, technology and data

One major implication of the transition to net-zero is the transition from fossil to renewable energy resources. With this comes the relative decline in the role of natural resources vis-à-vis technology. The existing literature has hypothesized that the declining role of fossil fuels not only reduces the power of those countries that control these resources, but is also likely to reduce the degree of conflict over them [13]. While this may appear plausible in the long-run, more recent developments, such as the energy price shocks in the wake of Russia’s 2022 invasion of Ukraine, indicate that during the transition period - as investments in fossil resources decline - those with control over fossil resources may temporarily even gain a degree of leverage and may weaponize their resource endowments.

Nevertheless, over time, fossil resources will decline in importance, shifting influence to those who control climate-friendly technologies. This implies not only a shift in the locus of geoeconomic power; it also reduces the ability for wielding geoeconomic power. While interruptions in the *flow* of energy resources may cause immediate and severe interruptions of energy supply, the control over energy technologies will only gradually affect the *stock* of installed generation capacity and offers affected countries a chance to adapt by ramping-up manufacturing

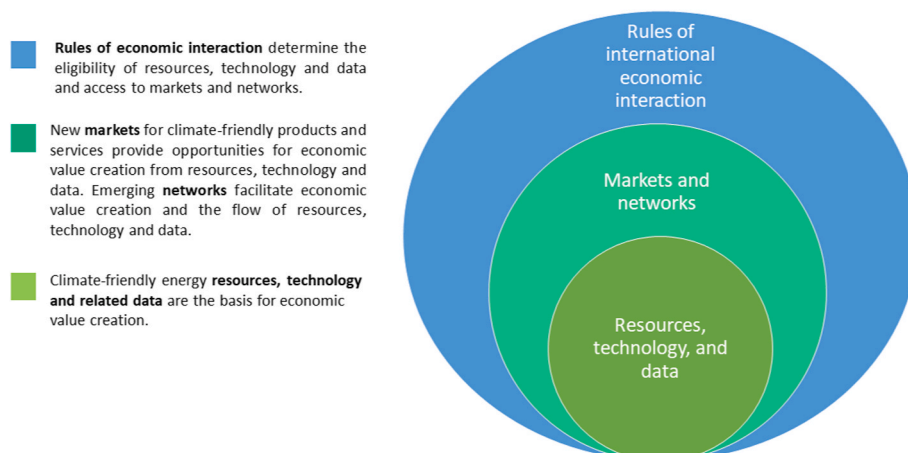


Fig. 1. Analytical framework for the geoeconomics of net-zero energy and industrial transformation.

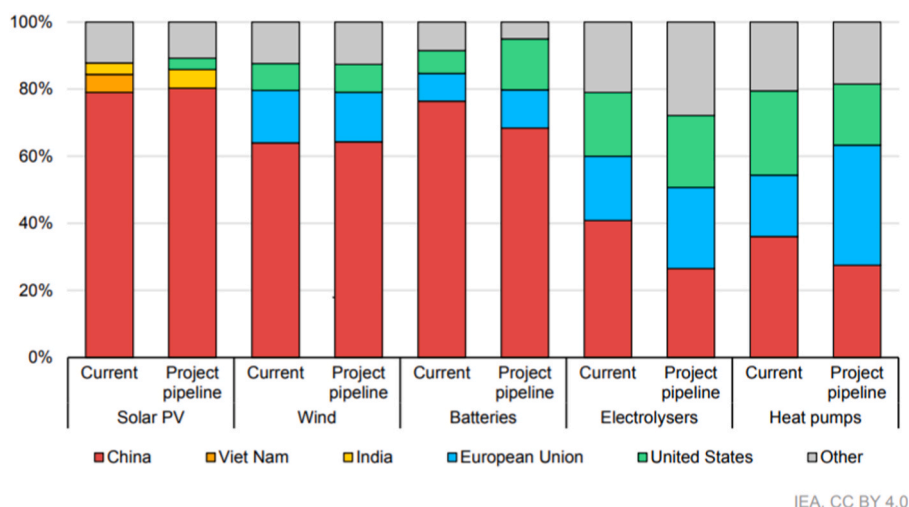
capacity. Nevertheless, as hypothesized by Bazilian et al. in their Tech Breakthrough scenario of the energy transition [48], the cleantech sector represents a “source of economic power” and is giving rise to strategic trade policies and protectionist measures. The emerging clean subsidy race between the US, China and the EU is a case in point. The growing role that China now plays in many areas of clean technology, like solar and wind energy and batteries and electric vehicles (see Fig. 2), shows that the transition to these technologies can also represent a window of opportunity for emerging economies to gain geoeconomic influence [49]. This relative weakening of Western power has been met by increasing efforts by the US and Europe to reassert themselves in these clean energy supply chains. In the US, the Inflation Reduction Act (2022) has introduced large-scale tax breaks to promote the domestic deployment and manufacturing of clean technologies. By also tying them to local manufacturing requirements, this has raised important concerns in the EU [50]. In 2024, the EU responded by adopting the Net-Zero Industry Act (NZIA), with the express goal of scaling up European cleantech manufacturing capacity and increasing the recycling rates for critical minerals [51].

