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Original article

Spatial aspects of natural gas supply diversification in the context of energy security in the countries of the European Union

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ABSTRACT

This article examines the issue of diversification of natural gas supplies to European Union countries through a range of indicators. The aim of the study was to conduct a geographical analysis of existing natural gas sources and to identify potential new supply directions. The study's spatial scope was limited to the European Union, a supranational organisation that currently faces challenges in the field of energy security. The study covered the years after the end of the Cold War, a period of significant changes in the geography of both natural gas supplies and the methods of gas transportation. The analysis used data from international organizations specialising in natural gas policy, including IEA (International Energy Agency), Global Energy Monitor and IOGP Europe. Other data came from government documents, laws and agreements of the European Commission. The article provides a spatial analysis of resources, reserves, production, import, and storage of natural gas. Particular attention is given to the impact of the new geopolitical circumstances after the Russian invasion of Ukraine, including the functioning of the main gas pipelines, new interconnectors and LNG terminals serving the needs of the EU energy sector. Apart from certain countries like Hungary and Slovenia, it has been concluded that the adapted policies have significantly broadened the pool of suppliers. The European Union has effectively addressed significant energy security concerns in the face of the current geopolitical unpredictability.

KEY WORDS: natural gas, diversification of gas supplies, energy security, LNG, European Union

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1. Introduction

The domestic natural gas reserves of EU countries cover only a small fraction of the overall demand for this energy resource. As a result, the need to diversify both the sources and supply routes of natural gas from non-EU countries has become increasingly critical (AL-MASNY, 2015). Due to the timeliness and practical significance of this issue, this article explores the current and potential directions for diversifying natural gas supplies within the framework of the EU's energy security. For many years, EU countries have been heavily reliant on a limited number of suppliers. This unfavourable trend was pointed out by, among others, GODZIMIRSKI & NOWAK (2018, p. 255): in the mid-2010s, "import covered around two-thirds of the EU's gas needs and the bloc had to rely on a relatively small number of gas suppliers, as almost 70% of external gas supplies were coming from only two countries – Russia and Norway."

The spatial and economic analysis of natural gas resources, production, and imports has long been a focus of academic studies (RUSZEL &PODMIOTKO, 2019;

Sobieraj, 2022; Zawisza, 2011; Rychlicki & Siemek, 2007; Voytyuk, 2013). While acknowledgement of the need for diversification has been encountered in political practice, it is a relatively recent focus of study within the fields of economic geography and international relations (Ruszel, 2013; Tomaszewski, 2017; Szulecki, 2018; Červinková & Jirušek, 2021; Selei & Tóth, 2022), in East-Central Europein particular. This article focuses on the concept of diversification, defined as the ability to import a particular raw material from various producers, ideally from multiple geographic locations (Ruszel & Podmiotko, 2019). A diversified supply strategy enables countries to mitigate the risk of supply disruptions while fostering competition, which in turn affects price formation (Krzak, n.d.).

The last few decades have seen the "energy trilemma" become a focal point in the discourse on energy production, highlighting the critical issues of security, equity, and environmental sustainability (Shirazi, 2022). This article primarily examines energy security (Kama, 2016; Radovanović et al., 2017) in the context of the capacity to transport and diversify natural gas supplies efficiently. This conception varies according to the perspectives of different stakeholders, including producers, consumers, consumer countries and transit countries (Szulecki, 2018, p. 8, citing Dellecker & Gomart, 2011). Energy security is typically defined as "a state of the economy characterised by the certainty of uninterrupted energy supply at an acceptable price to consumers, generated while adhering to environmental and climate protection standards" (Wiech, 2022). Achieving this requires proactive measures to meet the economy's demand for energy carriers. In order to address the energy needs of both national and European economies, it is essential to ensure "an adequate level of energy supply at reasonable prices, in a manner that does not compromise fundamental values and state objectives" (Laskowicz, 2016).

