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Toward a Secure and Resilient Energy Supply Chain

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Global value chains (GVCs) are facing the greatest challenges from significant geopolitical changes. Combined with the COVID-19 pandemic shock, the energy transition and the increasing uncertainties, global value chains are at risk and need to be rebuilt to strengthen resilience. Chapter 3 examines the new geopolitical evolution due to the People's Republic of China (PRC)-US trade tensions, the ongoing Russian war in Ukraine and other regional tensions and their impacts on the rules underpinning the multilateral trading system, discuses the dynamics and the new patterns of energy supply chains, analyses the future of renewable energy supply chains, and explores the rebuilding of green, secure, and resilient GVCs that support the achievement of carbon neutrality targets.

The long-lasting PRC-US trade tensions and the ongoing Russian war in Ukraine are fueling geopolitical tensions and having huge impacts on global value chains, including global energy supply chains. These events have made geopolitical concerns rather than economic interests the dominant factor in shaping the policies governing energy trade. The data indicate that the PRC-US trade tensions are gradually leading to a decoupling between the two countries in some high-tech industries. Simulation analysis indicates that the Russian war in Ukraine and the various sanctions against Russia will reshape the patterns of world energy trade to form five segmented regional energy supply chains, including the EU-US energy supply chain, the Eurasia energy supply chain, the diamond shaped energy supply chain of US-Japan-Australia-India, the new Russia-Mongolia-PRC energy supply chain and the existing OPEC energy supply chain. These groupings will change the routes and patterns of world energy trade, and in turn could lead to further geopolitical conflicts.

All these dynamic movements are likely to affect the world energy transition and climate governance. One optimistic assumption is that the EU countries will use these crises as opportunities to speed up the development of renewable energy and formulate a new green energy supply chain to accelerate its energy transition. However, under the pressure of the energy crisis and huge demand for energy in the post COVID-19 economic recovery, some economies postponed the phasing-out of coal and indeed increased the use of coal by restarting coalfired power generation plants. These one-step forward but two-steps backward policies could lead to temporary increases of carbon emissions and delay the UN's zero-emissions strategy and carbon neutrality timetables.

The remainder of this chapter is organized as follows. Section 1 evaluates the rising geopolitical tensions and their impacts on the rules underpinning the multilateral trading system to provide a legal background for the subsequent analyses. Section 2 discusses the dynamics of energy supply chains and analyses the impact of the Russian war in Ukraine on the world energy market in terms of price and the direction of changes in energy trading. Supported by CGE model simulations, Section 3 analyzes the new patterns of energy supply chains and describes a possible future for the energy geopolitical landscape. Section 4 presents new developments in renewable energy and examines the green and low-carbon energy supply chains under construction. Section 5 predicts the potential for achieving carbon neutrality in the context of environment regulation and climate mitigation targets, and section 6 summarizes the major arguments.

3.1 The Impact of Rising Geopolitical Tensions on the Rules Underpinning the Multilateral Trading System

This section sets the legal framework for the subsequent economic study of the impact of recent geopolitical crises, such as the Russian war in Ukraine, on GVCs and, more particularly, the global energy supply chains. It analyses the legal impact of the geoeconomic measures adopted in the context of these shocks and proposes some responses to preserve the legal system on which supply chains depend in a geopolitically more volatile world.

Why are GVCs, Including Energy Value Chains, Vulnerable to an Erosion of WTO Norms through Geoeconomics?

For over 70 years, trade experts have sought to keep geopolitics and trade separate. It is only recently, due to a shift in governments' priorities towards protecting their economies against a combination of external threats ("risk-based policies") that the term "geoeconomics" as a conceptual category of trade policies has appeared in international trade studies (Roberts, Choer Moraes et Ferguson, 2019). "Geoeconomics" are defined as trade and investment measures used for geopolitical reasons, or trade and investment policies considered as geopolitical objectives (Ciuriak, 2022).[1]

[1] According to Klaus Dodds, "geopolitics involves three qualities. First, it is concerned with questions of influence and power over space and territory. Second, it uses geographical frames to make sense of world affairs. Third, geopolitics is future-oriented. It offers insights into the likely behavior of states because their interests are fundamentally unchanging" (Dodds, 2019).

Geopolitical “risk-based” or “geoeconomic” trade policies currently promoted around the world are fundamentally at odds with the legal principles underpinning the multilateral trading system (MTS) and the functioning of GVCs (Bacchus, 2022). Geoeconomic policies are not designed to seize the benefits of trade opportunities in a win-win manner. Rather, they use trade to protect a country’s interests from real or perceived geopolitical threats. Geoeconomics may be intended to ensure economic security, but mainly in terms of economic or technological superiority or independence from geopolitical rivals. For instance, geoeconomics seeks to achieve economic security not through cost-based trade diversification, but by reshoring production or trading with “friends” or “like-minded” countries (WTO, 2023).

In contrast, the development of GVCs is highly dependent on low trade costs. Trade liberalization has contributed to lower trade costs since the inception of the GATT in 1947 through a significant, negotiated reduction in tariff and non-tariff barriers and the liberalization of trade in services within the framework of legally binding commitments. The growth of GVCs was, thus, largely made possible thanks to the legal system put in place by the GATT and the World Trade Organization.

The role of international economic law is essentially to provide stability and predictability to trade and investment, but the legal system set up by the GATT introduced two additional features favorable to the development of GVCs. One was multilateralism, which allowed economies to make use of their comparative advantage more fully. The second was non-discrimination between similar imported goods and between imported goods and similar domestic goods. The implementation of those principles under the GATT and the subsequent WTO Agreements has ensured a progressive liberalization of international trade, eventually facilitating the development of value chains (WTO, 2023).

However, whether WTO rules should apply to trade in natural resources needed to produce energy or to direct trade in energy (e.g., cross-border sale of electricity) has been subject to discussions. During the Uruguay Round, very little was achieved both in terms of reducing barriers to trade in energy goods and with respect to market access in energy-related services. It has been argued that current WTO rules do not deal properly with trade in energy, notably due to the presence of natural monopolies and large -- often state-owned – enterprises (Cottier et al., 2010). Nevertheless, a number of WTO rules appear relevant, and energy-specific norms are often negotiated in the context of the WTO accession of energy-producing Members (Marceau, 2010).

The debate surrounding the suitability of existing multilateral trade rules to energy goods and services has not, however, prevented regional attempts to structure oil and gas markets along the principles of open trade and competition, such as the Energy Charter Treaty (ECT). The ECT originated in an initiative of the European Economic Community (the predecessor of the European Union) to organize the European and Central Asian oil and gas markets along the principles of the multilateral trading system after the fall of the Soviet Union and its dismemberment into several independent oil and gas producing states. The ECT is a multilateral trade and investment agreement providing a legally binding framework for energy cooperation and designed to promote energy security through more open and competitive energy markets (Energy Charter Secretariat, 2023). The ECT provisions on trade apply the WTO principles of "most favored nation" and "national treatment" to foreign goods and investors. Contracting parties to the ECT must also eliminate quantitative restrictions on the import or export of energy products and related equipment. Moreover, under the ECT, energy trade disputes between countries that belong to both the WTO and the ECT have to be resolved under the WTO Dispute Settlement Understanding (DSU) (European Parliament, 2017).

However, the history of the Energy Charter is also revealing of the degree of exposure and vulnerability of trade in energy goods and services, as well as energy value chains, to the current erosion of multilateralism. The ECT entered into force in 1998. However, Russia ended its provisional application of the Treaty in 2009. Russia's withdrawal from the multilateral investment and trade framework of the ECT was probably founded not only on geopolitical reasons -- such as its suspicion of Western initiatives – but also on geoeconomics, with implications on energy value chains. Indeed, Russia was apparently concerned that "the ECT would force it to open its pipelines to transit of natural gas from Central Asia [to Europe] or that it would be forced to accept the construction of new transit pipelines across its territory (Romanova, 2014) (European Parliament, 2017). Without Russia, the ECT could no longer fulfil its original objectives and had to redefine its role in the multilateral organization of energy value chains.

How Geopolitical Crises are Eroding the Legal Fabric of the MTS and of Global Value Chains: The Effects of the Russian War in Ukraine on Energy Supply Chains

Geopolitically-motivated trade policies, such as trade sanctions, can significantly disrupt value chains. A number of WTO Members had already adopted trade sanctions against Russia after its annexation of Crimea in 2014. However, after the current Russian war in Ukraine started in February 2022, several western countries impose trade sanctions against Russian economic interests on a scale never seen before. Even though those sanctions targeted only Russian interests, they led to a reorganization of the supply chains between the PRC and Europe. With the Russian Railways placed under western sanctions in 2022, sectors such as electronics and car manufacturers sought alternative routes to avoid the transit of components or finished products through Russia (Pomfret, 2023). Russia reacted to western sanctions in the WTO by raising a "special trade concern" before the Committee on Market access (WTO, Unilateral Sanctions against Russia (ID77) 2022) but did not initiate any dispute settlement procedure.

Russia's own trade restrictions against Ukrainian exports to some CIS countries transiting through its territory, imposed from 2014 onward, had already been subject to a WTO dispute settlement procedure in which, for the first time, a panel had interpreted Article XXI GATT (Security Exceptions). Essentially, the panel had found that the geopolitical situation between Ukraine and Russia at the time amounted to "war or other emergency in international relations" (Article XXI(b)(iii)) and that Russia had legally invoked Article XXI as a justification for its trade restrictive measures against Ukraine (*Russia - Traffic in Transit,* 2019).

The disruption to global value chains caused by the trade sanctions against Russia was aggravated when Russia responded by gradually cutting its supply of oil and gas to European countries, among others.

Natural resources are often subject to export restrictions (OECD, 2010). Such practices are legally acceptable as long as they are justified under one of the non-application clauses or exceptions provided for in the WTO Agreement (domestic shortage, environmental protection, price or production regulation, etc.). Nevertheless, the imposition of export restrictions by a country that is the main supplier of certain raw materials could seriously disrupt the functioning of global value chains. The vulnerability of supply chains from excessive reliance on a single supplier who could also use such dependence for geoeconomic purposes was pointed out by some authors (see Gavin, 2013) when the PRC restricted its exports of rare earths and other raw materials used in electronics. These policies were challenged (*China - Rare Earths,* 2014) and subsequently withdrawn.

"Trade Weaponization" and Trade Sanctions are Escalating

The adoption by western countries of unprecedented trade sanctions on Russia and the subsequent progressive reduction in Russia's exports of oil and gas to Europe probably represent the most significant example of "trade weaponization" in recent history.

"Trade weaponization" is not a trade law concept. It refers to the use of trade for non-trade purposes in a geopolitical context (Reinsch, 2021). The idea is to disrupt or threaten to disrupt trade with another country so as to inflict or threaten to inflict economic losses, in order to force it to change its policy. The use of the term "weapon" underlines the unamicable nature of the action.

To be effective, trade weaponization normally requires the existence of trade between the country intending to weaponize this trade and the targeted country(ies) and that the former be the exclusive or at least a predominant supplier/client of the product(s) concerned. The products concerned should preferably be "essential" or "strategic". Most importantly, it must be difficult for the targeted country(ies) to quickly find a substitute for the product, the supplier or the client, hence its potentially significant impact on supply chains. In the case of the Russian war in Ukraine, oil and gas exports were perfect "trade weapons" given the high degree of dependence of many European countries on Russian energy supply at the time and the expected damage to European economies before they could switch to other suppliers or sources of energy.

It is unlikely that any challenge before the WTO of either the sweeping trade sanctions imposed against Russia or the ban on exports of oil and gas imposed by the latter would be successful. In light of the findings of the panel on *Russia – Traffic in Transit*, the context in which those sanctions were adopted would most probably be deemed consistent with Article XXI(b)(iii) GATT (see above).[2] Thus, the current trade sanctions could remain in place for as long as the Russian war in Ukraine is not fully resolved.

While Article XXI(c) GATT 1994 and its GATS and TRIPS equivalents acknowledge the possibility for WTO Members to adopt trade sanctions in application of their "obligations under the United Nations Charter for the maintenance of international peace and security," UN-sponsored trade sanctions are only a part of the trade sanctions WTO Members impose on each other (Yotov and al. 2020). An increasing share of trade sanctions is unilaterally adopted by individual Members (Mulder, 2022).

The appeal of trade sanctions partly comes from their flexibility. They offer a wide range of variations, from temporary sectoral restrictions (*Japan--Measures Related to the Exportation of Products and Technology to Korea*, WTO, 2023) to waging war without formally being at war (WTO, 2022). In a world increasingly subject to geopolitical volatility, their use can only increase.

Trade sanctions add to the complexity and cost of trade and are a major source of legal uncertainty, in contradiction with the WTO principles of stability and predictability. Indeed, not only each economy has its own sanction regime but, when the scope of sanctions expands, regimes are modified to address loopholes and secondary sanctions are added to primary sanctions. The lists of targeted entities can sometimes be several hundreds of pages long (Reinsch, 2021).

This complexity can lead to "overcompliance". Out of caution, manufacturers will refuse to sell certain goods to certain clients, or shipping companies will not ship specific cargos to certain destinations, insurance companies will not ensure shipments or banks will refuse to finance trade with certain countries lest they become subject to criminal proceedings and fines for breaching national sanction regimes.

Possible Legal Responses to Protect the MTS and Global Value Chains Against Geoeconomics

As mentioned above, GVCs depend on open trade. The objective of the WTO reform outlined at the 12th Ministerial Conference (June 2022) remains to make the MTS work for all, particularly by restoring its capacity to solve disputes (WTO, 2022).