However, competition in the transition to net-zero is not only about control over domestic and international technology supply but also about the demand for specific technologies in the transition to net-zero. Countries are seeking to promote and legitimize technology options and decarbonization pathways internationally that suit their domestic preferences and capacities by developing related narratives and building alliances [52,53]. Germany and Japan, both renewable energy-scarce economies that are keen on decarbonizing their large, energy-intensive industrial sectors, are strongly promoting the development of an international hydrogen economy where this energy carrier is traded internationally via pipelines and ships. For this, the countries are building international partnerships and promoting multilateral cooperation to catalyze the needed investments in knowledge and infrastructure [54]. France, which traditionally has strong competencies in nuclear energy, has succeeded in pushing for nuclear power’s inclusion into the EU’s sustainable financing taxonomy, allying with several other EU Member States in this effort [55]. France also made sure that nuclear is identified as a strategic technology in the EU’s Net-Zero Industry Act.

Meanwhile, hydrocarbon-rich countries have all put a special

emphasis on CCS/CCUS. Norway, for instance, has invested large amounts of funding into research into CCS technologies and has engaged strongly with its European neighbors to promote the capturing of CO₂ from industrial sources and transporting it for offshore subsea storage in the North Sea [56]. Saudi Arabia and its national oil company Aramco have been promoting the concept of a “circular carbon economy” [57]. CCUS also plays into competition between different options for the production of hydrogen. Indeed, the promotion of a hydrogen economy to decarbonize hard-to-abate sectors in industrialized countries has provided an entry-point for a recent renaissance of the technology. The production of hydrogen from natural gas using CCS technology – labeled as blue hydrogen – has garnered the interest of both potential producers and consumers of hydrogen, providing new space for mutually beneficial cooperation [54]. Especially for the highly hydrocarbon rent-dependent Gulf Cooperation Council states, producing and exporting blue hydrogen or blue ammonia would offer another way to monetize their fossil fuel resources, draw on existing technical competencies, avoid turning the existing infrastructure into stranded assets, and use existing trade routes. It would thus help them safeguard, at least partly, their hydrocarbon-reliant export model [58]. For countries like Germany, which is scarce in both renewable and fossil energy resources, blue hydrogen offers the prospect of a technology to preserve its energy-intensive industrial assets, framing it as a transitional solution on the way to a renewable-based economy [59].

As these hydrogen-related developments indicate, despite the eventual decline in importance of fossil resources, securing access to energy resources (and capitalizing on the resources available) remains an element of competition, although its dynamics are changing in nature. While all countries have renewable energy potential, large energy-intensive industry and green hydrogen producers require access to the best renewables-rich sites to decarbonize. As a result, the quality of the renewable resource endowment represents an important factor. However, due to their distribution across a much larger number of localities, rents will be significantly lower than for fossil fuel resources, and the ability of well-endowed countries to leverage this for economic gain will be lower. Nevertheless, in the transition period, leading industrialized countries who seek to promote an ambitious transition to net-zero – in particular those building on the vision of international green hydrogen trade – will have to convince potential supplier countries of the benefits



Notes: PV = photovoltaic. Wind refers to onshore wind nacelles in this analysis. For electrolysers, the analysis only includes projects for which location data was available. Shares are based on manufacturing capacity. ‘Current’ refers to installed capacity data for 2022 and Q1 2023 where available. ‘Project pipeline’ refers to the sum of current installed capacity and all announced manufacturing capacity additions (as of end-Q1 2023) through to 2030. ‘Other’ refers to the aggregate of all capacity besides that of the top three countries/regions for each technology and timeframe.

