Svetlana A. Ikonnikova and *Sofia Berdysheva*

Managing Energy Security: The Analysis of Interfuel Substitution and International Energy Trade

Over the past two decades, global energy markets have undergone major shocks and dramatic transformations in demand and supply. The "Shale Revolution" in the US brought new and vast supply possibilities for natural gas and oil, and economic growth in China greatly increased demand for energy. A decade ago, the International Energy Agency's (IEA) report on the future of natural gas envisioned an increasingly prominent role for natural gas in global and individual countries' energy mix as a result of the climate change agenda (Birol et al. 2011). However, reliance on natural gas has put many countries into a vulnerable position because Russia, the top producer and exporter of fossil energy, had severe sanctions imposed on energy supplies after the start of the Russian-Ukrainian war.

Energy scarcity and high prices pose a major threat for an increasing number of countries around the world, including Germany, which was especially dependent on Russian imports. Although energy transition objectives have attracted increasing policy and economic attention, energy security issues are gaining heightened relevance in many countries, especially those with large import and export volumes.

Using UN Comtrade, the BP Statistical database, and IEA data on international energy flows, domestic production, and consumption, we uncover some important patterns in trade concentration. Our analysis suggests that countries not only compete in the markets by determining prices and trade volumes, but also consider the distribution of trade across their trade partners, i.e., optimizing trade concentration (Berdysheva and Ikonnikova 2021).

Expanding our analysis to assess energy portfolios and account for the share of domestic versus imported supplies, we have found that countries with a more balanced portfolio, with respect to both supplier and fuel diversification, are less exposed to security risks.

Using the results of the data analysis and our empirical observations, we discuss Germany's current position and develop policy recommendations. In particular, we point out the need to diversify suppliers, and/or make trade with existing suppliers more balanced in terms of their concentration. In addition, we explain how diversification across fuels and growth in a country's own supply, e.g., through investments in renewables, may help to boost energy security and mitigate potential future risks. We emphasize that governmental support may need to be coordinated across countries when devising energy transition incentives, energy security, and scarcity management measures (i.e., energy rationing). Finally, we highlight the positive impact of such international coordination.

KEY MESSAGES

- **Energy security and affordability are major concerns in the coming winter as Germany seeks substitutes for Russia's energy supplies**
- **We highlight the role of energy transition on its exposure to energy price shocks and its failure to include security considerations in its trading arrangements**
- **We analyze the global trade of coal, oil, and natural gas to track 1) interfuel switching, and 2) cross-country variance in security of supply (i.e., import concentration)**
- **We examine how energy security and affordability can be improved by domestic production, interfuel demand allocation, and trade balance**
- **We provide policy recommendations on coordination in 1) domestic energy production, 2) energy mix, and 3) new imports by destination, emphasizing the role of multinational coordination.**

GLOBAL ENERGY BALANCE AND THE GERMAN ECONOMY

While Germany is the European Union's largest economy, its GDP accounting for around 25 percent[1] and its total primary energy consumption (TPEC) for about 20 percent,[2] its share in the global TPEC has fallen from nearly 5 percent in the 1990s to only 2 percent in pre-Covid 2019. Such a dramatic reduction is linked to the decrease in country's energy consumption, which dropped by around 12 percent in total and by 17 percent in per capita terms. A further contributing factor to the change in Germany's position is the growth in global TPEC, almost 75 percent over the past 30 years, largely driven by economic growth in developing countries, in particular China and India.

Motivated by environmental considerations, Germany has incentivized advances in energy efficiency and the transition to low-carbon energy sources, such

[1] Throughout the paper, we use a database developed by compilation of UN Comtrade, the BP Statistical database, and IEA data. Unless mentioned otherwise, we refer to 2019 energy balances for consistency.

[2] In what follows, unless mentioned otherwise, we refer to the database combining BP Statistical Survey data, IEA, and UN Comtrade following Berdysheva and Ikonnikova (2021).

Svetlana Ikonnikova

is the Associate Professor for Resource Economics at the Technical University of Munich, School of Management. As a Research Director at the Center for Energy Markets, she leads the research programs on the energy transition, evolution of international energy trade, and emerging hydrogen market.