2 Trade sanctions are increasingly targeted against an individual or entity, rather than the state (Reinsch, 2021). While individuals targeted by western sanctions have sometimes successfully contested them before national courts or the European Court of Justice, these judgements were mostly based on technicalities and apply only to the business of the complaint.

However, many experts seem to have embraced a "realist" or "structuralist" approach to international relations and accepted the return of geopolitics in trade as some "fact of life" (Howse, 2022) that their predecessors, overly focused on the rule of law, naively refused to acknowledge (Nishimara, 2023). For them, the MTS was designed in the 1990s for a unipolar world sharing the same economic values – the "Washington Consensus." It is no-longer adapted to the inevitable resurgence of power-based diplomacy and it may survive only at the cost of loosening-up the rule-based system and giving governments more "policy space" to use trade for non-trade purposes (Howse, 2022). Even pro-MTS experts recognize that certain governments' economic "preferences" may no longer be reconciled (IMF, 2023), and that the only way to prevent an excessive impact of geopolitics on international trade is to introduce some minimum guidelines for unilateral policies ("guardrails") when differences in points of view are such that no agreement can be reached (Hoekman et.al., 2022).

Until the Second World War, international trade was essentially organized around discrimination or privileges (Spanish "Asiento", British "Imperial Preference"). By contrast, the GATT 1947 negotiators opted for a legal construction based on non-discrimination and transparency. They also made the choice to found the MTS on binding norms legally enforceable by any individual Contracting Party, irrespective of its economic or military power, as illustrated by the early case between The Netherlands and the United States (*United States - Restrictions on Dairy Products,* 1952) (WTO, 2023). Trade negotiations aimed at achieving a "balance of rights and obligations", as well as the principles of the most-favored nation and "special and differential treatment" for developing and least-developed economies also ensured that all contracting parties would benefit from the MTS. Any shift away from a system based on mutually negotiated rights and obligations towards a less legal and more political organization and functioning of the MTS, and from binding rules and disciplines towards "soft law" or "guardrails" would largely amount to a return to power-based diplomacy and spell the end of 70 years of "win-win" trade cooperation.

More consistent with the existing legal structure of the MTS would be to adapt the WTO rulebook to emerging challenges (Hoekman et.al., 2022), including political ones. It may indeed be preferable to allow certain policies as exceptions -- subject to multilaterally supervised conditions -- than having to declare them illegal, as in recent cases where Articles XXI GATT or 73 TRIPS were invoked, and run the risk that such rulings be disregarded. This would eventually compromise the rule-based trading system as a whole. WTO general and security exceptions could thus be adjusted to the new policy needs of Members, either through negotiation or interpretation under Article IX:2 WTO. Not everything needs fixing, however. Many of the derogations necessitated by the new health or environmental challenges are already covered by Articles XX GATT and XIV GATS. It may also not be judicious to seek to renegotiate the text of the WTO exceptions in the present geopolitical environment. However, a carefully drafted interpretation of WTO security exceptions to include contemporaneous security issues that the GATT 1947 negotiators could not have contemplated, such as state-sponsored cyber-criminality or hybrid warfare, may be considered.

Some negotiated settlement on the question of the reviewability of security exceptions under the DSU would also contribute to restore the faith in and support for the MTS among those Members that do not have the means to engage in power diplomacy. A broader trust in the capacities of the rule-based system would contribute to stabilize trade relations and reduce the occasions to invoke security exceptions.

The mandatory and binding WTO dispute settlement mechanism was one of the core features of the rule-based MTS until the appellate mechanism ceased to function in 2019. A largely non-operational dispute settlement system both limits Members' legal capacities to respond to geoeconomic policies through peaceful means and serves the interests of countries that want to selectively comply with their WTO obligations (Van den Bosche and Akpofure, 2020). A restoration of the WTO dispute settlement system is, thus, essential to preserve a non-discriminatory and transparent MTS.

However, restoring the WTO dispute settlement system faces two particular obstacles to which only adjustments towards more consideration of the broader political context, as panels used to do under GATT 1947, could bring a solution at this stage.[3]

One is the risk of a member not complying with Dispute Settlement Body (DSB) recommendations and rulings against a measure for which it invoked a security exception. Even a return to a fully operational DSU will not prevent some Members from not implementing rulings of the DSB, even if they are subject to "sanctions" in return. Normally, Members have an obligation to comply with DSB rulings, but some have nonetheless occasionally preferred in the past, mainly for domestic political reasons, to maintain controversial measures and face a suspension of concessions or other obligations by the other party(ies) to the dispute. Given the intimate link between security and sovereignty, this risk is likely to be even higher with measures adopted for geopolitical reasons. The current mechanism of suspension of concessions and other obligations in case of non-compliance is not particularly well suited to the invocation of security exceptions because such "countermeasures" may only be adopted at the outcome of a DS procedure, sometimes years after its initiation, risking to create a period of impunity during which a Member may continue to apply unjustified protectionist or trade coercion measures with potentially lasting economic consequences for its trading partners.

A proposed solution could be to allow Members aggrieved by a security-based measure to immediately respond to such measure through the suspension of substantially equivalent concessions (Lester and Zhu, 2019). Another option would be to limit

3 After all, GATT contracting parties, from communist Poland to western European social democracies to liberal Chile, used to follow more diverse economic models than WTO Members probably do today.

disputes on security justifications to non-violation cases4 (Benton-Heath, 2020). Aggrieved Members could eventually seek compensation or take countermeasures, but negative political reactions in the responding Member to the WTO "condemnation" of a measure adopted for the protection of "essential national security interests" could be minimized.

The question of the "self-judging" nature of security exception clauses first argued in the *Russia – Traffic in Transit* case (2019) by Russia and the United States - and systematically raised by the latter in subsequent similar cases – also must be resolved. Options include the unequivocal acceptance of the judicial review of cases where such clauses are invoked under the terms defined by the panel in *Russia – Traffic in Transit*[5] or in some other form, if only to prevent protectionist abuses or coercion. A radically different approach would consist of excluding the review of security clauses from the scope of the DSU (Lester and Manak, 2022). However, in the latter case, the systemic consequences of this choice should be carefully assessed.

Indeed, a total absence of "judicial" or third-party review of the invocation of security exceptions could impact the predictability of a rule-based MTS, particularly in a period of geopolitical instability. Therefore, if security justifications are removed from the scope of the DSU, some substitute mechanism, e.g. in the form of a deliberative process, (Manak, 2023) should be put in place to review them in order to limit their spillover and avoid that they be used for protectionist purposes. This process could be purely diplomatic or evidence-based and led by experts to facilitate the identification of alternative solutions and compliance options. A specialized WTO security committee could be created for that purpose (Lester and Manak, 2022).

[4] Under the DSU, complainants must demonstrate that a benefit accruing directly or indirectly to them under the WTO Agreement has been "nullified or impaired" through the application of a measure by another Member. Nullification or impairment can occur in three situations: (a) in presence of a violation by another Member of its WTO obligations ("violation" complaint), (b) due to the application of a measure by another Member, whether or not it conflicts with the WTO Agreement ("non-violation" complaint) or (c) as a result of the existence of any other situation. When nullification or impairment occurs in the absence of a violation, there is no obligation to withdraw the measure at issue, but a mutually satisfactory adjustment must be reached (Article 26.1(b) DSU).

[5] In the *Russia – Traffic in Transit* (DS512) dispute, the Panel concluded that Article XXI(b) was not "self-judging" but vested in panels the power to review whether the requirements of the subparagraphs of this provision were met. The Panel considered that an "emergency in international relations" referred generally to a situation of armed conflict, or of latent armed conflict, or of heightened tension or crisis, or of general instability engulfing and surrounding a state. Both the existence of an "emergency in international relations" and whether the action was "taken in time of" such emergency, within the meaning of subparagraph (iii) of Art. XXI(b), were subject to objective determination. As to whether the action was necessary for the protection of the invoking Member's essential security interests, the Panel said that, in general, while it is for every Member to define for itself what it considers to be its essential security interests, such essential security interests must be sufficiently articulated to demonstrate their veracity. Moreover, the obligation of good faith also required that the measures at issue meet a minimum requirement of plausibility in relation to the proffered essential security interests, i.e. that they are not implausible as measures protective of those interests. (https://www.wto.org/english/tratop_e/dispu_e/cases_e/1pagesum_e/ds512sum_e.pdf)

3.2 New Dynamics of Global Energy Supply Chains

As the world shifts towards cleaner and more sustainable energy sources, various factors can influence the dynamics of energy supply chains and trade in energy, especially renewable energies. Here are some key issues and channels through which the energy transition and climate change mitigation will affect global energy supply chains and renewable energy trade.

The COVID-19 Shock to Energy Supply Chains

Since 2020, the COVID-19 pandemic has created a significant shock to global value chains which led to major temporal and geographical disruptions in the energy supply chain through lockdowns, border closures, logistical interruptions of population and labor mobility (even stopovers in air travel), layoffs of workers and temporary shutdown of production lines, demand distortions, and a diversion of government funding from energy projects to pandemic relief efforts.[6]

The COVID-19 damage revealed the weakness and risks of energy supply chains

The COVID-19 pandemic exposed the weaknesses and risks of global supply chains, underlining the importance of sustainable and resilient energy systems. This will prompt renewable energy companies to strengthen their efforts to improve the resilience of supply chains. While to some extent this could imply reliance on more diversified sources for components and equipment, it also could lead to the regionalization or localization of certain supply chain elements to reduce risk and lessen the impact of future trade disruptions driven by quarantine measures (Quitzow et al., 2021).

The COVID-19 shock to energy supply chains

In some respects, the COVID-19 pandemic is expected to make the power generation mix greener. The pandemic exposed vulnerabilities in energy access and affordability, which may drive a shift towards decentralized energy systems. Distributed renewable energy generation, such as rooftop solar, may see increased adoption to enhance energy reliability at the local level. Governments and businesses may now prioritize the transition to renewable energy sources as a key component of their long-term energy strategies, leading to increased investments in renewable energy projects. The pandemic also accelerated the adoption of digital technologies in the renewable energy sector. The increased availability of remote monitoring, data analytics, and smart grid technologies should improve the efficiency and reliability of renewable energy systems.

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6 Hoang, A.T., Nižeti´c, S., Olcer, A.I., Ong, H.C., Chen, W.-H., Chong, C.T., Thomas, S., Bandh, S.A., Nguyen, X.P., 2021. Impacts of COVID-19 pandemic on the global energy system and the shift progress to renewable energy: opportunities, challenges, and policy implications. Energy Policy 154, 112322.

The decline in energy demand also reduced the production of power generation with higher variable costs, mainly fossil fuels, and thus increased the share of renewables in the power generation mix. This generation mix change accelerated the transition towards low carbon energies in the short run (Li et al., 2022). However, when considering broader factors and in the long run, the COVID-19 pandemic may undermine the energy transition. The comprised economic growth due to COVID-19 pandemic will undermine the readiness and other enabling factors of the energy transition and thus slow down the energy transition in the long run (Shen et al., 2022)

The US-PRC Trade Tensions and Its Impact on Energy Supply Chains

The US-PRC trade tensions, which began in 2018, are a protracted and escalating economic conflict between the two largest economies in the world. The trade tensions have caused disruptions in global supply chains, including the supply chains for clean energy technologies and critical minerals. The United States is actively promoting the concept of 'friend-shoring' and other strategies to strengthen and build resilient supply chains. Additionally, it aims to create a more extensive alliance among advanced economies to counter the PRC's technological advancements, as described in the Science and Chips Act of the US.

The escalation of the US-PRC trade tensions and the overall geopolitical tensions introduce a lot of uncertainties, alter trade patterns, and impact investments in the renewable energy industry. The geopolitical tensions may potentially slow down the global energy transition and hinder efforts to achieve climate goals.

The trade tensions and geopolitical tensions may disrupt established supply chains for renewable energy technologies. Disruptions in renewable energy trade and investments may impact the pace of decarbonization and the adoption of clean energy technologies. Many renewable energy products involve the sourcing of components from multiple countries. The trade tensions and geopolitical tensions may prompt countries to seek alternative sources for renewable energy technologies and components to mitigate the impact of trade restrictions. On the positive side, increased trade restrictions could lead to the emergence of new trade alliances and partnerships in the renewable energy sector and spur development in countries or regions that are otherwise not part of the energy supply chains. For example, the US tariff on the PRC's solar panels led to the relocation of assembly business to Southeast Asia (Nichola Groom, 2022).

The trade tensions and geopolitical tensions may reduce market access for renewable energy products and technologies, and lower investment in these activities. Both the US and the PRC are major players in the renewable energy industry, and the trade dispute can limit their access to each other's markets, hindering the flow of renewable energy products and services. More generally, governments may implement protectionist measures to safeguard domestic industries, which could impact the flow of renewable energy products and services across borders. Investors may be more cautious about investing in the PRC due to increased risks and uncertainties, and host countries may become more cautious about the PRC's investment, leading to delays or cancellations of renewable energy initiatives.

The geopolitical tensions and uncertainties may slow the pace of decarbonization and the adoption of clean energy technologies. The imposition of tariffs and trade barriers or changes in trade patterns can lead to delays, higher costs, and shortages of critical components, potentially affecting their affordability and accessibility in certain markets. For example, as a result of significant disparities in energy, labour, investment, and overhead costs, manufacturing all components of the solar PV supply chain in the PRC is 10% less expensive than in India, 20% less expensive than in the United States, and 35% less expensive than in Europe (IEA, 2022b). And these tensions could lead to an escalation of broader geopolitical conflicts and rivalries. This could affect international cooperation on renewable energy initiatives and the energy transition and hinder collaborative efforts to address global climate challenges.