Fig. 2. Geographic concentration for manufacturing operations for key clean technologies.

Source: IEA (2023). The State of Clean Technology Manufacturing: An Energy Technology Perspectives Special Briefing, p. 14. <https://www.iea.org/reports/the-state-of-clean-technology-manufacturing>.

of investing in their net-zero vision. This not only involves the development of a coherent narrative and continuous trust-building efforts, but also requires the provision of tangible financial resources and tools to mitigate the risks within an uncertain process of socio-technical change [60].

Finally, despite the declining role of resources overall, critical minerals play a prominent role in the transition to net-zero. Emerging economies rich in critical minerals are beginning to devise geoeconomic strategies by applying export controls (as Indonesia did for nickel or Zimbabwe and Namibia for raw lithium), requiring more processing and value added to be generated domestically, increasing state control of key mining sectors, or considering OPEC-style cartel formation [61]. Moreover, China has developed a strong position in the global market for critical minerals, having established itself as a major buyer and processor of minerals (see Fig. 3), on the one hand, and leading exporter of processed minerals, on the other [62]. In the case of a number of so-called rare earths that are mined in China itself, its dominance is even greater. In 2010, China gained notoriety for weaponizing its privileged position in rare earths supply chains and abruptly reduced exports globally by 40 %, causing a major price hike [63]. With some delay, this is now leading to major efforts by the US and Europe to reduce their dependence on Chinese rare earths and other minerals, as exemplified by the US Department of Energy’s Critical Minerals and Materials Strategy (2021) and the EU’s Critical Raw Materials Act (2023).

With the growing risk that other producing countries may also attempt to flex their geoeconomic muscle on critical materials supply, there have been intensified efforts at finding substitutes or reducing the content of selected materials in key green technologies, such as cobalt in batteries [61]. Technological innovation may thus play a decisive role in defusing the risks of geopolitical confrontation over access to critical materials [64]. Especially the EU is investing in R&D on finding substitutes for such materials and promoting recycling. Circular economy is an oft-overlooked aspect in the theoretical discussions on the geoeconomics of the net-zero transition. It cuts down on the use of virgin materials, creates local jobs, and reduces one’s dependence on imports [65]. For instance, recycling electric car batteries would allow car-makers to satisfy a large part of their demand for critical materials without imports. The EU has acknowledged the importance of circular economy development for meeting its net-zero target as well, as circular approaches and greater material efficiency can deliver up significant reductions in GHG emissions. In the buildings sector, for instance, these savings up can potentially reach up to 80 % [66].

Finally, as a result of digitalization, data has emerged as a new type of resource, which continues to increase in value and has a growing

security dimension. This trend is also manifesting itself within the transition to net-zero. Firstly, digitalization represents an important enabler of decarbonization, leading to the growing importance of data within the energy and industrial system. Smart grids, for instance, are essential for harnessing distributed renewable energy more efficiently. As a result of sector coupling, fluctuating energy supply, and demand flexibility, renewables-based energy systems are far more complex to manage than conventional fossil-based systems, requiring much larger amounts of data and the use of Artificial Intelligence (AI). This, again, gives leverage to Big Tech companies seeking to control or even monopolize the digital infrastructure needed for the energy transition [67].

Reliable data on carbon emissions and other sustainability-related impacts will represent a key to success in a net-zero industrial system. For instance, the development of a circular economy is not possible without pooling and sharing data from multiple business actors along the value chain [68]. Without credible data on the sustainability performance of technologies and production processes, firms will be increasingly uncompetitive. Investors and regulators will require emissions data to make investment decisions and grant market access to products and services, respectively. Actors who are able to provide such data will gain in importance. Similarly, enabling technologies for collecting and managing such data, like remote sensing technologies for measuring methane emissions in the gas sector or digital passports for tracking sustainability-related data along the value chain, will play a key role within the transition to net-zero. Approaches like the EU’s Sustainable Batteries Directive or its Sustainable Products Initiative provide first examples of this trend. With their growing economic significance, data and data technologies will also take on geoeconomic relevance. Not only access to the data but defining and controlling how data is collected and analyzed and whose data is considered trustworthy provide entry-points for geoeconomic competition. This in turn is closely related to competition in setting the rules of economic interaction, discussed in more detail below.