In recent years, energy supply has taken on increasing importance in both national and international security policies. For decades, EU institutions, in collaboration with member state governments, have worked toward developing a common energy policy, with a key focus on diversifying oil and gas supplies (Al-Masny, 2015). This effort stems from concerns about the potential influence of energy-exporting countries on individual importing nations. To counter such influence, countries engage in international agreements that balance the interests of both energy exporters and importers: a principle enshrined in the European Energy Charter, signed in Lisbon in 1994 (The Energy Charter Treaty and Protocol, 1994). An essential step towards liberalising the EU gas market became the adoption of the Third Energy Package in 2009 (Bownik-Trymucha, 2010). This set of legislative initiatives, aims to secure optimal gas prices for consumers and promote the development of a single energy market. Most recently, the European Energy Union and the European Green Dealbecame the initiatives with the highest impact on navigating the EU energy policy. The former serves as a strategy aimed at decreasing the EU's reliance on imported energy sources. According to reports from the European Energy Union for 2024, the import of Russian gas into the EU has been reduced from 45% to 18%. This figure has further declined following the suspension of Russian transitthrough Ukraine. Additionally, there has been a notable shift towards wind energy as a partial substitute for gas in energy production (State of the Energy Union Report..., 2024). In turn, to fulfil the aim of carbon neutrality by 2050, the European Green Deal intends to minimize the consumption of natural gas in the production of energy(Hydrogen and decarbonised gas market. n.d.).

2. Data and methods

This study examined the processes involved in the production, transport, and long-term import of natural gas. The primary aimwas to conduct a geographical analysis of historical trends in natural gas imports within European Union countries. Accordingly, the following analyses were conducted:

1) an analysis of gas production, self-sufficiency and imports across EU countries;

2) an assessment of the evolving pipeline and interconnector networks, along with the increasing role of liquefied natural gas (LNG) terminals in the ongoing geographical diversification of natural gas supply; and

3) the identification of potential directions for diversification of natural gas supplies to EU countries.

Data sourcesincluded publications from the European Commission, the International Energy Agency (IEA), the Global Energy Monitor (GEM), and the International Association of Oil & Gas Producers (IOGP Europe). The data provided by these organisations formed the basis for an objective diagnosis of the status and current trends in natural gas production, imports, and diversification. The largest repository of reliable and up-to-date data, including information on gas imports, was found on the European Commission's website (Komisja Europejska, n.d.). The International Energy Agency (IEA) also provided crucial empirical data. Another valuable data source was the Global Energy Monitor, an organisation established in 2007 (Global Energy Monitor, n.d.).

The individual sections of this article analyse selected indicators over time, with changes in gas production and the structure of imports between 1990 and 2020 presented for countries now part of the EU. With respect to gas storage fill levels, the available data facilitated the identification of intra-EU differences for the years 2017 and 2023. The impact of the outbreak of full-scale war in Ukraine on the dynamics of these indicators in the first months of 2022 is also addressed.

Based on these indicators, a classification of EU countries was developed, and maps illustrating the spatial distribution of the phenomena under study were generated using GIS software. The use of mapping tools enabled the identification of countries and regions that have been more or less successful in diversifying their natural gas supplies. Some results were derived using the energy self-sufficiency index (Ws), a method developed by Kaliski & Staśko (2003). This index measures the current state and profile of energy security.

$$Ws = \frac{P \cdot 100}{Zk} [\%]$$

In this formula, *P* represents the amount of fuel extracted in a given year, while *Zk* denotes domestic consumption, equal to the sum of the volumes supplied to the domestic market for each fuel, minus the balance of domestic stocks (Kaliski & Staśko, 2003).

3. Changes in natural gas reserves, resources, and storage fill levels

Natural gas reserves and storage fill levels within the European Union were assessed using data from IOGP Europe and Gas Infrastructure Europe. These strategic indicators illustrate the capacity of member states to meet current energy demands, particularly in the face of sudden market fluctuations.