Sofia Berdysheva

is a Doctoral Researcher at the Technical University of Munich, School of Management. She is a part of the Center for Energy Markets and works on various issues of energy transition modeling international energy trade.

as wind, solar, biomass, and hydrogen. As a result, not only has Germany's total energy use decreased, but also its fossil fuel use has lessened. Despite being the fourth-largest global economy, with nearly 4.5 percent of the world's GDP, Germany consumes only ~2 percent of the fossil fuels produced globally.[3] In contrast, China, the world's second-largest economy and four times larger than Germany, consumes almost a quarter of the global energy to meet its demand and to fuel economic growth (Table 1).

Following the Kyoto Protocol and then the Paris Agreement, Germany has been replacing high-carbon with low-carbon energy sources, notably by replacing coal and (heating) oil with natural gas (Figure 1, left). A versatile fuel, natural gas is used in (1) heating, with the share of close to 45 percent, (2) power generation, where its share surpassed 30 percent in 2020 and 2021, and in (3) transportation, directly in (compressed) natural gas vehicles and indirectly in electric and fuel cell cars.[4]

Increased use of natural gas has helped Germany address its environmental goals, but it has made its economy more exposed to natural gas market shocks than previously. Germany's position in the international energy trade is remains prominent: it accounts for about 5 percent, 7 percent, and 9 percent of world oil, coal, and natural gas trade, respectively (Dale 2021).

In 2019 and until the war in Ukraine, Germany's primary energy trade partner, Russia, provided about 35 percent of its oil, around 55 percent of its coal, and almost 50 percent of its natural gas imports, both directly and indirectly. The heavy reliance on a single supplier, meeting about 45 percent of the entire country's energy need, has been a concern for several decades (Duffield 2009; Westphal 2014; Ikonnikova and Zwart 2014; Finley 2019). Yet, as its EU neighbors and other large energy buyers, including China, were working on diversifying towards liquefied natural gas (LNG), German policy objectives, focused primarily on the environmental sustainability agenda, paid scant attention to energy security. The transition to clean energy was expected to boost domestic energy production and therewith, to reduce the dependence on the imported fuels. Hence, investing in clean energy solutions should have improved energy security, considering the envisioned future fuel mix with the sharply reduced share of fossil fuel. In this context, the financial gains from trade with Russia were supporting the transition and future security. Neglecting the current security issues, Germany has avoided the costs of diversifying its supplies.

In the current reality, with a growing list of sanctions on Russia and its energy supplies, however, Germany and other countries are faced with energy scarcity and high prices. Our goal in this article is to offer some practical advice on energy mix rebalancing and trade rebooting, using the knowledge gained on energy markets participants' behavior combined with energy security concerns.

ENERGY SECURITY: INTER- AND INTRA-FUEL VIEW

Using UN Comtrade data, our analysis of energy import concentration across countries reveals an interesting pattern. Countries with smaller import volumes exhibit higher concentration, as measured by the Herfindahl-Hirschman Index (HHI).[5] In contrast, most large energy buyers show lower concentration and more even distribution with respect to trade partners (Figure 2). However, Germany has not reduced its supply concentration despite the increasing reliance on natural gas and growing import volumes. It appears as a visible outlier on the plot presenting 2019 data. It

[3] According to the World Bank database.
[4] Based on the 2019 Energy Balance reported by AG-Energiebilanzen.
[5] The HHI varies between 0 and 1. The higher the HHI is, the higher is the concentration and the lower the security.

Table 1

Total Primary Energy Consumption (TPEC) by the Major 2019 Economies as percent of the World TPEC

	Oil	Natural gas	Coal	Nuclear energy	Hydro- electric	Renewables	Total energy
USA	19	22	7	30	6	20	16
China	14	8	52	12	30	23	24
Japan	4	3	3	2	2	4	3
Germany	2	2	1	3	0	7	2
India	5	2	12	2	4	4	6
United Kingdom	2	2	0	2	0	4	1
France	2	1	0	14	1	2	2

Source: Authors' Calculation based on the BP database.

is worth noticing that France, Japan, and China have been especially successful in reducing supplier concentration by expanding the number of trade partners through liquefied natural gas (LNG) trade.