3.2. Markets and networks

To facilitate the transitions in technologies and resources outlined in the previous section, markets and networks will also have to undergo significant changes. Markets have to be created or adapted to allow clean technologies to mature and eventually compete with incumbent technologies. Similarly, tangible and intangible networks have to develop – among firms, governments and other stakeholders - to allow new markets and industries to emerge and flourish.

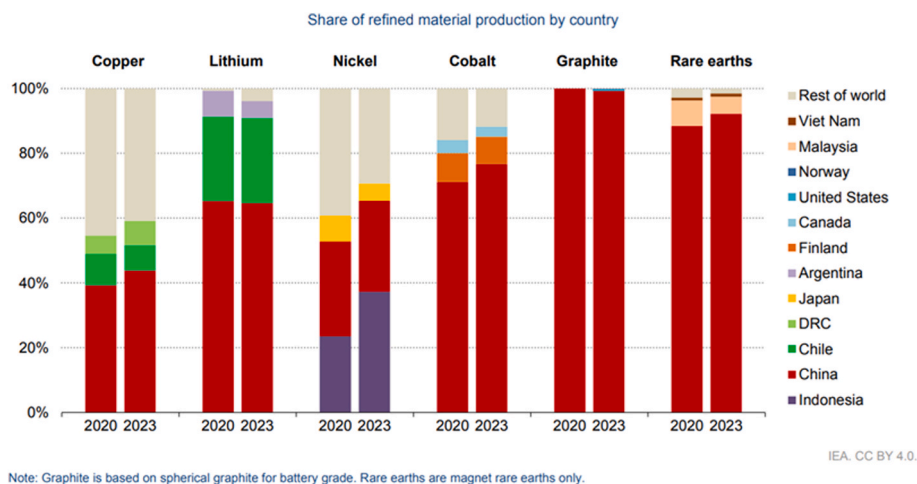


Fig. 3. Critical minerals for the energy transition: share of refined material production by country. Source: IEA (2024). Global Critical Minerals Outlook 2024, p. 42. <https://iea.blob.core.windows.net/assets/ee01701d-1d5c-4ba8-9df6-abeaac9de99a/GlobalCriticalMineralsOutlook2024.pdf>

The creation of new markets as well as adaptation of existing market systems to the needs of a climate-friendly economic model offer central entry-points - and pitfalls - for geoeconomic competition, as governments manage and accelerate the transition to net-zero. Given their prominent role in shaping this new market environment, governments have the opportunity to strengthen the position of their domestic industry as market leaders. However, these opportunities come with limits and trade-offs. Firstly, only those governments with influence over major world markets, most prominently the EU, China and the US, can expect to wield substantial power via their interventions in these markets. Secondly, while governments may gain in geoeconomic power if they position their domestic industries as market leaders, they run the risk of betting on the wrong horse. In this case, they may spend financial and political resources on promoting solutions that prove ineffective or uncompetitive. Hence, frontrunner countries need to both carefully consider competing technology options and devise strategies to internationalize the markets they seek to lead. Germany's international promotion of renewable energy technologies, as epitomized by its successful effort to create the International Renewable Energy Agency (IRENA), is emblematic of such an approach [69]. The country's current efforts to promote an international hydrogen economy is another case in point [59]. Thirdly, even the successful development of so-called "lead markets" does not guarantee industrial leadership, as the experience in the solar photovoltaics sector has demonstrated [70]. Both Japan and Germany invested heavily in the development of early market demand, yet China has emerged as the uncontested leader in the manufacturing of solar panels [71]. As a result, governments have become increasingly concerned that investments in market creation translate into domestic industrial success, leading to more protectionist approaches to green industrial policy. However, an overly protectionist approach to market development may result in a loss of influence over external actors, as they lose their stakes in the process. It may also result in the loss of international competitiveness and raise the cost of the transition to domestic actors, with possible knock-on effects in other industries. Finally, recent efforts to decarbonize energy-intensive industry, most notably the steel sector, are revealing new challenges for successful lead market development. While international competition has been fierce in the sphere of renewable energy technologies and their industrial-scale production, competition between renewable and fossil-based power generation takes place on domestic power markets largely under the regulatory control of national governments. In the case of energy-intensive commodities like steel, decarbonized products are exposed to international competition from both conventional and decarbonized commodities.