Geopolitical Tensions and Their Impact on Energy Supply Chains: Energy Geopolitics

The discipline of energy geopolitics and the term energy geopolitics were formed relatively late compared to when energy geopolitical wars occurred historically. Global energy geopolitics was formed long before 1960, and after decades of changes in global politics, economy, technology, and other factors, energy geopolitics has been constantly reconfigured (Amineh, 2003). Therefore, this chapter takes energy geopolitics as the research object, combs the evolution of energy geopolitics, and forecasts the changes of the future energy geopolitics pattern in combination with the epidemic situation and the Russian war in Ukraine, so as to provide some reference for global energy layout and energy development.

The Russian war in Ukraine fragmented the traditional energy supply chains and altered global energy trade routes. While the direct impact of the Russian war in Ukraine on renewable energy trade may be limited, its broader effects on global energy markets, geopolitical stability, and the investment climate have indirectly influenced the renewable energy sector.

The Russian war in Ukraine led to both physical disruption and institutional sanctions that directly affected the global energy trade. It disrupted transportation and logistics networks, which directly affected energy supply chains, including those for renewable energy technologies. Many countries implemented trade measures or sanctions that indirectly impact renewable energy trade. For example, Russia has redirected crude oil shipments to Asia as a response to the Europe's sanctions on its energy exports (IEA, 2023b). These measures may have affected the flow of raw materials, components, or finished renewable energy products across borders.

The war has had complicated impacts on the energy transition, especially in Europe, which further affect the trade of fossil fuels and renewable technologies. Russia's reduction in the supply of gas to Europe led to an increase in European coal consumption in 2021 and 2022 to partially fill gaps in the energy mix. The impact, however, is limited and temporary, as projections indicate that the demand is set to decrease below the levels seen in 2020 by the year 2025 (IEA, 2022c).

Moreover, the economic upheaval triggered by the Russian war in Ukraine has intensified efforts to expedite the energy transition. Numerous countries and regions are currently exploring policy measures to accelerate the clean energy transition through initiatives such as the Inflation Reduction Act in the US, the REPowerEU plan in Europe, and the GX Green Transformation program in Japan (IEA, 2023b). In May 2022, the European Commission unveiled the REPowerEU plan, which aims to eliminate the European Union's dependency on Russian fossil fuels by 2027. The plan also sets ambitious targets, including raising the share of renewables in final energy consumption to 45% by 2030, surpassing the previously negotiated 40% goal (IEA, 2023b).

The Energy Crisis and Energy Security

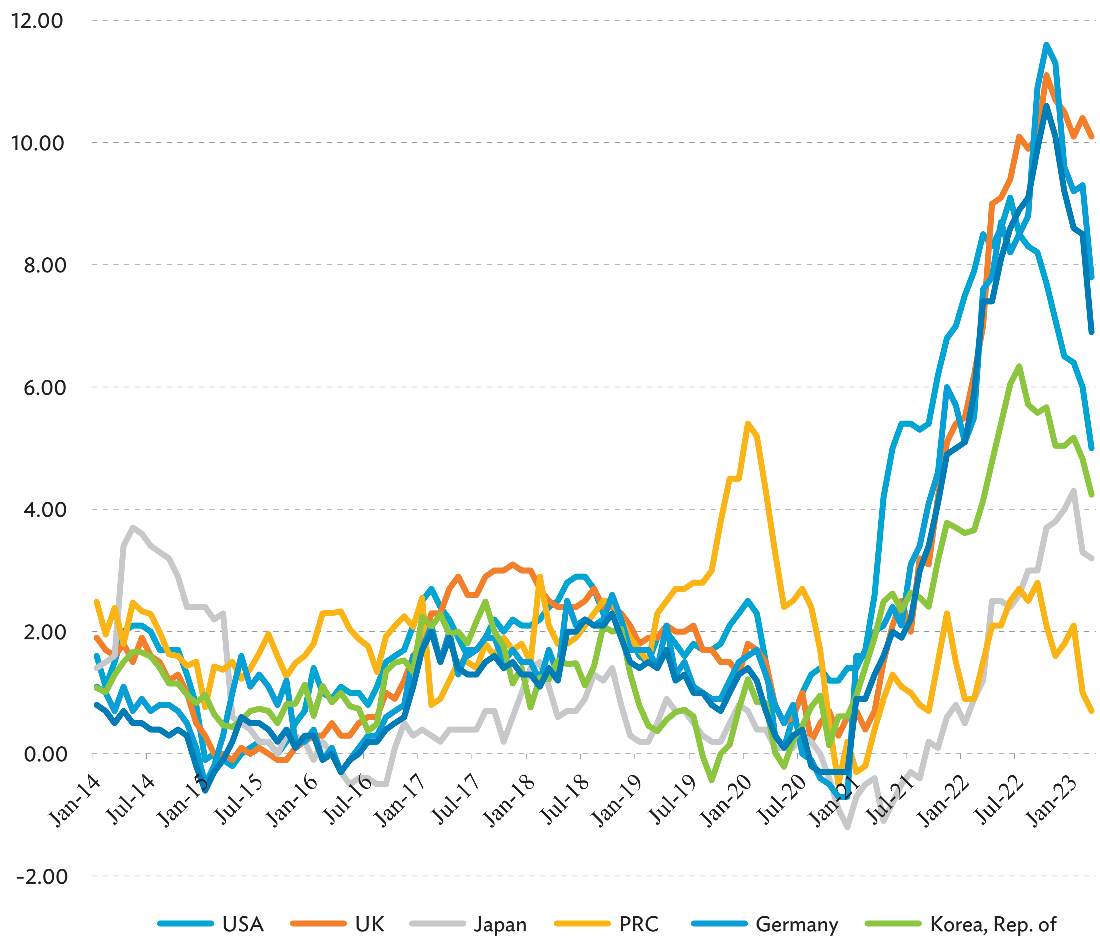
Energy security is a base or guarantee of energy supply chains. The energy price rise induced energy crises, and energy crises deepened energy insecurity and threats to the energy supply chain. According to an IEA report, the global spot price of natural gas reached an unprecedented level of over $250 per barrel in the second half of 2022, while coal prices also reached a record high level (IEA, 2022d). In addition to this, diesel prices in Northwest Europe surged after the Russian war in Ukraine, exceeding $200 per barrel, while North Sea Brent crude oil as well as Urals crude oil also saw sharp increases in the short term before falling back (IEA, 2022d).

Energy price driven inflation

After the outbreak of the Russian war in Ukraine, the restrictions on energy exports from Russia to European countries and the sanctions imposed on Russia by European and American countries led to sharp increases in global energy prices, which led to an increase in price levels in various countries (refer to Figure 3.1). Between February 2022 and September 2022, the CPI indices of the US, U.K., Germany, Republic of Korea, and Eurozone countries increased by 9.1, 10.1, 10, 6.34, and 9.9 percent, respectively.

Many governments provide energy subsidies to mitigate the direct impact of energy shortages and price increases on residents and businesses. As of August 2022, European countries have distributed $276 billion to mitigate the impact of high prices on residents and businesses. Specifically, Germany is giving a $300 one-off energy allowance to workers, while Italy is giving workers and pensioners a $200 cost-of-living bonus (refer to Visual Capitalist). In addition, the break in the energy supply chain with

Figure 3.1: Changes of Global CPI Due to Energy Shock



Source: Wind.

Russia has caused European countries to increase energy imports from countries such as the United States at higher prices, thus increasing government spending.

High prices of natural gas and coal not only bring a heavy burden to governments and businesses, but also profoundly affect the lives of the global population (IEA, 2022d). Therefore, the increase in electricity and food prices caused by the rise of fossil energy would have a far-reaching impact on the global population. As households in low-income countries spend a large portion of their income on energy and food purchases compared to high-income countries, changes in energy and food prices can have a greater impact on them and at the same time increase regional development disparities (Von Cramon, 2022). According to the IEA report, some 75 million people who recently gained access to electricity are likely to lose the ability to pay for it, the total number of people worldwide without electricity access has started to rise, and almost 100 million people may be pushed back into reliance on firewood for cooking instead of cleaner and healthier alternatives (IEA, 2022d).

European dependence on Russian energy

With the intensification of the Russian war in Ukraine, the global energy supply chain has broken down. The EU, which relied on Russia for one-fifth of primary energy consumption in 2021 (IEA, 2022a), has been severely affected. In this energy crisis, all fuels (coal, oil, etc.) are affected, but gas markets are the epicenter. Daily pipeline flows from Russia to the EU dropped by about 80% from March 2022 (Russia invaded Ukraine in late February) to October 2022 (IEA, 2022d). The Nord Stream pipeline between Russia and Europe was subject to outages, leaks, and explosions, and experienced a shutdown in August 2022. As Russia has the world's largest natural gas reserves (19.88% of the world's proven volume) and exports (7.67% of global exports) (BP, 2022), the Russian war in Ukraine has led to a broken link in the global energy (especially natural gas) supply chain, which is a huge challenge for the global economy and for European countries.

3.3 Geopolitical Changes and New Evolution of Energy Supply Chains

Historical Evolution of Energy Domination and Energy Geopolitics

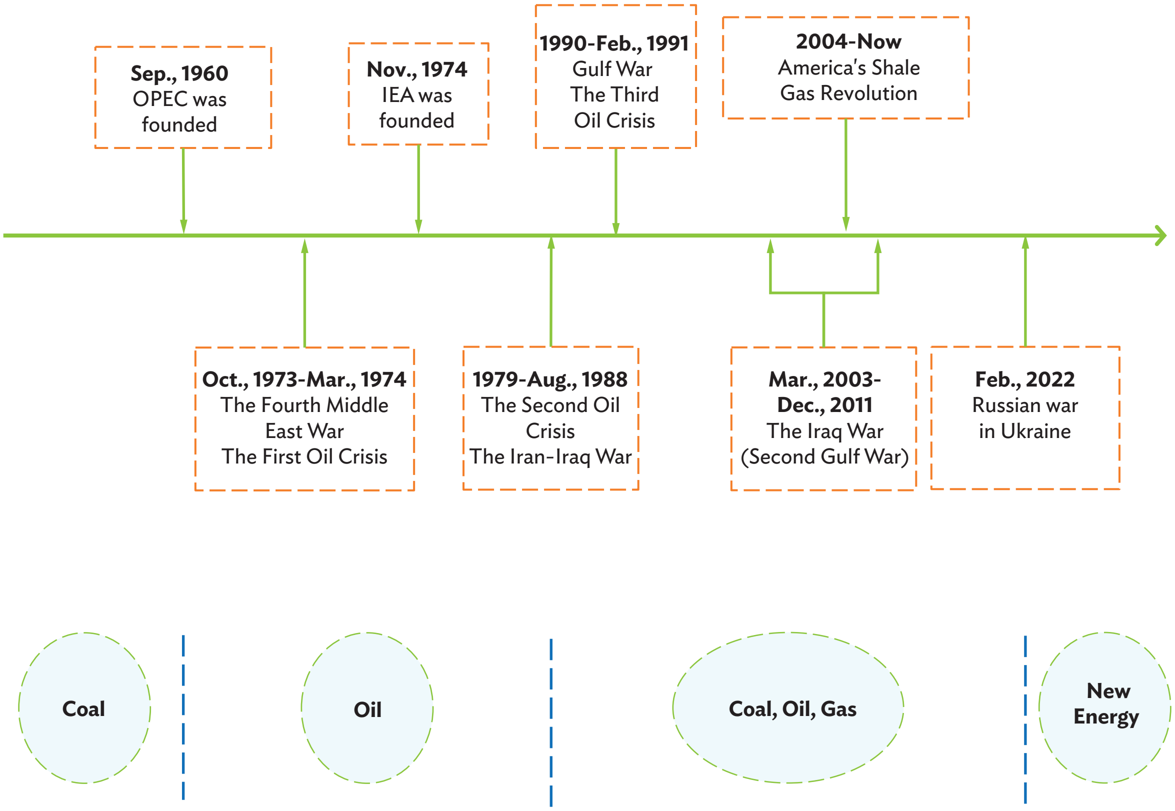
We can divide the historical evolution of the energy geopolitical scene into 4 eras, according to which source of energy was most important and the influence on world politics (Figure 3.2).

Coal-centric energy supply chain and the UK-USA Era

During the first industrial revolution, the emergence and widespread use of improved steam engines and steam turbines marked that human society entered the era of fossil energy. Coal became the primary energy product of European countries. European countries, led by the United Kingdom, through oversea expansion and long-distance transportation, built the "coal supply chains" connecting Europe with Asia, Africa, the Americas and other countries, and providing power for their industrial production. In addition, the U.K.'s advanced technology and its global network of "coal stations" enabled the U.K. to dominate coal and strengthen its control over the world's energy sources.

While the United Kingdom continued to expand its world energy footprint, to meet the energy demand from industrialization, in 1859, the United States began to develop oil commercially and established its offshore empire in the Caribbean and the Philippines. Oil is easier to extract and store, and is more efficient, compared to coal (Vaclav Smil, 2006). Oil gradually became a primary energy since the World War I and the object of the competition between Britain and the United States. At that time, the area around the Gulf of Mexico, dominated by the United States, and the Persian Gulf, dominated

Figure 3.2: Historical Evolution of Energy Domination and Energy Geopolitics



by the United Kingdom, became the world's oil centers. The signing of the Treaty of La Palo prompted the United States and Britain to cooperate in oil, thus forming a pattern in which the United States and Britain jointly controlled the world's energy.