Following Berdysheva and Ikonnikova (2021), we have accounted for domestic production and calculated the concentration of individual non-EU suppliers in Germany's total primary energy import (HHI) and consumption. The latter has been described by the Consumer Security Index (CSI).[6] We have found similar trends of increasing concentration in natural gas and coal. Since the reduction in coal consumption has coincided with the abandonment of domestic production, the security of coal supplies has decreased. Finally, we have considered all the primary energy source concentration and revealed that despite significant investments in renewable energy, there has been only a small change in combined-energy security. We attribute this result to two factors: the cutback in coal and the expansion of natural gas, which together outweigh the gains brought by diversification of the energy mix through renewables.

COMPETITION FOR SECURITY

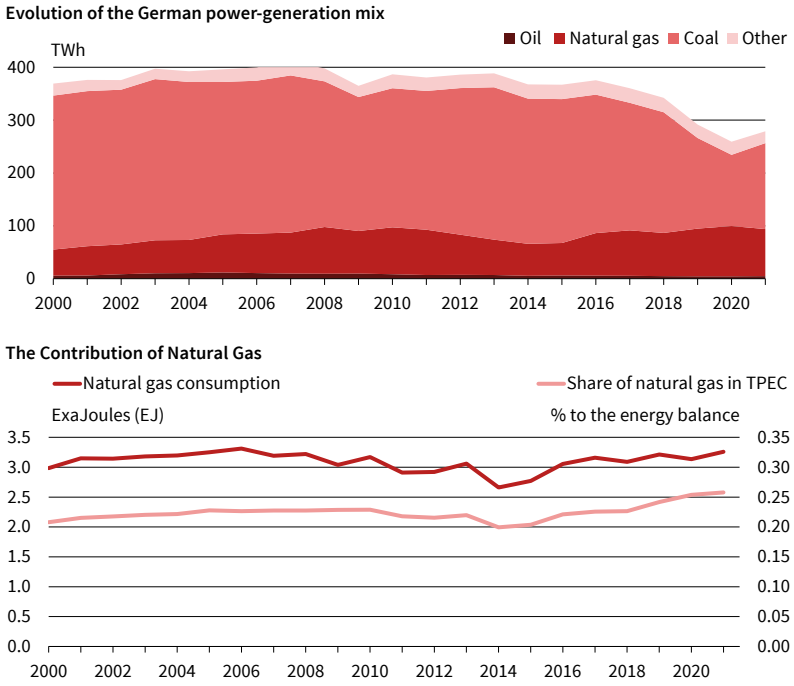
These observations and our review of ongoing policy discussions in the major global economies motivated us to perform a formal analysis and develop a model in which market participants – namely, buyers and suppliers – try to achieve the best possible trade concentration in addition to trade surplus maximization. This trade concentration, measured through HHI, was used to both characterize and proxy the security of supply, in line with the IEA definition. The outcome of the model describes market interaction and includes 1) the volumes traded (bought or sold) by an individual country, 2) the quantity exchanged between each importer-exporter pair, and 3) the trade concentration index for an individual country and the market as a whole.

Solving for security and trade surplus optimization, we considered sequential interaction. First, market participants communicate their demand and supply preferences to sign long-term contracts and bid on the spot market. Then, they finalize the trade by choosing the distribution of supply and demand volumes across the trade partners. Instruments such as swap and resale contracts, along with the hub trade, allow for the redistribution of volumes among the EU buyers.

Using data on volumes traded in the EU market, we have found that the optimal distribution of quantities sold and bought correlates with the patterns revealed by our empirical analysis. Hence, we explain the tendency of larger buyers to have a lower concentration index with a view to attaining higher security of supply. Based on our analysis, Germany should trade more with other suppliers than it currently does. Thus, in the case of the natural gas market, we have