To maneuver this landscape, government actors are experimenting with a mix of policies and incentives at different levels of governance. In addition to domestic interventions to catalyze investment in climate-friendly technologies and industrial production, these increasingly include trade policy measures supported by diplomatic efforts to bring international partners on board. Based on its liberal approach, the EU has long promoted carbon pricing in the form of the EU emissions trading system (EU ETS) as a central, market-based vehicle for reducing greenhouse gas emissions. To counterbalance the risk of deindustrialization, the EU has complemented the ETS with the carbon border adjustment mechanism (CBAM), which will, from 2026 onward, gradually impose the EU's internal carbon price on a range of imported industrial goods. While unilateral in nature, the CBAM is complemented by a number of multilateral initiatives to promote the EU's regulatory regime [72]. A case in point is the German- and Chilean-led climate club launched in 2023 with the aim of providing technical and financial assistance to developing countries in decarbonizing their hard-to-abate sectors. For its part, the US under the Biden Administration proposed the so-called Global Arrangement on Sustainable Steel and Aluminum (GASSA) to create a managed market for decarbonized steel and aluminum products among OECD countries, explicitly excluding China as a partner [73]. These two initiatives exemplify the emerging

dynamics of geoeconomic competition between the major economic blocs vying for influence in a future net-zero economy.

While markets represent the arena where market exchanges take place, both political processes and economic value creation are underpinned by different types networks and alliances. In the economic realm, so-called global value chains or production networks (GPNs) have been used as "explanatory frameworks for understanding the global market engagement of firms, regions and nations" to analyze "geographical patterns of value creation, retention and capture in the global economy" [74]. Originally, this literature did not have a strong focus on the state, since managing supply chains was traditionally the domain of large corporations, while the state merely set the context for the actions of firms. Yet over time, research on GPNs has increasingly occupied itself with the role of state institutions [74]. Being increasingly aware of the destructive impact of supply chain disruptions as witnessed during the Covid-19 pandemic, and of the growing prominence of geopolitical risks, governments are seeking to raise the resilience of supply chains in critical areas, often with a special focus on prioritizing domestic networks. In this vein, governments are increasingly supporting the development of industrial alliances and networks [75,76]. Publicly-supported networks like the European Clean Hydrogen and Battery Alliances serve as platforms for coordination among private sectors actors as well as between government and industry [77]. The latter plays an important role in the process of allocating public finance. Supplier diversification is another important task, relevant both with regard to present and future energy imports, as well as for the supplies of critical raw materials needed for cleantech manufacturing.

This is complemented by the development of international networks and alliances to promote alignment of visions and regulatory regimes governing markets and their underlying supply chains. Germany, which plans to import large amounts of clean hydrogen to decarbonize its energy-intensive industry, has engaged in an active global outreach to develop a wide network of potential suppliers and partners in the hydrogen sector (see Fig. 4).

Western-led initiatives compete with initiatives led by not only by China with its well-established Belt and Road Initiative [78] but also by other major emerging economies. The International Solar Alliance, initiated by the Indian government in partnership with France, has been launched to promote financing of solar energy installations in the Global South and to position India as a leader in the sector [79]. While China's Belt and Road Initiative is not primarily driven by climate and energy policy concerns, it has seen an expansion of related issues over time, seeking to position China as the epicenter of global political and economic networks in this field as well [80].

Finally, network infrastructure in the form of oil and gas pipelines and maritime shipping routes has played a central role in the geopolitics of conventional energy [81,82,83,84]. Guaranteeing the security of these corridors – as well as of undersea power (and data) cables - remains one of the central spheres of hard power projection in international affairs. The transition to net-zero will not make this type of international infrastructure for trade in energy resources obsolete. However, in the current phase of the transition, the central question is what kind of network infrastructure will be needed and how to develop and adapt existing infrastructure under conditions of uncertainty. As the transition to net-zero unfolds, government intervention to mitigate the resulting investment risks is taking on a central role, both for the conversion of existing infrastructure and for the roll-out of completely new infrastructure, such as charging systems for electric vehicles. Governments also need to help create infrastructure for clean energy flows where no market exists yet – such as hydrogen and its derivatives.

Systemic infrastructure is thus used as a technopolitical sphere of influence to project political power and authority [85]. Acknowledging this, China's Belt and Road Initiative and the EU's Global Gateway represent efforts to influence and shape infrastructure systems internationally, both for traditional and clean technologies [86] and thereby to project geoeconomic power.