3.1. Gas reserves and resources

IOGP Europe defines resources as the expected total recoverable resources, while reserves are classified as proven or probable raw material resources (European Natural Gas Reserves and Resources, n.d.). This subsection presents a short outlook on the gas reserves in the EU and neighbouring regions, which should play a more significant role in the policy of supply diversification. The IOGP Europe report states that the gas reserves of the European Union in 2022 are 694 bcm, with gas resources estimated at 2,220 bcm.[1] Due to the scarcity of reserves, EU countries are compelled to import and store natural gas. There are substantial differences between the resources and reserves of EU member states and those who control and have access to the gas resources in the Northern and Southern North Sea gas basins, the West Siberian Basin, the Arabian Basin, and the Zagros Basin. Another essential characteristic is that most EU member states exhibit very low levels of both reserves and resources. Poland stands out with comparatively high resource values (811 bcm, and gas reserves estimated at 107 bcm), whereas other countries generally report lower figures for both indicators. Alongside Poland, Cyprus, which has 372 bcm of gas resources, and the Netherlands, with 269 bcm, are among the countries with the highest levels of gas resources.

Considering the broader European continent and its neighbouring areas, it is crucial to highlight the presence of regions with substantial natural gas reserves and resources. Traditionally, geographical closeness of such countries was particularly important for exploring alternative for the Russian gas supply routes and sources. Along with the Russian Federation, which controls the largest gas reserves in the world, countries such Iran, Saudi Arabia, Qatar, and United Arab Emirates also have substantial gas reserves. The same is true of Norway, with reserves estimated at 2,775 bcm, followed by Algeria (2745 bcm), Egypt (1448 bcm) and Israel (1138 bcm). Additionally, concerning gas resources, some states from the EU neighbourhood like United Kingdom, Ukraine, and Libya, hold relatively high quantities. However, it should be noted that the availability of LNG supplies opened up extensive opportunities for European nations to diversify gas sources beyond their eastern, southern, and southeastern neighbourhoods. This has resulted in an increase in LNG imports from the United States, which has emerged as the primary

[1]This data excludes the Baltic States, the Czech Republic, Belgium, Bulgaria, Finland, Sweden, Malta, and Luxemburg as no information is available for these countries.

supplier of LNG to the EU, following a consistent upward trend since the mid-2010s.

3.2. Dynamics of gas storage fill levels

The level of storage capacity utilisation serves as a critical indicator of the disparities among member states. Using data from *Gas Infrastructure Europe*, we can compare storage fill levels from 2017 (Figures 1 and 2) for selected countries (AGSI, 2023).

Increased storage fill levels facilitate more effective management of low resource levels and reliance on single-supply sources. Since 2017, there has been a significant shift in the attitudes of European governments regarding gas storage. In 2017, storage fill levels varied, with Hungary recording below 40%, while the UK exceeded 80%. The lowest levels were found in Southeastern Europe and Latvia. Many of these countries were landlocked and maintained strong relations with the Russian Federation, which was their primary gas supplier. Consequently, they did not prioritise their energy security. Conversely, Denmark, Italy, the UK, Belgium, and Poland recorded the highest storage fill levels in 2017, ranging from 50% to 69.99%.

After six years, in 2023, the storage fill levels for most Central and Western European countries had risen to between 85% and 94.99%. Latvia reported the lowest level at 47%, whereas Poland and Portugal achieved over 95% fill levels, at 97% and 98%, respectively. In light of the ongoing conflict, EU governments have heightened their commitment to enhancing energy security. An analysis of the countries providing data reveals significant increases in natural gas storage across the board. Portugal exhibited the most substantial rise, from 51% to an impressive 98%, while Sweden, which joined Gas Infrastructure Europe in 2022 with an initial fill level of 7%, increased its storage to 87% within a year. Other notable increases were observed in Croatia, Hungary, Spain, and Austria. It is also worth mentioning that Portugal and Spain are particularly recognized in Europe for their high density of LNG import terminals. Nonetheless, along with factors such as EU policy and the internal competition between member states, the pipeline infrastructure of these two counties is insufficient to enable further gas distribution to Western Europe.

The available data highlight widening disparities in gas reserves, resources, and storage fill levels among the studied countries. The map of resources and reserves (Fig. 1) illustrates the challenges faced by certain EU Member States while also indicating potential future gas suppliers. After 24th February 2022, significant changes occurred in this domain, with many countries prioritising the security of their gas sectors by increasing storage fill levels amidst ongoing uncertainty.