Oil-centric energy supply chain and the OPEC Era

To counter the oil empires of Britain and America, five major oil-producing countries - Iran, Iraq, Kuwait, Saudi Arabia, and Venezuela, established the Organization of Petroleum Exporting Countries (OPEC) in September 1960 to coordinate and unify the oil policies of member countries and to ensure the stability of oil prices. According to the record of OPEC, in 1962, the proven oil reserves of all OPEC countries were more than 60 billion tons, accounting for about 69% of the world's total. Their crude oil output and export volume accounted for about 50% and 85%, respectively, of the world's total. This helped OPEC to control oil production and exports, as well as oil pricing, and to expand its energy trading network and build a new oil empire. Furthermore, the fourth Middle East War in 1973 and the first oil crisis in 1974 confirmed OPEC's monopoly position of oil production and trade. European and American developed countries established the International Energy Agency (IEA) in November 1974 to reduce their dependence on oil imports, but OPEC's power and international influence gradually enlarged, which changed the global energy supply chains and energy geopolitical pattern.

The shale gas revolution and the oil-dollars era

The second oil crisis in 1979 and the Iran-Iraq war split OPEC's internal forces, making it gradually lose its ability to control the energy market. The Iraq War in 2003 and the American "shale gas" revolution in 2004 further weakened OPEC's power and strengthened the US's control over energy. At the same time, Russia, as a member of the "world's energy heartland," is rich in traditional fossil energy and keeps a significant position in the world energy market. In addition, North Africa, the PRC, Malaysia, Australia, Mexico, and other countries have also joined the international energy market, eroding the monopoly position of the original OPEC members, promoting the energy market to develop in a diversified direction, and gradually forming a new pattern of world energy geopolitics with mutual checks and balances.

The Russian war in Ukraine and the energy-mix era

The Russian war in Ukraine has led to the restructuring of the global energy value chain, affecting the control of energy by countries around the world and triggering new energy geopolitical changes. In addition, the traditional energy crisis has aroused global attention to new energy sources, and countries are gradually turning to the competition for new energy sources such as polysilicon, cobalt and lithium. New energy sources are gradually replacing traditional energy sources in the center of the world energy stage. As a result, a new energy geopolitical era is gradually taking shape and the energy-mix era is coming. The next section will discuss a simulation analysis for the new energy geopolitics.

The Dynamic Evolution Global Energy Supply Chains

The Russian war in Ukraine has disrupted the long-standing and relatively stable geopolitical landscape, with far-reaching implications for the global energy supply chains, driving the formation of a new global energy geopolitical landscape.

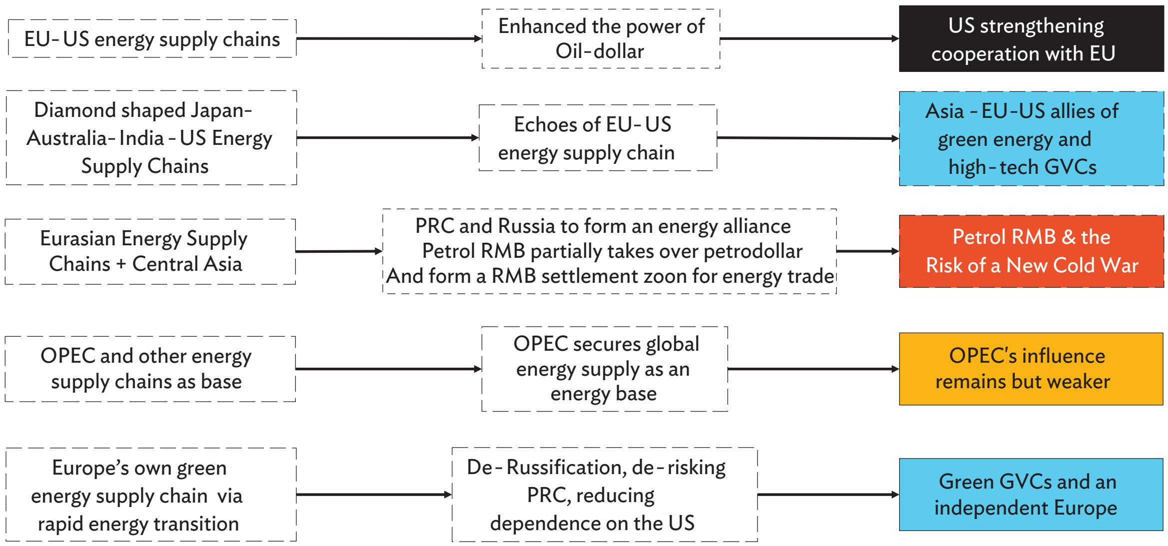
Scenario analysis of energy supply chain re-shaping

The future trend of the new energy supply chains and energy geopolitics will be shaped by developments such as US-EU cooperation, Russia-PRC cooperation, and OPEC's declining role. These developments are summarized in Figure 3.3.

The New EU-US Energy Supply Chain

The ongoing de-Russification of the EU is reducing the dependence on Russia while strengthening the energy trade between the EU and the United States by importing more American LNG and refined oil products. As a result, the United States will build a US-EU energy supply chain to replace the Russia's gas pipeline in the next few years. Consequently, the US will dominate the European energy market and maintain the strong power of the oil-dollar through increasing the volume of energy exports and international settlement by US dollars.

Figure 3.3: The Dynamic Evolution of Energy Supply Chains and Geopolitics



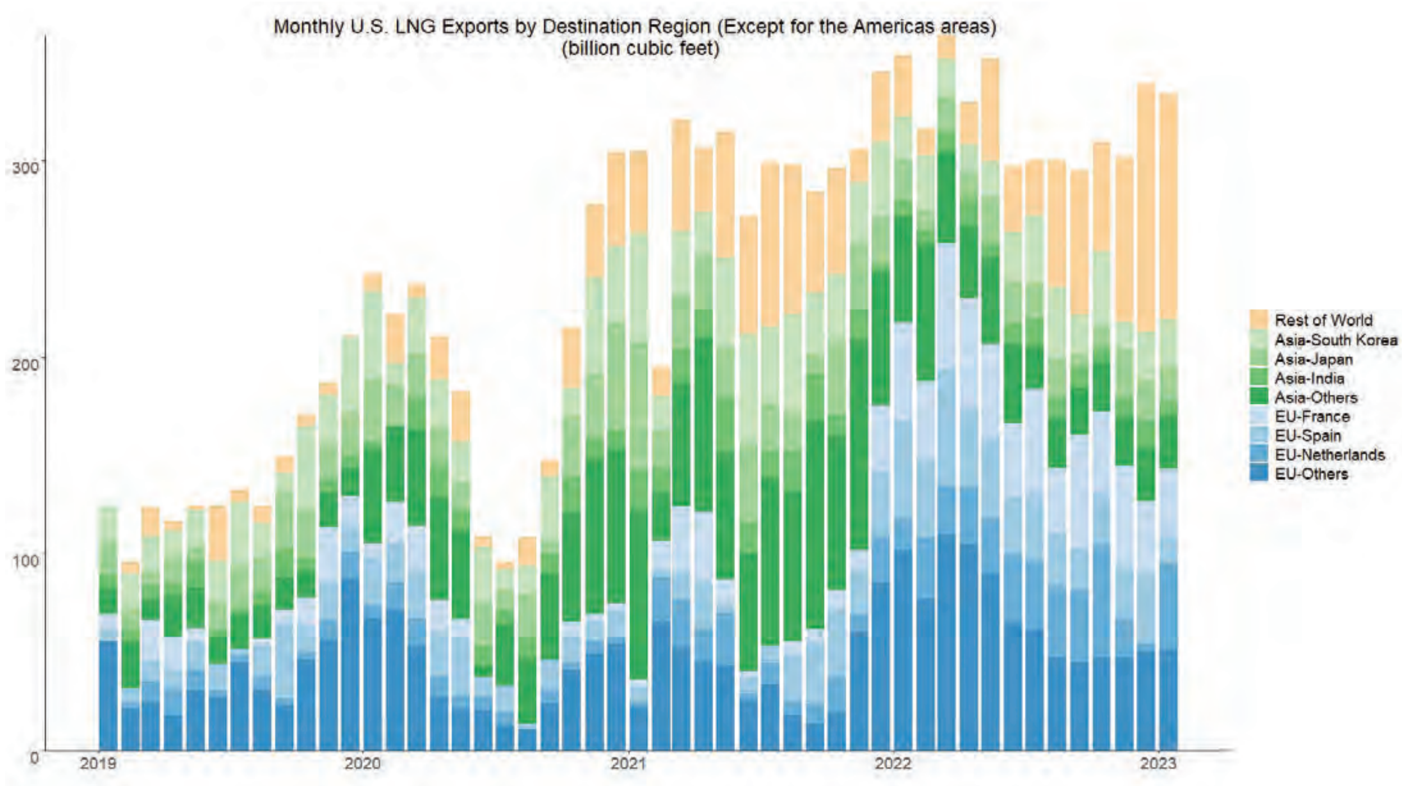
To ensure its energy security. the E.U. and other countries turned to import LNG from the US by sea. Figure 3.4 shows that before 2022, most US LNG exports went to Asian countries (e.g., Republic of Korea, Japan), while in 2022, the E.U. was the main importer of LNG from the United States. Consequently, the E.U. is practicing a strategy of transiting from over dependence on Russian gas to "de-Russification." Conversely, the EU-US energy supply chain is strengthened and the economic and political ties between the United States and the E.U. have been consolidated, making the oil-dollar stronger. As a result, the global natural gas supply chain is partially regionalized.

The "Diamond Shaped" energy supply chain in the Asia-Pacific region

Energy cooperation and energy security have an important place in the Indo-Pacific Strategy launched during the Obama administration by the United States and Japan. Since the shale gas revolution, in addition to having large coal reserves, the United States has also become a major natural gas producer, turning it from an importer to an exporter. At the same time, the rapid economic growth of the emerging economies in the Indo-Pacific region has increased energy demand. Therefore, by strengthening energy cooperation with the Indo-Pacific region through energy infrastructure construction, the "Indo-Pacific" energy cooperation model led by the United States is gradually forming[7]. As can be seen from Figure 3.5, the structure of the United States' natural gas exports changed dramatically from 2000 to 2022. In 2000, the United States exported 11.3 million tons of natural gas, primarily to countries in the Americas and Asia such as Mexico, Canada, Japan, Brazil, PRC, Chile, Guatemala, Germany, and Republic of Korea. By 2022, US natural gas exports had increased to 82.0 million tons,

7 Remarks by Senior Deputy Assistant Administrator for Asia Gloria Steele at the Asia EDGE Virtual Workshop: Supporting Indo-Pacific Industry Engagement through Asia EDGE | June 25, 2020 | Archive - US Agency for International Development (usaid.gov)

Figure 3.4: Change in US LNG Exports



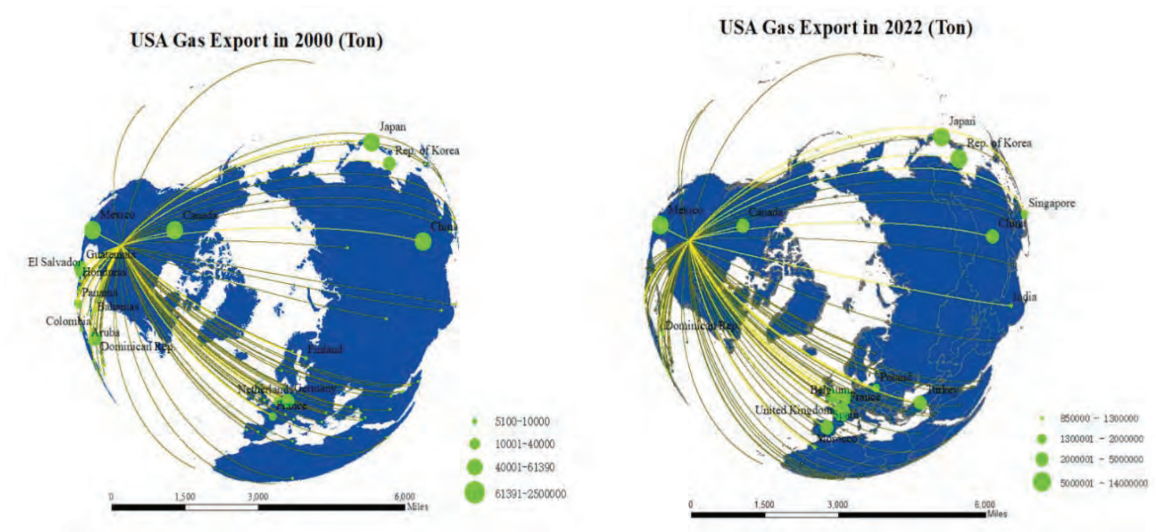
Source: EIA

a growth of 623.97%. The main export destinations included Mexico, Japan, PRC, Republic of Korea, Canada, Brazil, Türkiye, Spain, New Zealand, the UK, France, and India, spanning both Asia and Europe. This indicates that the US has intensified its energy exports to the Indo-Pacific region and Europe, securing a significant leadership role in energy consumption and supply within the Indo-Pacific area.

On July 13, 2022, in the wake of the Russian war in Ukraine and to discuss natural gas supply and future energy security issues, the "Quad Mechanism" energy ministers' meeting was convened in Australia. During the meeting, the four parties (Japan, US, Australia and India) reached a consensus on collaborating to develop the next generation of energy sources like hydrogen and ammonia, to promote future energy security. Japan actively discussed natural gas supply schemes with the United States and Australia to ensure energy supply security. In addition, the four parties agreed on the widespread adoption of technologies such as energy storage batteries that contribute to energy supply, establishing a stable "diamond" energy cooperation model and strengthening energy cooperation in the Indo-Pacific region (refer to Figure 3.6).