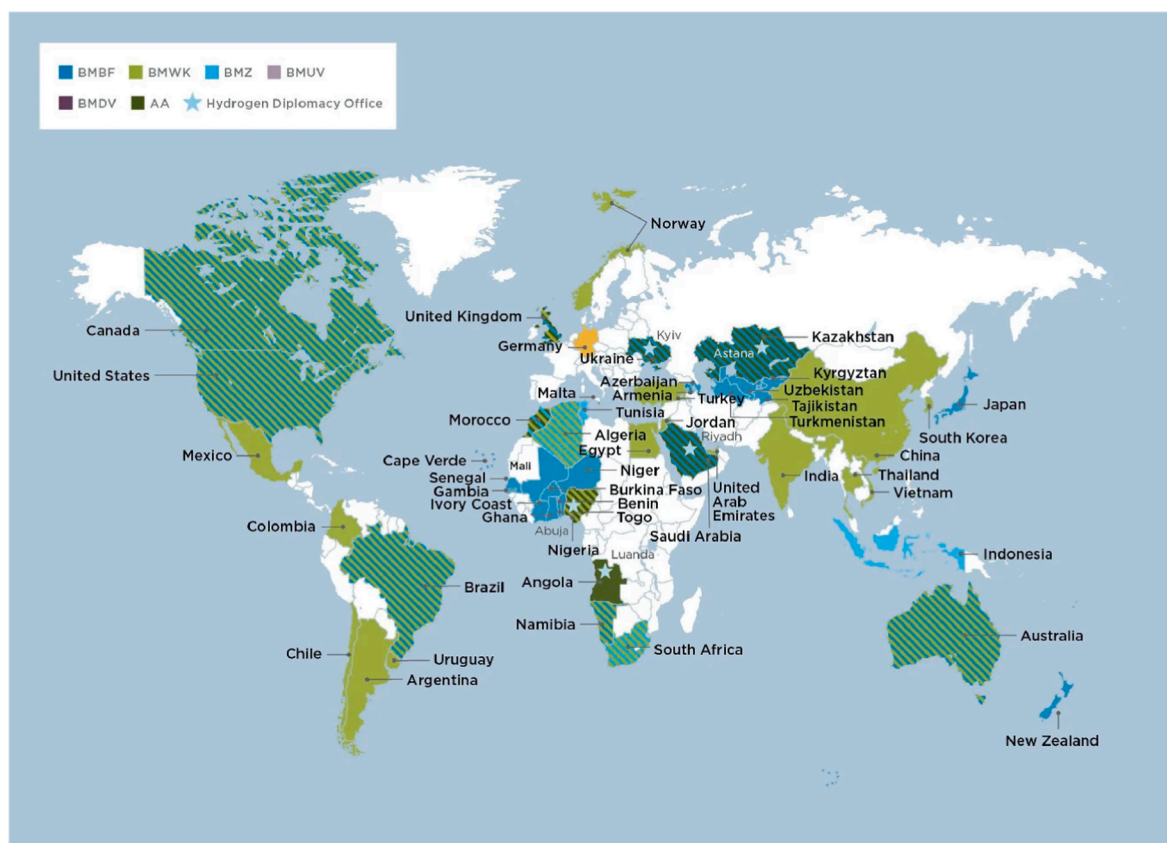


Fig. 4. German federal ministries' international engagement on hydrogen.
Source: Authors' own, based on official government sources (Status: April 2024)

3.3. Rules of international economic interaction

Finally, as an overarching dimension, the far-reaching changes in the global economy spurred by the transition to net-zero require the development of new rules of economic interaction, which integrate climate-based requirements. Climate and sustainability have emerged as the most prominent focal area of global energy governance, which has traditionally also encompassed such areas as security of energy supply and demand, economic development, international security, and domestic good governance [87]. The European Union in particular has positioned itself as a global climate champion [88]. This has been accompanied by the emergence of new institutions active in the area of the global energy transition, such as, for example, the International Renewable Energy Agency (IRENA) in 2009. Similarly, the promotion of an international hydrogen economy is giving rise to a growing set of multilateral institutions [89].