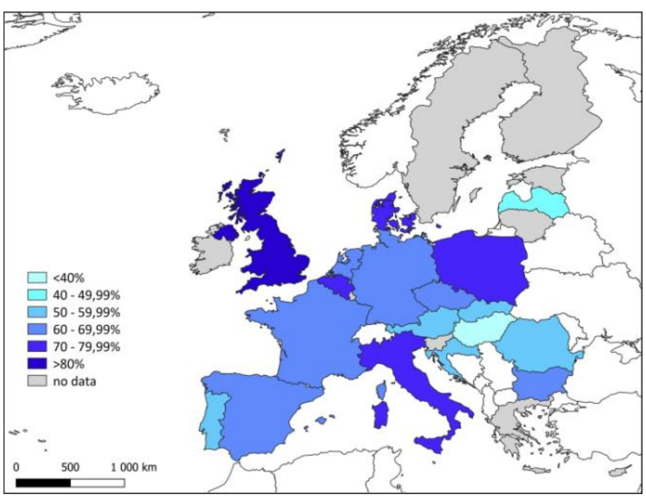

Fig. 1. Gas storage fill levels in EU Member States (as of 1 January 2017) (Source: own elaboration based on Gas Infrastructure Europe data)

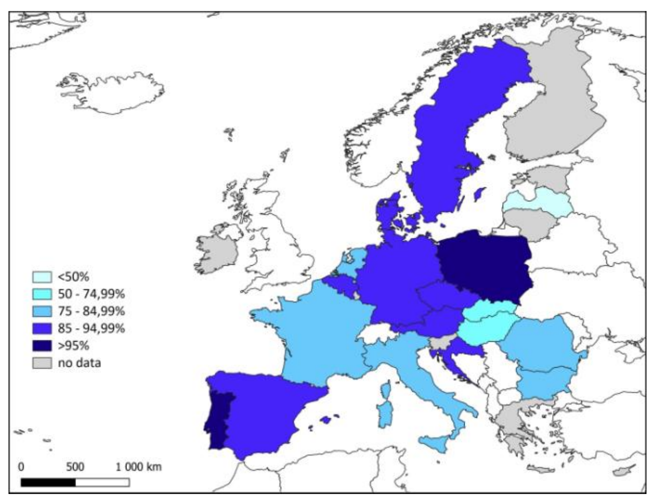

Fig. 2. Gas storage fill levels in EU Member States (as of 1 January 2023) (Source: own elaboration based on Gas Infrastructure Europe data)

4. Gas production and self-sufficiency of EU countries: General trends and spatial variations

Gas production is a critical factor influencing supply security within the European Union. This section examines the evolution of gas production among the current EU27 members using data from the International Energy Agency (Figures 3 and 4). The values are presented in terajoules (TJ). It is noteworthy that some countries did not provide data on imported gas volumes.In 1990, Romania and the Netherlands recorded the highest gas production outputs, while Belgium, Bulgaria, and Slovenia reported the lowest figures. The initial spread of production levels began with index values below 1,000 TJ and extended to between 1.5 million and 2.8 million TJ. No comparator countries have achieved such high levels of production in the subsequent 30 years.

In 2020, similarly as at the beginning of the period under review, the lowest production values, recorded below 1,000 TJ, were observed in Belgium, France, Greece, and Slovenia. The final production values were, however, significantly lower, with the Netherlands producing between 500,000 and 750,000 TJ. A notable trend in this data is the general decline in gas production levels, attributed to the depletion of existing deposits and the necessity for more advanced production technologies from deeper geological formations, which can render exploitation economically unfeasible.

Based on the differences in natural gas production and consumption, a self-sufficiency index (Ws) was calculated, with results summarised in Table 1. This table illustrates the considerable spatial variations among EU countries and the significant dynamics of change over time. It is important to highlight that in both 1990 and 2020, most countries reported below-average production and consumption levels. The self-sufficiency index should be interpreted such that higher values indicate greater energy security; specifically, an index value exceeding 100 signifies self-sufficiency.