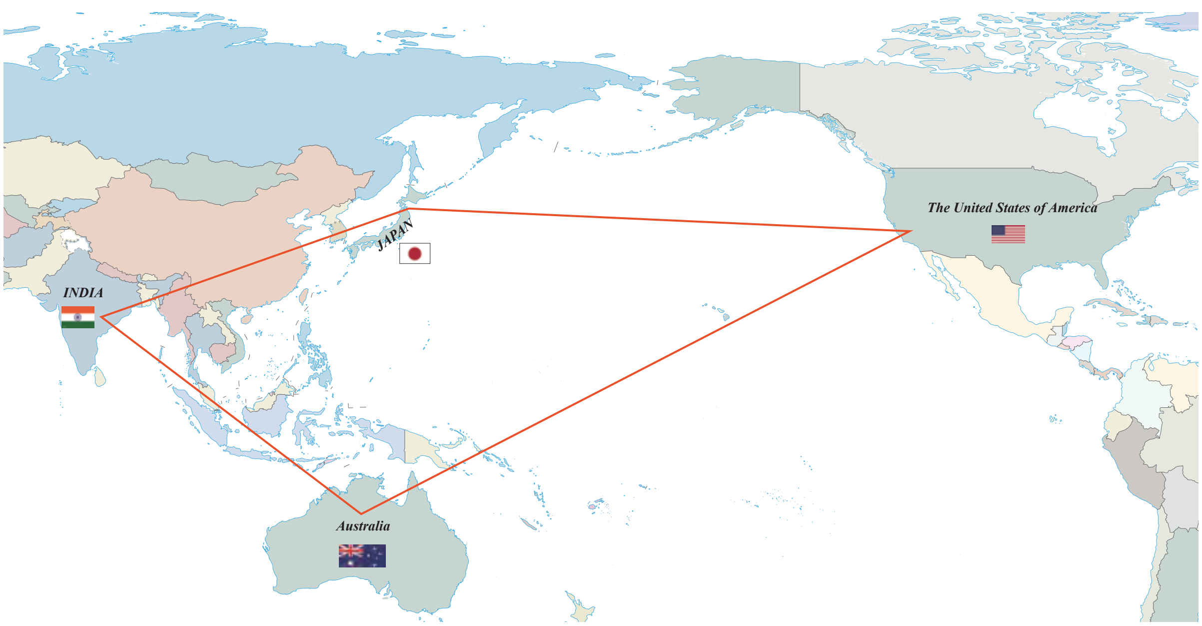
From the view of geopolitics, the "diamond" shaped energy cooperation model echoes the energy supply chains between Europe and the United States, which has consolidated the global energy dominance of the United States.

Figure 3.5: Change in US Gas Exports



Source: UN Comtrade.

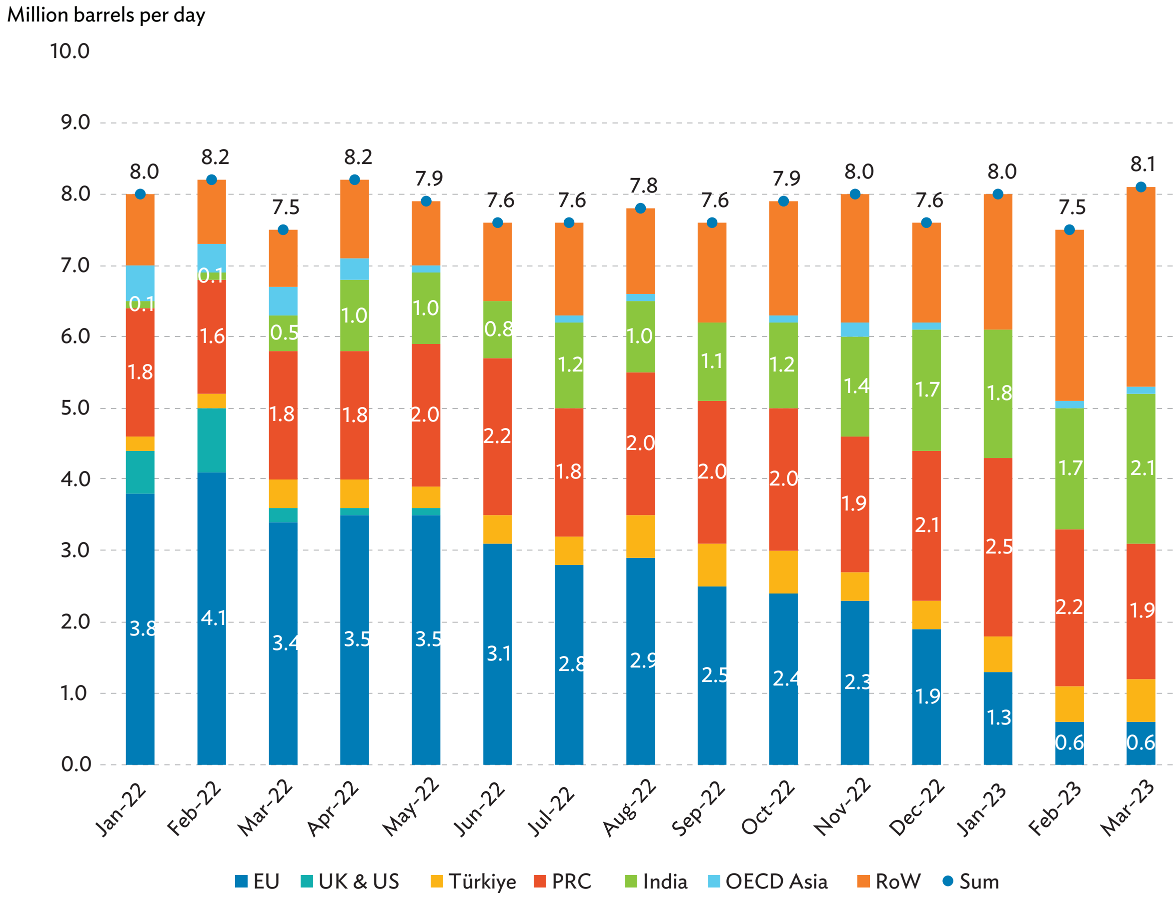
Figure 3.6: The Diamond Energy Supply Chain in Asia-Pacific



The Eurasian energy supply chain

European countries rely as much as 20-40% on Russia's oil and natural gas imports. The economic sanctions on Russia have led Russia to increase energy exports to neutral countries such as the PRC and India, making Asia a vital part of the Eurasian energy supply chain (Figure 3.7). According to the latest data, India and the PRC have become the largest buyers of Russian energy. In June, the PRC imported record-breaking levels of Russian crude, a 44% increase compared to the same month in 2022[8]. Russia's share in India's crude oil imports soared to 19.1% from 2.0% a year ago, according to the latest annual report by the Reserve Bank of India (RBI)[9].

Figure 3.7: Change in Russian Oil Exports



Source: IEA.

The New Russia-Mongolia-PRC East Gas Pipeline

In May 2014, the PRC and Russia signed the Sino-Russian Eastern Gas Pipeline project, the first natural gas cooperation agreement between the PRC and Russia, which was officially implemented in December 2019. The pipeline starts from East Siberia, Russia, and enters Heilongjiang, the PRC from Blagoveshchensk. In the same year, the PRC and Russia signed the PRC-Russia Western Pipeline Cooperation Agreement, further strengthening the energy cooperation between the PRC and Russia. In February 2022, the cooperation between Russia and the PRC was further strengthened by signing the

8 PRC Snaps Up Record-High Volumes Of Russian Crude In The First Half Of 2023 | OilPrice.com

9 Fortune India: Business News, Strategy, Finance and Corporate Insight

Far East Gas Purchase and Sale Agreement, which plans to build the "Siberian Power 2" pipeline through Mongolia. As a result, for the first time, Russia connected the natural gas fields supplied to Europe with Asia, forming a "Eurasian energy supply chain," strengthening Russian-Chinese energy cooperation at the international level, as well as the position of the RMB and ruble in the world (Figure 3.8). In addition, the construction of the western line has laid the foundation for Russia's energy cooperation with other Asian countries, allowing it to transport natural gas to Asian nations through the PRC.

Figure 3.8: The West and East Pipeline of Russia to Asia

With the construction of the "Eurasian energy supply chain", "European and American energy supply chain", and "Diamond energy supply chain", the global energy supply chain has undergone significant changes. This has resulted in the formation of two major regional energy systems centered around PRC-Russia and the US. In this process, these two energy systems will engage in intense competition for a broader energy market and greater influence, creating a new mode of confrontation, eventually leading to the formation of a new Cold War system.

The OPEC Energy Supply Chains

As an oil monopoly, OPEC has dominated global energy supply and energy pricing for a long time. However, OPEC's position in the world energy market has declined as internal conflicts within OPEC have intensified and other energy supply chains have emerged. Especially, the large-scale development and sale of shale gas from the US strengthened the oil-dollar power and weakened OPEC's voice and influence. However, as the largest energy supply group, OPEC still maintains its fundamental position in energy supply. In 2021, OPEC countries exported 19.7 million barrels per day of crude oil, down 0.2% from 2020, but still accounting for 47% of global crude oil exports. Thus, OPEC plays an important role in guaranteeing basic global energy supply and energy security. However, there has been some change in OPEC's behavior since the outbreak of the Russian war in Ukraine. Saudi Arabia is gradually strengthening its effective cooperation with Russia in OPEC+ and developing mutually beneficial cooperation in trade and economic matters. In addition, OPEC+ decided at the 33rd Ministerial Meeting of OPEC+ on October 5, 2022 to reduce total crude oil production by 2 million barrels per day from November, which is equivalent to about 2% of global oil demand. As a result, OPEC has strengthened its cooperation with Russia and other countries while ensuring the basic supply of global energy, which has a certain impact and influence on global energy supply lines and global energy prices in the context of the Russian war in Ukraine.

The above analysis shows that the future global energy supply chain will change in the direction of regionalization, and the energy cooperation in each region will be gradually strengthened. On the one hand, the strengthening of the US-European energy supply chain may strengthen the US influence over the EU countries and global energy market, and at the same time strengthen the petrodollar. Also, the four-sided "diamond" cooperation model formed by Japan, the US, Australia and India echo the European and US energy supply chains, forming a larger regional energy supply relationship, which to a certain extent also enhances the international status of the US dollar and further strengthens America's grip on world energy.

On the other hand, the energy cooperation between Russia and Asian countries (PRC, India, Mongolia) promotes the formation of the Eurasian energy supply chain, strengthens the international status of the RMB and ruble, and may result in a confrontational relationship with the European and American energy supply chains, eventually leading to the emergence of a new Cold War system.

The next section discusses how European countries may reduce their energy dependence on Russia and the United States due to the development of renewable energies. This would enable European countries to maintain a relatively independent position and perhaps to take a leading position in the development of renewable energy globally, thus strengthening the position of European countries and strengthening the euro.

Expectation of an independent European energy supply chain

The cost and risk of imported US energy is high in Europe, due to the long transport distance involving both sea and land, and the lack of pipeline transport. According to energy expert Laurent Segalen, the European purchase price of a ship filled with LNG from the United States in 2022 had risen to 275 million dollars, compared to the original price of $60 million. Therefore, the E.U. countries may seek to avoid excessive reliance on the US by reducing LNG imports from there. Also, the EU could seek a compromise with Russia to maintain a basic level of gas imports, for example, according to a report from the Russian Satellite News Agency in Ankara on the 19th, President Vladimir Putin of Russia has now reached an agreement with President Recep Tayyip Erdoğan of Türkiye on the issue of the natural gas hub, allowing Europe to use Russian natural gas via Türkiye. An important alternative for the EU over the next few years would be to accelerate the development of renewable energy to speed up its energy transition and build an independent energy supply chain. The development of renewable energy can not only help European countries reduce their dependence on Russia but also lessen their reliance on the United States. This can lead to a relatively independent position.

CGE Simulation Analysis for the Impact of the Energy Supply Chains Re-Shaping

This section simulates the Russian war in Ukraine and some energy supply chain re-shaping scenarios in Section 3.2 using the GTAP-E model (Mcdougall and Golub, 2007) to predict their impact on the global economy and energy trade. This section aims to quantify the changes in the global economy and energy trade under some of the energy supply chain restructuring scenarios presented in Section 3.2. In the scenario setting, we try to capture all possible factors that have led to the formation and stabilization of various energy supply chains, The simulation assessment here is a comparative static analysis that aims to compare the difference between the designed scenario and the baseline scenario results to determine the impact of the former.

Scenario setting

Scenario 1: The Russian war in Ukraine. This scenario considers the impact of the Russian war in Ukraine on the global energy market, including the rise of global energy prices and energy transportation costs, and the restriction of Russian energy exports. Based on the data tracker, it is assumed that the Russian war in Ukraine will increase the prices of coal, oil, gas, and oil products by 10%, 2.5%, 3%, and 10% respectively, and the cost of energy transportation will rise by 10%. In addition, we simulate the decrease of Russian energy exports as a shock to the technical coefficients of the economies' energy imports from Russia.