The new rules of the game are set by frontrunner states and powerful economic blocs, which seek to shape these rules to their geostrategic advantage. Regulations and standards have always functioned as so-called non-tariff barriers to trade and have constituted important points of conflict in the negotiation of international agreements on trade and investment, such as the failed Transatlantic Trade and Investment Agreement between the US and Europe. Scholars have long identified the standard-setting power of the EU as one of its central levers of geoeconomic power [90,91]. With the transition to net-zero, regulations and standards related to carbon footprints and other sustainability-related dimensions [92] represent the institutional underpinnings of all the other aforementioned categories. They are required for promoting new technologies and markets and for steering the phase-out of incumbent technologies. The regulatory environment and the underlying standards will determine which technologies receive

government support and delineate markets and who has access to them.

The centrality of these regulations for the success of businesses in a net-zero economy have made this a contested arena of political negotiation at different levels of governance. In Germany, for instance, the automotive industry is exerting pressure on the government to promote e-fuels as an alternative to battery-electric vehicles, [93] the most efficient option for decarbonizing passenger vehicles. At the EU-level, negotiations over the definition of renewable hydrogen led to a drawn-out political process, ultimately carving out special conditions for jurisdictions like France with a significant share of nuclear energy in the power mix [94]. As alluded to above, the EU's CBAM [72] and the US-led GASSA offer examples of the emerging international competition over these rules [73]. A central element of these parallel processes is the determination of which methodologies and accounting rules to apply when measuring the carbon footprint of the energy-intensive products covered by these competing schemes. In addition, the US-led scheme bars companies that are subject to a certain degree of government involvement, in a clear attempt to exclude Chinese state-owned enterprises from the arrangement. In the meantime, China has announced its own scheme for measuring carbon emissions based on a lifecycle approach that it intends to develop [95]. As indicated above, these accounting rules will not only shape market and technology development, but they will also give rise to new fields of data collection along with certification schemes to verify compliance. These mechanisms can also become instruments of geoeconomic competition.

Negotiations over the specific rules governing a net-zero economy are taking place in new types of fora that are likely to develop and possibly replace existing global governance arrangements over time. A case in point is the Energy Charter Treaty. With the Treaty viewed as a barrier to investment in climate-friendly technologies, a number of countries have chosen to exit the agreement rather than engage in a

protracted negotiation over its amendment [96]. Instead, the EU, for instance, has begun to pursue so-called Trade and Sustainable Development chapters in negotiations of new trade agreements [97].

4. Discussion: Geoeconomics of the transition to net-zero and the return of the state

The analytical framework outlined above provides a structure for the analysis of geoeconomic competition. Its novelty lies in the focus on the key physical and institutional dimensions that are specific to the complex geoeconomics of the net-zero transition, as well as in its emphasis on the conceptual delineation between geoeconomics and geopolitics. The framework can be applied to analyze and compare the geoeconomic positions and strategies of individual countries within the net-zero transition. The review has utilized it to depict the main features of the emerging dynamics of geoeconomic competition within the different elements of the framework. In contrast to the existing literature, it focuses primarily on the ongoing *process* of transition rather than a climate-friendly or renewables-dominated future. The analysis has highlighted the challenges of shaping decarbonization pathways within the context of multiple uncertainties, while seeking to secure geoeconomic advantage. The uncertain nature of the transition process is conferring increasing power to state actors who are indispensable for absorbing and mitigating risks and setting the evolving rules of engagement. Governments are playing an increasing role in defining and supporting the intertwined process of market, technology and infrastructure development. To do so, they are not only subsidizing investment in technology and infrastructure, but they are also developing and promoting institutions and networks at different levels of governance.

This increasing state influence provides important entry-points for pursuing geoeconomic objectives. Governments in the leading economic blocs are pursuing leadership and strategic autonomy across different net-zero technologies and value chains. This is leading to the re-emergence of strategic trade and industrial policy and rising protectionism. However, this inward-oriented dimension of geoeconomics competition is only one side of the coin. Although countries are keen on protecting their domestic industry and gaining strategic autonomy, this is balanced by the necessity to build alliances and persuade a critical mass of countries to adopt similar decarbonization pathways and regulatory regimes. Given the high degree of uncertainty, even large countries and trading blocs like the EU cannot afford to go it alone and have to invest significant efforts into this outward-oriented dimension of geoeconomic competition. While increasing trade barriers are emerging, this is tempered by efforts to find common ground in the context of bi- and plurilateral processes, such as GASSA or the G7 climate club.