Figure 1

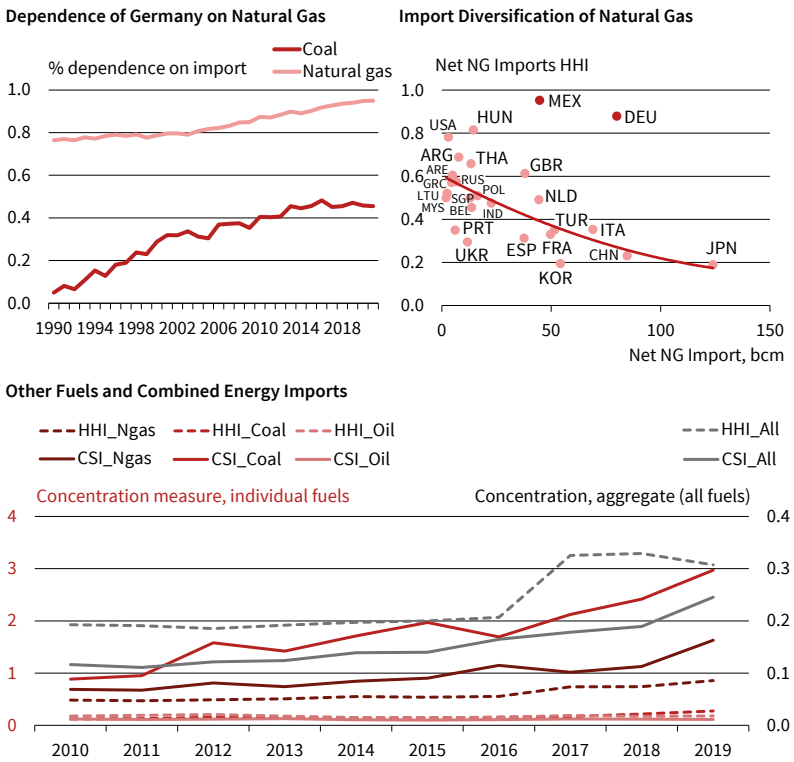
Electricity Generation And Natural Gas Consumption in Germany



Source: BP 2020 Energy Statistical Report. © ifo Institute

Figure 2

Natural Gas and Other Fuels



Note: The growing dependence of Germany on natural gas imports and stagnating reliance on coal has been accompanied by the weak import diversification, especially in the case of natural gas, but also in other fuels and combined energy imports.
Source: BP 2020 Energy Statistical Report; Authors' calculations. © ifo Institute

[6] With the total consumption instead of the total import used as a base for CSI, its values range between 0 and 1 for importing countries and can be greater than 1 if a country (re-)exports. Thus, Figure 2 indicates that Germany re-export natural gas and exports coal.

concluded that Germany should have a more diverse trade, e.g., buy more Algerian gas or LNG, for example, by means of swap contracts with France if not through physical deliveries.[7]

INTERFUEL SUBSTITUTION AND MARKET INTERACTION

The conducted analysis allows highlighting how both trade and the security outcome depend on supply and demand. If a country changes its demand for a given fuel, for instance, replacing coal with natural gas, its security would be affected unless further actions are taken.

Understanding the interdependency of security of supply and the distribution of energy demand across different energy sources brings us to the interfuel trade analysis. We examined how trade and its concentration change if countries choose their energy demand allocation across various fuels, first, and then interact in the individual fuel markets. Similarly, we considered energy suppliers, like Russia, which may manipulate their supply of different fuels in order to affect market prices and profits. The Nord Stream 1 and 2 pipelines' leakage and the OPEC quotas can also be seen as such manipulations.

We have studied the energy demand allocation to gain intuition critical for current decisions on investments in non-fossil energy supply and rebalancing of energy demand between coal and natural gas. Our analysis addresses the developments in the natural gas and coal markets in late 2021 and the current year (2022), when shortages of natural gas, caused by Russian gas export disruptions, have spilled over into the coal market: soaring natural gas prices stabilized and even exhibited some short-term downward trend, even as the coal prices rose. Subsequent fluctuations in coal, natural gas, and oil prices, in part, are the result of fuel substitution and its limitations.

Adding another stage to the model and solving it, we found that buyers' demand allocation across the fuel markets depends not only on competition on the seller-side, but also on buyer-side competition. Thus, an increase in the number of buyers in one market might induce some buyers to reduce their demand, shifting the difference to other fuel markets. Similarly, the elimination of a seller or decrease in its supply capacity would incentivize buyers to turn over to other fuel markets, just as observed in the natural gas and coal markets in 2022. Naturally, the change in the number of participants, their willingness to buy, and willingness to supply, might affect trade and, consequently, inter-participant flows, altering the concentration index and security of supply.

Finally, our analysis ends with an examination of a hypothetical scenario in which buyers may affect the size of their import demand through investing in domestic production, e.g., of renewable energy. The results are non-trivial: a reduction in import translates into an increase in trade concentration and thus, security is likely to worsen. However, the shrinkage of the total and individual fuel import share in total consumption has an opposite effect: improving security. In other words, reducing the reliance on import makes the concentration of import flows less important.