The vast majority of countries are now reliant on imports to meet their needs. In 1990, Denmark, the Netherlands, Ireland, and Greece were able to secure self-sufficiency among the then EU Member States, with index values for Denmark and the Netherlands exceeding 200. Among the current EU Member States, Croatia and Romania also exhibited favourable self-sufficiency levels during this period. Conversely, countries like Belgium, as well as new Member States such as Bulgaria, the Czech Republic, Slovakia, and Slovenia, recorded the lowest index values (below 10), indicating significant supply security challenges. In 2020, a marked decline in self-sufficiency index values was evident, largely due to reduced production levels and increased consumption across most EU countries. Romania remained an exception, maintaining its self-sufficiency through domestic resources and production. In contrast, the majority of other Member States recorded index values below 100 TJ, with Belgium, Spain, Greece, and Slovenia exhibiting the least favourable situations, failing to exceed an index value of 1.

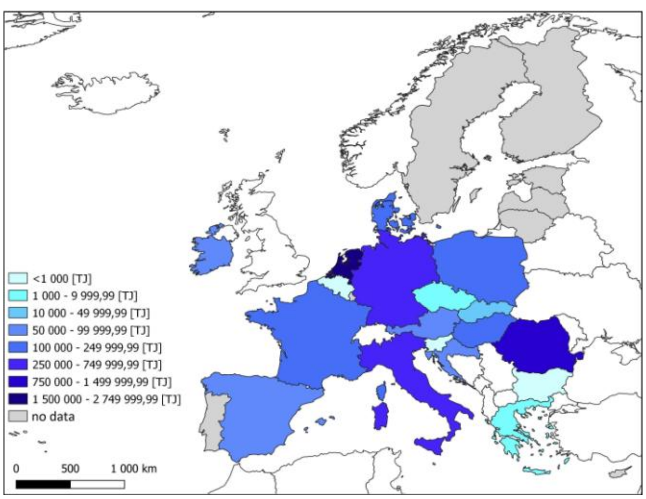

Fig. 3. Natural gas production in current EU Member States in 1990 (in TJ) (Source: own elaboration based on International Energy Agency data)

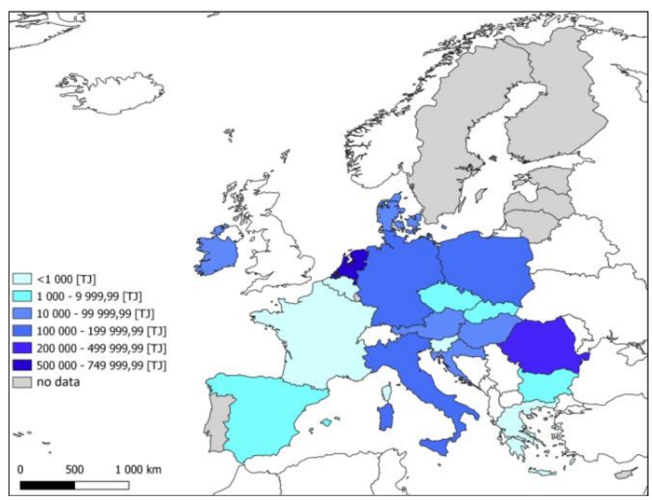

Fig. 4. Natural gas production in EU Member States in 2020 (in TJ) (own elaboration based on International Energy Agency data)

Table 1. Energy self-sufficiency index for EU countries in 1990 and 2020 (own elaboration based on International Energy Agency data)