These developments contrast with the geopolitical confrontation between NATO and Russia, reflected in the combination of military confrontation in Ukraine, the weaponization of energy resources and the widespread application of economic sanctions. Especially the US has also resorted to interventions aimed specifically at China, including targeted trade restrictions, export and investment controls. Such steps towards harder forms of geoeconomic rivalry are ultimately at odds with the logic of geoeconomic competition in the transition to net-zero, which needs to be complemented by cooperation. This does not mean that more overt geopolitical confrontation and securitization strategies are obsolete within the transition process. Indeed, the transition to net-zero may come with a temporary intensification of competition over scarce fossil fuel resources as well as the increased securitization and potentially geopolitical conflict over critical minerals needed for the transition to net-zero as well as the parallel digital transition. However, ultimately, more overt geopolitical confrontation will not only restrict the ability of the affected countries to exert geoeconomic influence in the transition process, but it will also slow down the transition process itself. It will weaken the ability of leading countries to promote their vision and regulatory regimes of a net-zero future and may come at the expense of economic efficiency, ultimately raising costs for consumers.

It will also lower the incentives for laggards to pursue ambitious decarbonization pathways.

In sum, as the transition to net-zero increases the need for state intervention, governments are not only increasing their engagement in the economy, but they are also increasingly considering geostrategic questions in their actions. However, these geostrategic choices are not straightforward but require the constant consideration of trade-offs, operating at different levels. As already discussed above, geoeconomics is by its nature a balancing act between autonomy and connectedness. Geoeconomic rivalry within the transition to net-zero is embedded in the intrinsic paradox that success of the transition to net-zero energy and industrial systems hinges on the cooperation of countries around the world. It does not suffice to build net-zero industries at home. To mitigate climate change, all countries and economic blocs will have to cooperate in the effort to build a net-zero economy. Managing this dilemma – competing to build an advantageous geoeconomic position while cooperating to ensure the broad participation of actors around the world – lies at the center of the geoeconomics of the transition to net-zero.

5. Conclusion

Geoeconomics is a promising lens to analyze the complex global processes that accompany the transition to net-zero energy and industrial system. While geopolitics has often been described as a zero-sum game, focusing on actively projecting power, geoeconomics features a more subtle pursuit of economic power and influence. Geoeconomic strategies can employ instruments on the economic spectrum from coercion to cooptation. Moreover, the focus on decarbonization as a truly global challenge adds an additional layer with a tension between competition for industrial and technology leadership and access to clean energy resources, on the one hand, and the need for cooperation and engaging international partners, both large and small, on the other. The success of the transition to net-zero will hinge on finding win-win solutions, based on cost-sharing and a readiness to allow the partner countries to capture a share of the value added at home.

The geographic determinism of geopolitics is attenuated in the geoeconomics of the transition to net-zero: the overriding importance of geographic locational factors and natural resource (especially hydrocarbon) endowments gives way to a landscape where resources are distributed more evenly, and clean technologies, data and new business models rooted in new ways of production and consumption increasingly act to diminish the primacy of geographic factors. Also, the ways in which nations act geostrategically in a decarbonizing world are primarily economic: the transition to net-zero is about distributing the costs internally and internationally, about seizing the economic opportunities associated with green industrial policy, pursuing technology leadership, promoting innovation, creating markets, and shaping and reshaping new and old value chains. Conversely, a strong geopolitical turn, which resorts to overt geopolitical confrontation and hard geoeconomic measures, will severely hamper the urgently needed transition to net-zero.

The analytical framework proposed in this work captures the most important dimensions of the transition to net-zero and provides a tool for analyzing and comparing the positions of individual countries. Further research should focus on refining the categories in the framework. Moreover, it might provide the basis for additional conceptual refinement. For instance, more work is required to clearly distinguish between sources and instruments of geoeconomic power. This requires the development of stronger links to the literature on the instruments of economic statecraft, including finance – excluded here to limit the scope of the article to those dimensions that are most affected by a changing energy and industrial system.

CRediT authorship contribution statement

R. Quitzow: Conceptualization, Investigation, Visualization,

Writing – original draft, Writing – review & editing, Funding acquisition.
Y. Zabanova: Conceptualization, Investigation, Writing – original draft,
 Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Yana Zabanova reports financial support was provided by Foreign Office of Germany. Rainer Quitzow reports financial support was provided by Foreign Office of Germany. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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