Scenario 2: The EU-US energy supply chains. The main measures of this scenario are assumed as follows: (1) Europe and the United States impose an energy embargo on Russia. Specifically, European and US imports of coal, oil, and oil products from Russia are 0. Given Europe's dependence on Russian natural gas and the difficulty of replacing natural gas imports, it is assumed that Europe's natural gas imports from Russia are cut by 80% and US natural gas imports from Russia are 0. (2) The EU and G7 countries' energy sanctions against Russia also include the imposition of price limits on Russia's energy exports. The assumption here is that Russian gas export and coal export prices fall by 2% and oil and oil products export prices fall by 5%. (3) Europe will strengthen energy imports from the United States to replace its dependence on Russian energy. This is bound to increase the cost of European imports, which is reflected through the following treatment: 30% of the energy subsidies of European countries are used to subsidize imports from the United States and Norway[10].

Scenario 3: Eurasian energy supply chain. This scenario includes: (1) Russia increases energy exports to neutral countries such as the PRC and India. This is achieved by simulating a fall in the cost of energy imports from Russia[11].(2) The PRC's energy supply chain from Central Asia is strengthened. This is mainly achieved through the improvement of energy trade facilitation. Assume that the PRC's oil and oil products trade facilitation from Central Asia is improved by 5% and gas trade facilitation is improved by 2.5%. (3) The Eurasian energy supply chain may face energy sanctions from the European and American Allies. Here we assume that the US and EU raise export taxes on energy products to the PRC by 1%.

Scenario 4: Japan-Australia-India-US energy supply chain. With the Indo-Pacific Strategy, Japan, India, Australia, and the United States will promote energy cooperation and accelerate infrastructure construction for the energy supply chain, assuming a 5% reduction in the cost of non-tariff barriers.

Scenario 5: This scenario is the combination of the above four scenarios.

CGE simulation results[12]

The impact on real GDP

In terms of GDP impact (Figure 3.9), the Russian war in Ukraine scenario results in varying degrees of recession in different economies, except for Norway. The strengthening of energy supply chains between the EU and the US has come at the cost of economic losses in Europe and the US. For instance, Germany's GDP is projected to decrease by 1.6 %. The effect of the Eurasian energy supply chain on the global economy

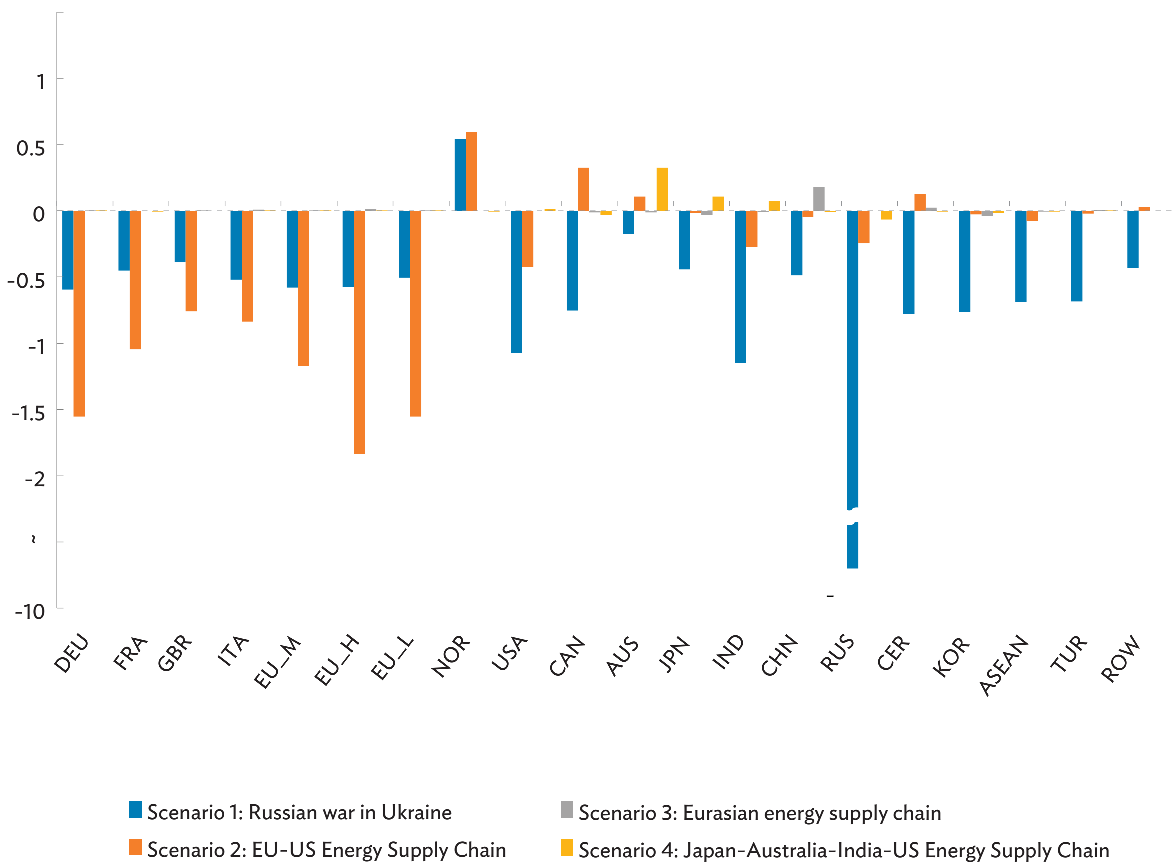
10 Bruegel reported on the proportion of fiscal subsidies provided by EU countries and the UK to GDP in response to the energy crisis(https://www.bruegel.org/dataset/national-policies-shield-consumers-rising-energy-prices). Assume that 30% of these subsidies are used to completely replace Russian gas imports with the United States and Norway. The change in natural gas import price $pims_{s,r}^{gas}$ can be obtained by the formula $pims_{s,r}^{gas} = \left(\frac{\delta_{s,r} * F_r^{gas}}{VIMS_{s,r}^{gas}} - \frac{\gamma_{s,r} * QIMS_{RUS,r}^{gas}}{QIMS_{s,r}^{gas}}\right) * 100$. Where r represents the EU countries and the UK, s represents the US and Norway, F_r^{gas} represents the amount of natural gas import subsidies for the economies of the EU countries and the UK, *VIMS* and *QIMS* are the value and quantity of imports, respectively. δ is the distribution share of natural gas import subsidies in the US and Norway, and it is assumed that the subsidies received by the US account for 0.8 of the total subsidies in the simulation, and γ is the distribution coefficient of the amount of natural gas imported to replace Russia, and γ is assumed to be 0.5 in the simulation. The change of import cost caused by import price can in turn be countered by the reduction of import tariff rate, so the tariff reduction shock is used here to simulate the substitution of natural gas imports from the US and Norway in the EU and the UK.

11 Based on the data of changes in the price of energy imported from Russia by PRC and India in 2022, it is assumed that the price of Russian oil imported by the PRC and India falls by 10% and 20% respectively, and the price of gas imported by 40% and 20% respectively. Import tariffs on coal from Russia fall to zero for the PRC and India.

12 The GTAP version 10 database used for the simulations, which has the base year of 2014, covers 121 countries as well as 20 regional collections, including 56 industry sectors (Aguiar et al., 2019), and the countries were processed in groups for the analysis, resulting in 20 country groups, as shown in the annex 3.1.

is limited, with the PRC benefiting relatively significantly. The facilitation of energy trade between Japan, Australia, India, and the US has had a minimal impact on the US but contributes to economic growth in the other three countries.

Figure 3.9: Real GDP Impact of Energy Supply Chain Restructuring
(% Changes Relative to the Baseline)



Note: See annex 3.1 for a key to country abbreviations.
Source: simulation result based on GTAP-E model.

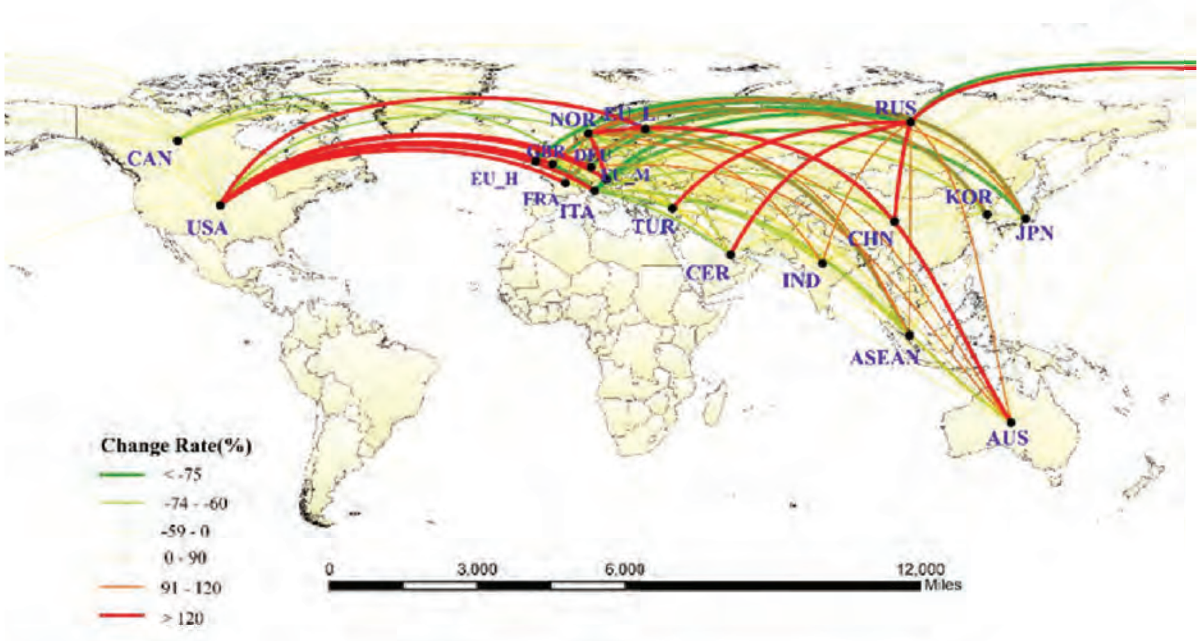
The impact on gas trade

The restructuring of energy supplies in the EU-US results in a notable decrease in their gas imports from Russia and a significant rise in US gas exports to Europe (Figure 3.10). Russian gas exports shift primarily towards Asia.

The Eurasian energy supply chain has not reshaped global gas trade as much as the EU-US energy supply chains, as the major changes in gas trade flows occur along two routes, with little impact on gas trade flows between other economies (Figure 3.11). The first route is the “Russian-Central Asia to PRC-India”. Russian gas exports to the PRC and India will grow significantly by 176.1% and 93.5% respectively, while Central East Region (CER) gas exports to the PRC will also grow by 68.2%. The second route is “EU-US to PRC”, where the US and the EU gas exports to the PRC are down by about 40 %.

Figure 3.10: Changes in Gas Trade Flows Under EU-US Energy Supply Chains Scenarios (% Changes Relative to the Baseline)

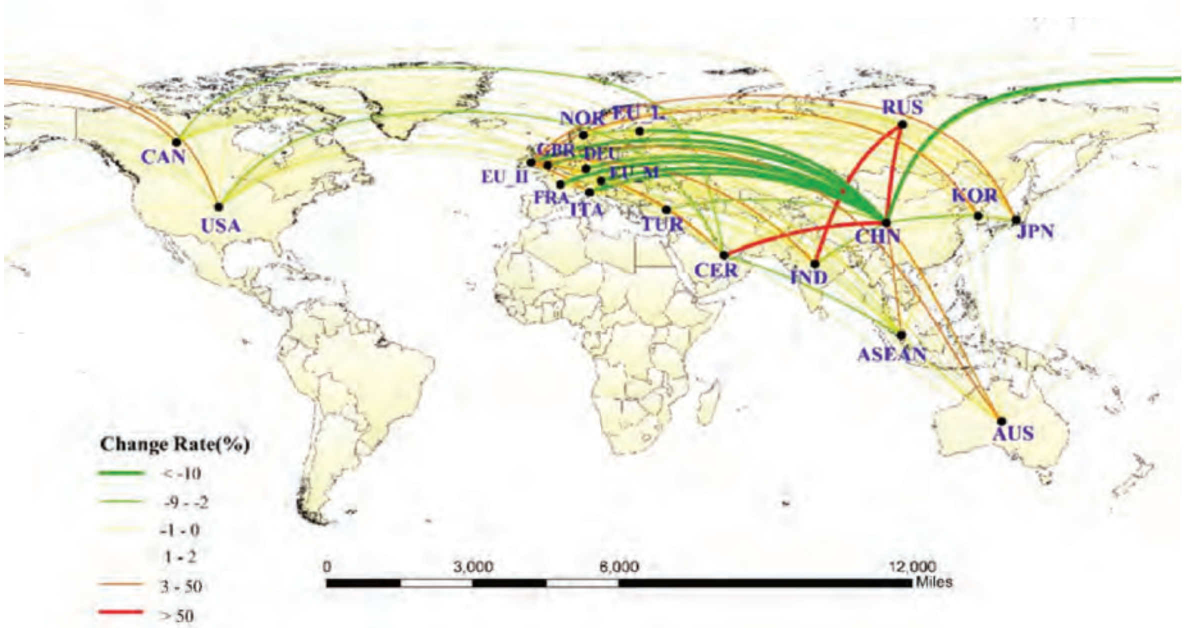
Rate of Change in Gas Trade Before and After the Shock



Source: simulation result based on GTAP-E model.

Figure 3.11: Changes in Gas Trade Flows Under Eurasian Energy Supply Chains Scenarios (% Changes Relative to the Baseline)

Rate of Change in Gas Trade Before and After the Shock



Source: simulation result based on GTAP-E model.