POLICY CONCLUSIONS: PATHWAYS TO IMPROVE SUPPLY RESILIENCE

Our analysis leads us to several key observations, policy-relevant conclusions, and recommendations on how to respond to the energy crisis. We start by highlighting the developments that have contributed to Germany's vulnerability.

Focused on its transition to carbon neutrality, Germany, along with many EU members, has envisioned its energy mix diversification and security improvement through the development of alternative energy sources and switching to natural gas. In the short- and mid-term, however, this transition has been thrown out of balance, with high import share and concentration of some fuels making Germany increasingly dependent on a single energy exporter, Russia. Investments in "clean" energy sources have not been sufficient to mitigate the loss in security of supply in Germany.

The energy mix transformation could have been more successful in terms of security had it been accompanied by supplier diversification. Russia has gained overwhelming power over German energy markets by delivering a significant share of total (primary fossil) energy. Yet, the interdependence has become increasingly asymmetric, as Russia has been diversifying its export through trade with Asia. By 2022, at the outbreak of war in Ukraine, Germany had limited ability to substitute Russia as the main energy supplier, which held a pivot position in the EU fossil energy market and a sizable share in the Asian region. Infrastructure constraints and lack of established trade relationships prevent Germany from getting new suppliers or expanding its imports in the short-term, with some exception for coal and oil (where the grade of fuel matters).

Investment in Fuel and Supply Source Diversity

The reviewed results and analyses suggest some useful insights for policy and ongoing energy-related planning. Germany is working on developing new energy supply routes and trade relationships to overcome its energy shortage. While finding another large partner to substitute for the lost one appears as a time- and monetarily efficient solution, its short-term benefits, including the savings on infrastructure and possible wholesale discount, may be overblown and hence should be weighed against the costs of

[7] Here we assume that most of the flows from the Netherlands to Germany consist of redirected Norwegian flows.

hold-up. The risk of renegotiations is especially high, given that many countries face energy shortages and might have incentives to try to entice suppliers.

Taking a lesson from the situation with Russia, Germany should *monitor the allocation of demand and trade across the markets*. Individual energy-buying companies often specialize in specific fuels and ignore developments in other fuels. It should be a governmental role to monitor that new supplies do not worsen the country dependence in the energy markets. The likelihood of a country's dependence on a particular specific fuel exporter, however, is high because oil, coal, and natural gas resources are frequently found in the same geographical locations.

Finally, the push to invest in fossil energy alternatives, including renewables, biofuels, and hydrogen, should be evaluated and coordinated with the individual fuel and across-fuel diversification mentioned above. Development of domestic production will improve energy security if it reduces import dependence. But an increase in reliance on imported energy, e.g., hydrogen, accompanied by the growth in energy demand, might lead to the opposite effect. Hence, the alternative energy policies should account for and be examined in light of the concentration and co-alignment with other energy trade plans.

Strategic Coordination and Buyer Competition

Despite the different conditions in which individual countries are finding themselves in these energy crises, the problems and the solutions considered are often similar. We observe a run into coal spurred by the unprecedented increase in natural gas prices, talks and steps towards establishing price ceilings or corridors, and accelerated development of hydrogen supplies and other alternatives, including nuclear energy.

The ongoing situation could be described as a buyers' "war of attrition." Competition for scarce energy supplies highlights the need for coordination among the energy-import dependent economies to survive and not to slip into severe energy poverty. Competition between European and Asia-Pacific markets has already brought a new kind of supply contracts, indexed to several, rather than one, trading hubs. While countries compete for resources and security of supply, demand size and fuel-switching capability limitations put them in unequal positions. To meet UN Sustainability Goals and to support equality, along with energy affordability, coordination of transition and diversification strategies at both global and regional levels is required.

To enable such coordination and cooperation, improved connectivity and inclusivity are needed. Developing countries with lower ability to pay should not be left to deal with politically unstable and geopolitically isolated countries, such as Russia, that are willing to expand into "indiscriminate" markets and expand their sphere of influence. Communication and coordination with other countries on energy trade and infrastructure development is critical, especially with developing nations. Such action is needed to avoid political and economic polarization that could boost insecure and unstable energy suppliers that threaten the market and geopolitical order.

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