The impact on oil trade

Table 1 reports changes in global oil trade under all scenarios combined. Russia's oil exports to Europe and the US disappear completely. Russia's total oil exports decline by 37.9 % although there has been an increase in exports to other economies, such as a significant increase of 236.4 % to India. For the PRC, energy sanctions imposed by Europe and the United States have also affected the PRC's oil imports from other economies, making energy cooperation with Russia and CER crucial for ensuring the security of the PRC's oil imports. Some EU economies would face challenges in meeting their oil demand after the closure of the oil import route from Russia, despite an increase in oil imports from other sources. For instance, EU_L (EU economies with low dependence on Russian energy) and Germany experienced a decline in their total oil imports by 7.8% and 2.3%, respectively. The energy cooperation between the US, Japan, Australia, and India leads to significant growth in four-way oil trade, but it has had little impact on the total oil imports of these four countries.

Table 3.1: Change in Oil Trade Flows Under the Combined Scenario
(% Changes Relative to the Baseline)

	ASEAN	AUS	CAN	CER	CHN	DEU	EU_H	EU_L	EU_M	FRA	GBR	IND	ITA	JPN	KOR	NOR	RUS	TUR	USA
ASEAN	-3.70	-1.11	2.46	0.74	-27.08	89.36	42.17	156.99	43.06	7.77	7.79	-0.72	41.77	-6.69	-7.30	1.99	-23.32	-8.80	-1.17
AUS	-3.70	56.36	-0.17	-1.50	-27.05	84.56	38.62	150.48	39.40	5.01	5.06	102.76	38.11	46.67	-7.19	1.99	-25.28	-11.15	56.28
CAN	-2.96	1.11	2.46	0.74	-27.02	89.36	39.90	156.99	39.51	5.01	5.02	-0.72	38.12	-4.23	-4.85	2.03	-23.32	-8.80	-1.45
CER	-3.69	-1.11	-0.16	-1.79	15.35	84.83	38.98	156.99	39.42	5.00	5.07	-0.73	38.16	-6.69	-7.30	1.99	-23.32	-8.80	-1.20
CHN	-2.53	-1.12	2.46	-1.45	-25.16	89.36	42.17	156.02	43.07	7.77	7.79	1.88	41.77	-4.21	-4.85	1.99	-23.32	-8.80	1.41
DEU	-1.15	-0.59	2.46	0.74	-32.59	89.36	42.17	156.24	39.03	4.87	7.79	1.88	41.77	-4.21	-4.85	1.99	-23.32	-8.80	1.14
EU_H	-1.15	-0.71	1.48	0.74	-32.59	89.36	42.16	150.40	39.02	0.99	4.78	1.88	37.77	-4.21	-4.85	2.00	-23.32	-8.80	1.41
EU_L	-1.15	-1.11	2.46	0.74	-32.59	84.01	40.55	149.75	39.05	5.00	4.75	1.88	41.77	-4.21	-4.85	1.99	-23.32	-8.80	-0.51
EU_M	-1.15	-1.07	1.65	0.58	-32.59	84.01	38.16	150.02	36.70	4.89	4.76	1.88	37.84	-4.21	-5.78	1.99	-23.32	-8.80	0.83
FRA	-1.15	-1.08	2.46	0.74	-32.59	84.44	41.55	156.99	39.42	7.77	7.79	1.88	41.77	-4.21	-4.85	1.99	-23.32	-8.80	1.41
GBR	-3.67	-1.08	-0.18	-1.31	-34.06	84.01	38.16	149.75	39.13	5.00	7.79	-4.00	37.77	-4.21	-7.30	1.77	-23.32	-8.80	-1.20
IND	-1.15	56.41	2.46	-1.75	-25.16	89.36	42.17	156.99	43.07	7.77	7.79	61.15	41.77	50.57	-4.85	1.99	-23.32	-8.80	60.41
ITA	-1.15	-1.04	2.46	-5.50	-32.59	84.01	39.75	139.94	38.43	5.00	5.28	1.88	41.77	-4.21	-4.85	1.99	-23.32	-11.14	0.08
JPN	-3.71	56.37	2.46	0.74	-25.16	89.36	42.17	156.99	43.07	7.77	7.79	61.15	41.77	50.57	-4.85	1.99	-25.03	-8.80	60.41
KOR	-3.70	-1.11	2.46	0.74	-25.16	89.36	42.17	156.99	43.07	7.77	7.79	1.88	41.77	-4.21	-4.85	1.99	-23.32	-8.80	1.41
NOR	-3.73	-1.15	-0.18	-1.85	-27.11	84.01	38.16	149.75	39.05	5.00	4.75	-0.76	37.77	-6.72	-7.33	1.99	-25.32	-11.17	-1.20
RUS	54.35	58.47	61.90	57.34	65.66	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	236.42	-100.00	48.63	48.59	63.46	26.93	42.42	-100.00
TUR	-3.69	1.18	2.46	0.74	-25.16	89.36	38.53	150.40	43.07	7.77	7.79	-0.73	38.13	-4.21	-4.85	2.17	-23.32	-8.80	1.41
USA	-3.69	56.42	-0.43	0.63	-35.80	84.49	38.59	155.34	38.88	5.90	7.25	50.62	32.43	46.69	-7.30	1.99	-23.32	-8.80	60.41

Note: The vertical coordinate represents the exporter and the horizontal coordinate represents the importer.
Source: simulation result based on GTAP-E model.

3.4 Renewable Energy and the Future Directions of Energy Supply Chains and Energy Trade

Carbon Neutrality, Energy Transition, and Renewable Energy Development

Energy transition is the key for carbon neutrality

Shifting to low-carbon renewable energy is a crucial step in meeting global climate goals outlined in agreements like the Paris Agreement. To implement the Paris agreement, most countries have committed to reduce greenhouse gas emissions and made roadmaps and timetables for carbon neutrality. To neutralize their carbon emissions, it is crucial to increase the share of renewable energy in their energy mix. For this purpose, governments worldwide have been setting renewable energy targets and increasing their investments in energy related sectors. As a result, there has been a significant expansion of renewable energy capacity across the globe, contributing to a more diversified and sustainable energy mix. Climate change mitigation efforts will lead to the implementation of policies and regulations that support renewable energy adoption. Supportive policies, such as feed-in tariffs and renewable energy standards, can incentivize investment in renewable energy projects and influence trade patterns.

Current globalizing energy supply chains

Renewable energy supply chains are global because they capitalize on diverse resources, technology specialization, economies of scale, and international collaboration. The global nature of these supply chains is essential to meet the growing demand for renewable energy and combat climate change on a global scale.

Renewable energy technologies need to be sourced from different countries with significant manufacturing capacity or natural resources such as lithium reserves, leading to a global supply chain. Renewable energy technologies are more technology and material intensive. However, the production of renewable energy technologies relies on specific raw materials and minerals. Different countries have comparative advantages in specific aspects of renewable energy technology production.
The materials that underpin renewable energy are more concentrated in fewer countries than those for fossil fuels (IEA, 2021). For example, lithium resources mainly present in Australia, Argentina, Bolivia and Chile. These comparative advantages necessitate cross-border trade and collaboration to access the best technologies and components.

Furthermore, the manufacturing characteristics of the renewable technologies lead to economies of scale, which further promote globalized energy supply chains. Renewable energy projects, such as large solar or wind farms, benefit from economies of scale. To achieve cost-effectiveness, these projects often involve the production and assembly of components in countries with efficient manufacturing capabilities. This global approach enables the mass production of renewable energy technologies at competitive prices and has driven continuous price declines in the past (Goldthau and Hughes, 2020).

Opportunities of Renewable Energy

Renewable energy development is boosted by both supply and demand factors. On the demand side, carbon neutrality targets are stimulating the demand for renewable energy and promoting the energy transition. The energy transition will lead to a surge in demand for renewable energy technologies such as solar panels, wind turbines, and energy storage systems. Thus the energy transition will lead to greater integration of renewable energy sources into global energy systems.

On the supply side, continuous research and development (R&D) is driving innovations in renewable energy technologies, leading to increased efficiency and cost reductions. The cost of renewable energy generation has been steadily declining, making it increasingly cost-competitive with traditional energy sources. In many regions, renewable energy sources have achieved grid parity, meaning they can produce electricity at a cost comparable to or even lower than conventional sources.

According to BP Energy Outlook (2023), renewables are expected to expand rapidly in the future. Their share in the primary energy supply is forecasted to increase from 11.8% in 2019 to 34.9-64.0% in 2050. Solar and wind power will experience significant growth

Their total installed capacity is expected to increase up to 16 times in 2050, from 1231 GW in 2019 to 11420-20225 GW in 2050. The PRC dominates the growth of solar and wind capacity between 2022 and 2035. The rapid expansion of renewables will lead to significant growth of manufacturing. For example, to support these ambitious targets, global production capacity for the key building blocks of solar panels – polysilicon, ingots, wafers, cells and modules – would need to more than double by 2030 from today's levels and existing production facilities would need to be modernized (IEA, 2022b).

Renewable energy supply chains and the new world energy market and trade

As renewable energy technologies continue to advance and become more economically viable, they are expected to play a pivotal role in shaping the global energy and even political landscape. The renewable energy development will require changes in the energy infrastructure and transmission networks to accommodate the variable nature of renewable energy. This will lead to opportunities for new investment. From green bonds to carbon trading, various financial instruments are emerging to support the development and deployment of renewable energy projects.

Renewable energy technologies allow for decentralized energy production, enabling communities and individual households to generate their own electricity. In contrast, in the present fossil fuel dominant system, electricity is generated by large companies. This democratization of energy empowers consumers, reduces dependence on centralized power systems, and fosters energy independence. Aggregately, by diversifying energy sources and reducing reliance on fossil fuel imports, countries can enhance their energy security and reduce exposure to volatile global energy markets.

Renewable power development increases regional power connectivity. Renewable energy sources, such as solar, wind, and hydro, vary in abundance across different regions. To harness the full potential of renewable energy, countries often need to tap into resources found in diverse geographical locations, necessitating more interconnected energy grids. Interconnected energy grids allow the efficient transmission of renewable power over long distances, facilitating the integration of renewable energy from various sources and locations.

Adoption of renewable energy technologies could even shape trade relations and geopolitical dynamics. For example, both Republic of Korea and Japan have experienced a significant transformation in their trade relationship with the PRC, moving from a state of strong complementarities to a situation of increasing competition in key strategic industries. Key among these are car exports – including the rapidly growing market of electric vehicles (EVs). The PRC surpassed Japan in the first quarter of 2023 to become the world's largest car exporter, and Chinese producers have started to exert dominance in domestic sales, resulting in a sharp decline in the fortunes of Japanese carmakers (Michael Harley, 2023). While this already presents troubling milestones for Japan's champion automotive industry, the PRC's growth in the EV sector potentially presents bigger challenges. In 2022, the PRC managed to secure around 35% of the global EV export market, while Japan's share has declined from approximately 25% to less than 10% over a four-year period (2018-2022) (IEA, 2023a). The PRC's growing competitiveness and market share in the EV export market is viewed as a threat to Japan and the Republic of Korea, which may affect geopolitical dynamics. Moreover, with the escalating EV sector competition, EV batteries, and the critical minerals needed to produce them such as lithium, are also increasingly being considered as an economic security issue (Corey Lee Bell et al., 2023).

Challenges facing to renewable energy supply chains

One of the challenges to renewable energy has been intermittency, as sources like solar and wind depend on weather conditions. The prevailing storage technologies can only provide at a maximum short-term backup, while power system reliability needs longer-term backup. A reliable power supply needs backup in five timescales: annual, quarterly, monthly, daily, and spinning back up. In contrast, battery and pumped hydrogen storage are designed to provide back up within an hour and a day, respectively (Blakers et al., 2021)home and electric vehicle batteries. Batteries are rapidly falling in price and can compete with pumped hydro for short-term storage (minutes to hours. Although widely viewed as a stable power supply source, hydropower can have seasonal and yearly variability, such as dry and wet seasons and years (Stokstad, 2016). In the absence of long-term storage capacity and before the extensive deployment of long-term storage technologies, mainly renewable electricity made from hydrogen, renewable energies will face increasing challenges over the term of their development.

Further advancements in energy storage technologies, such as batteries and pumped hydro storage, are required to enable greater utilization of renewable energy and ensure stable grid operations. Therefore, the crucial elements of energy innovation are breakthroughs in energy storage, grid integration, and smart energy management, which will make renewable sources more reliable and competitive.

Vulnerability of energy supply chains

Global supply chains that span multiple regions and nations can leave countries vulnerable to disruptions in international trade due to various factors. These vulnerabilities underscore the importance of carefully managing supply chains to promote the energy transition while securing the energy supply and economic development.

Countries heavily reliant on renewable energy imports may face supply shortages or increased costs during trade disruptions. For instance, trade disputes, tariffs, or geopolitical tensions can trigger disruptions in the global trade of renewable energy components and resources, leading to potential supply shortages or increased costs for countries heavily reliant on imports. According to IEA's Special Report on Solar PV Global Supply Chains, from 2011, the imposition of antidumping, countervailing, and import duties on various components of the solar PV supply chain has escalated significantly, rising from a single import tax to 17 duties and import taxes, with an additional 8 policies currently being reviewed (IEA, 2022b). Collectively, these measures now encompass 17% of global demand, excluding the PRC's domestic demand (IEA, 2022b). Moreover, some countries may introduce carbon border adjustment mechanisms to address the carbon leakage issue and protect domestic industries from imports with high carbon footprints. Such mechanisms could impact the competitiveness of renewable energy products in global markets.

Concentration of production and process of renewable energy technologies and materials leads to supply chain vulnerability. Energy production and distribution are often concentrated in specific regions or countries. For example, the PRC is set to attain a nearly 95% share of global polysilicon based on the manufacturing capacity currently under construction (IEA, 2022b). Many renewable energy technologies rely on specific raw materials that are sourced from a limited number of countries (IEA, 2021). Any disruptions, whether caused by geopolitical tensions, accidents, or extreme weather events, can lead to shortages and price spikes in the global energy market and further impact the production and deployment of renewable energy technologies globally.

Security issues with critical energy transition minerals

The energy transition requires significant development of critical mineral sectors since low-carbon technologies are mineral intensive. Due to natural resource endowment, the supply chains of critical minerals are more concentrated than those of fossil fuels(IEA, 2021). Therefore, meeting the 1.5 degree goals will require collaboration among suppliers to supply critical minerals. Despite the higher level of concentration, the energy security concerns of critical minerals should not be as serious as fossil fuels. The combination of high concentration and limited transparency renders critical minerals more susceptible to physical disruption, trade restrictions, or other developments in major producing countries compared to fossil fuels. However, unlike fossil fuels that need continuous supply of fuels, renewable energy does not need fuel and other continuous inputs.

Unfortunately, the contemporary global geopolitical environment, particularly the Sino-American competition and the global surge in protectionism, is increasingly weaponizing the critical mineral sector. An example is Canada's forced divestment of Chinese investors (Ismail Shakil and Siyi Liu, 2022).

Compromising international trade, investment and cooperation puts the energy transition at risk because low-carbon technologies rely on international trade networks and investment to keep costs down and encourage learning and innovation (Goldthau and Hughes, 2020; Helveston and Nahm, 2019) . While lithium prices have recently reached record highs, present lithium-ion battery prices per kilowatt hour are 30 times cheaper than in the early 1990s (Ziegler and Trancik, 2021).

3.5 Potential Impact of the Energy Dynamics on the Emission Goals

The IPCC Special Report on Global Warming of 1.5 °C (IPCC, October 8, 2018) urged limiting the global temperature rise within 1.5 °C by 2030 in order to avoid the catastrophic effects of extreme weather on the world. To do so, the 2019 climate Paris agreement confirmed that developed and developing countries have to achieve carbon neutrality by 2050 and 2060 respectively. Furthermore, all countries have to achieve net zero carbon dioxide emissions between 2070 and 2090, and the whole world achieve net zero greenhouse gas emissions by 2100. After the Paris agreement, most countries made plans to reach the carbon neutrality targets and attained some important achievements through developing renewable energy while reducing the use of fossil fuels. At the COP 26, more than 40 countries including US and EU countries, announced an agreement to phase-out coal by 2030 and promised to replace virtually all traditional energy with wind, solar or nuclear power and speed up energy transition around 2035. The PRC also promised to terminate oversea investment to coalfired power generation.

However, the disruption of energy supply chains during the COVID-19 pandemic (see above) and the current geopolitical changes, especially the Russian war in Ukraine, began to affect the speed of the world energy transition and the timetable for carbon neutrality. We predict the effects of the war on environment and climate governance from the perspectives of short-term and long-term.

a. Short term: energy dynamics will have an impact on global climate governance

The issue of energy supply remains severe in the short term. Since the carbon content per unit calorific value of natural gas (15.3 tC/TJ) is significantly lower than that of coal (26.37 tC/TJ), the increased use of coal by European countries in the face of the energy shortage increased carbon emissions. Similarly, to meet increasing electricity demand, the PRC has plans for more than 10 new coalfired power generation stations, some of which are under construction. And while energy-related CO_2 emissions declined during the pandemic-induced recession, this was offset by the 2021 increase of 1.9 Gt, the largest in history (IEA, 2022d).

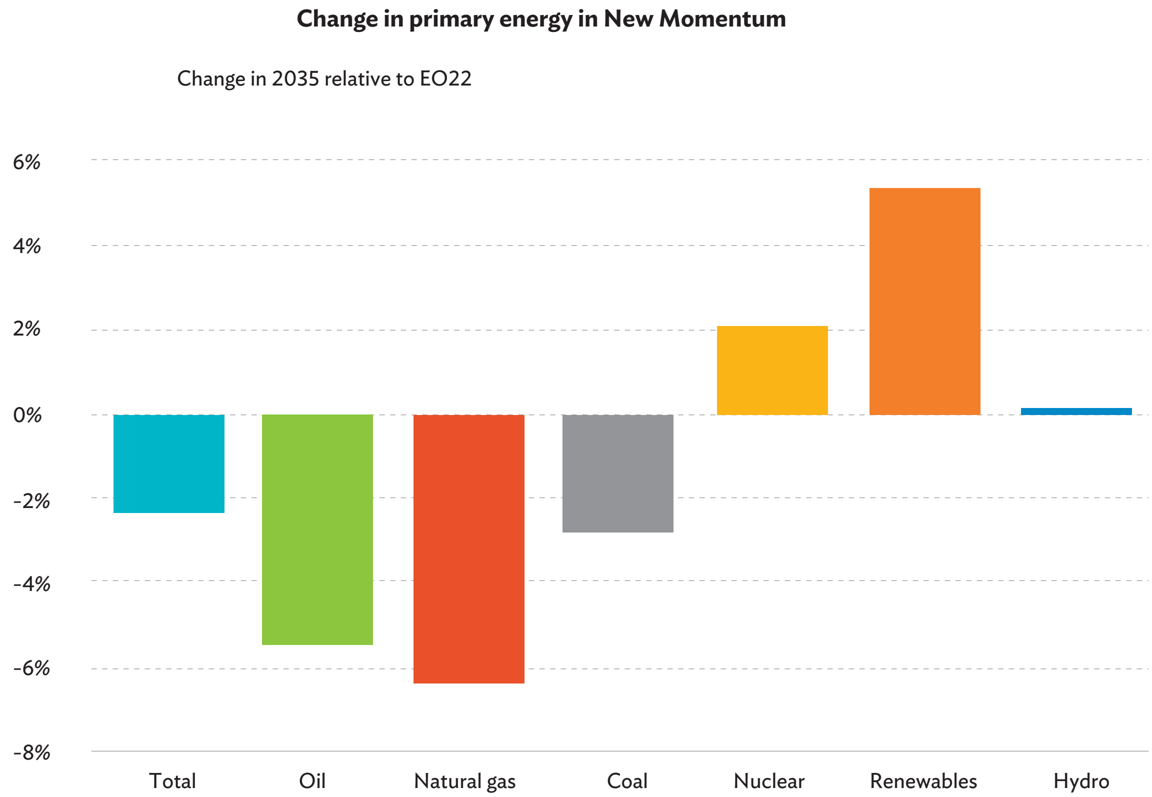
b. Long term: energy dynamics will accelerate the energy transition and promote the carbon reduction process

The disruption of Europe's natural gas supply chain has increased the impetus for investment in and use of renewable energy. On September 13, 2022, to achieve the "Fit for 55" goal, the E.U. Parliament adopted the Renewable Energy Development Directive (REDII), which stipulates that the share of renewable energy consumption will reach 45% by 2030. Thus, European countries may achieve the carbon neutrality earlier and take a leading position and voice in global environmental and climate governance.

c. Energy security and energy supply chains resilience will be the key for the future GVC design

In addition, the outbreak of the Russian war in Ukraine triggered a deeper global reflection on energy security and energy transition, with countries struggling to balance energy security, energy reliability and energy cleanliness. In terms of energy supply, global oil and gas prices have soared since the outbreak of the Russian war in Ukraine, and the subsequent sanctions imposed on Russia by Europe and the US have exacerbated the energy supply crunch. Governments around the world are bound to develop indigenous resources, many of which are not fossil fuels, on a larger scale in order to ensure energy security. This will reduce global dependence on fossil energy and change the global energy supply structure (as shown in Figure 3.12).

Figure 3.12: Change in Primary Energy in the Future

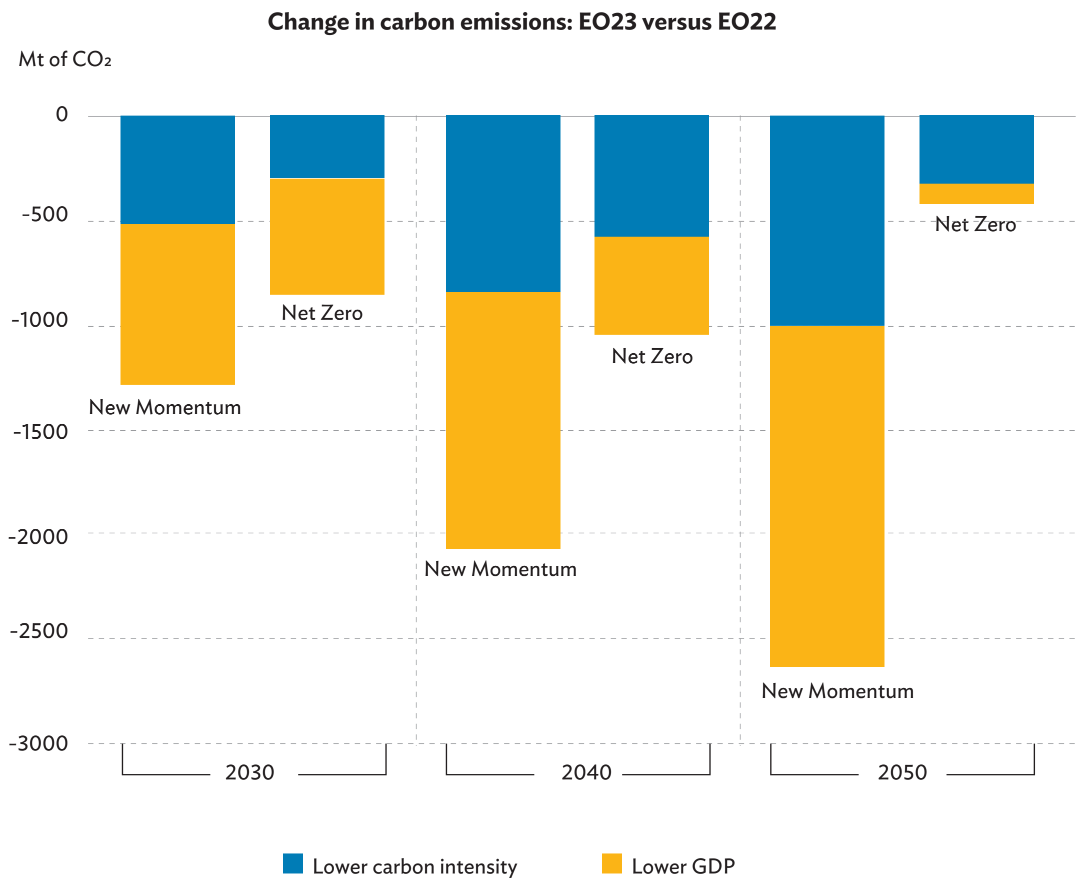


Note: New Momentum is designed to capture the broad trajectory along which the global energy system is currently travelling. It places weight on the marked increase in global ambition for decarbonization in recent years, as well as on the manner and speed of decarbonization seen over the recent New Momentum past. CO_2 emissions in New Momentum peak in the 2020s and by 2050 are around 30% below 2019 levels.

Source: BP Energy Outlook 2023. EO22 means Energy Outlook 2022

The change in the global energy structure and the increased demand for clean energy will not only improve energy security, but will also reduce global carbon emissions and accelerate the process of achieving carbon neutrality in all countries around the world. According to the BP Energy Outlook 2023, carbon emissions in this year's New Momentum scenario are around 1.3 $GtCO_2$ (3.7%) lower in 2030 than in 2022 Energy Outlook. This downward revision increases to around 2.0 $GtCO_2$ (6.4%) in 2040 and 2.6 $GtCO_2$ (9.3%) in 2050 (as shown in Figure 3.13).

Figure 3.13: CO_2 Emissions from Combusted Fuels in the Future



Note: CO_2 emissions in Net Zero by 2050 are around 95% below 2019 levels.
Source: BP Energy Outlook 2023. EO23 means Energy Outlook 2023.

Conclusions

The long-lasting Sino-US trade war and the ongoing Russian war in Ukraine are fueling geopolitical tensions and having huge impacts on global value chains, including global energy supply chains. These events have made geopolitical concerns rather than economic interests the dominant factor in shaping the policies governing energy trade.

Trade weaponization and trade sanctions are escalating. These will reshape the patterns of world energy trade to form some segmented regional energy supply chains, especially the EU-US energy supply chain and the Eurasia energy supply chain. These groupings will change the routes and patterns of world energy trade. WTO needs to follow these changes and update its functions. Shifting to green and low-carbon energy is a crucial step in meeting the net-zero-emission targets. As renewable energy technologies continue to advance and become more economically viable, renewable energy are expecting to play a pivotal role in reshaping the energy global supply chains and even political landscape.

All these dynamic movements are likely to affect the world energy transition and climate governance. One optimistic assumption is that the EU countries will use these crises as opportunities to speed up the development of renewable energy and formulate a new green energy supply chain to accelerate its energy transition and carbon neutrality.

Energy security and energy supply chain resilience will be the key for the future GVC design. Energy security is the cornerstone of stable national development, and unforeseen situations such as wars, extreme weather and large-scale pandemics can affect global energy supplies and pose a threat to energy supply chains. Therefore, ensuring the long-term security and reliability of energy supply chains is an issue that should be of concern to all countries around the world.

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