N	A member state	Natural gas production, TJ		Natural gas consumption, TJ		Is*		
		1990 r.	2020 r.	1990 r.	2020 r.	1990 r.	2020 r.	Change, 2020 - 1990
1	Austria	51 529	26 368	141 050	231 874	36,5	11,4	-25,1
2	Belgium	450	185	317 260	474 647	0,1	0,0	-0,1
3	Bulgaria	525	2 224	120 846	61 689	0,4	3,6	3,4
4	Croatia	75 328	32 800	57 545	69 555	130,9	47,2	-83,7
5	Cyprus	–	–	–	–	–	–	–
6	Czechia	9 337	7 802	197 426	244 400	4,7	3,2	-1,5
7	Denmark	128 825	50 076	52 189	70 159	246,8	71,4	-175,4
8	Estonia	–	–	20 425	11 411	–	–	–
9	Finland	–	–	44 703	33 038	–	–	–
10	France	117 032	930	1 113 041	1 279 294	10,5	0,1	-10,4
11	Greece	6 426	189	4 496	68 519	142,9	0,3	-142,6
12	Spain	59 228	1 584	201 194	663 365	29,4	0,2	-29,2
13	Netherlands	2 536 667	721 642	1 103 204	854 998	229,9	84,4	-145,5
14	Ireland	87 127	58 755	46 431	90 875	187,6	64,7	-122,9
15	Lithuania	–	–	98 937	69 237	–	–	–
16	Latvia	–	–	32 460	15 023	–	–	–
17	Luxemburg	–	–	19 533	26 254	–	–	–
18	Malta	–	–	–	–	–	–	–
19	Germany	629 513	172 024	1 817 221	2 527 908	34,6	6,8	-27,8
20	Poland	110 621	155 371	357 710	525 088	30,9	29,6	-1,3
21	Portugal	–	–	2 044	80 654	–	–	–
22	Romania	1 065 811	340 414	923 608	290 357	115,4	117,2	1,8
23	Slovakia	15 734	2 271	182 104	130 972	8,6	1,7	-6,9
24	Slovenia	940	202	33 240	27 323	2,8	0,7	-2,1
25	Sweden	–	–	15 558	39 347	–	–	–
26	Hungary	177 314	54 348	288 422	290 438	61,5	18,7	-42,8
27	Italy	652 664	121 318	1 414 339	1 510 064	46,1	8,0	-38,1
	Countries for which data was available	**318 060**	**97 139**	**344 199**	**387 460**	**73,0**	**26,0**	**-47**

– no data, *Is – self-sufficiency index
Countries with above-average values are highlighted in blue, while those below average are marked in orange.

The changes in the energy self-sufficiency index between 1990 and 2020 reveal another significant trend: an increase, albeit minimal, was only recorded for Bulgaria and Romania. All other Member States exhibited lower self-sufficiency values compared to 1990, underscoring their increasing vulnerability regarding "gas independence." Poland's self-sufficiency index remained relatively similar, showing only a slight decrease. Notably, Poland is the only country that, despite starting from below the average for the group, achieved a self-sufficiency rate that exceeds the average.

5. Changes in the structure of gas imports (1999-2020)

5.1. Imports in EU countries

The dynamics of gas imports, influenced by a confluence of political, institutional, and economic conditions, play a critical role in shaping opportunities for diversification. Import data is sourced from the European Commission and is presented in terajoules (TJ), as with production. Figures 5 and 6 illustrate the spatial distribution of gas imports for the years 1990 and 2020. In 1990, Germany emerged as the largest importer in absolute terms, followed by France and Italy. Conversely, Luxembourg recorded the lowest imports, totalling less than 20,000 TJ. Among the current EU Member States, Croatia, Estonia, Slovenia, and Sweden also exhibited low import levels.

In 2020, significant changes were observed, with Germany and Italy's natural gas imports reaching between 2.5 million and nearly 3.5 million TJ. Meanwhile, France, the Netherlands, and Spain imported over 1 million TJ. Malta and Estonia were noted as having the lowest imports, each under 20,000 TJ.

In contrast to natural gas production, the trend for imports demonstrates the opposite pattern. Over the 30-year period under consideration, a general trend of increasing imports across countries was evident (Table 1). Additionally, EU institutions, in response to environmental standards, have been promoting investments in clean energy sources, including natural gas (RUSZEL, 2013). The Baltic and Scandinavian countries, characterised by low gas consumption, are increasingly shifting away from natural gas in favour of alternative energy sources. In Romania, government initiatives aimed at reducing coal and gas power generation in favour of renewable energy are also noteworthy (BEŁDOWICZ, 2022). Slovakia is focusing on the expansion of nuclear power plants (SAWICKI, 2023), while Bulgaria is pursuing similar strategies with its plans to expand the Kozloduy power plant (MIHAYLOV, 2019).

5.2. Dynamics in the share of main suppliers

Analysis of data from the European Commission reveals a diverse array of countries exporting gas to the European Union. In 1990, the primary suppliers to the European Community included Algeria, Denmark, the Netherlands, Norway, and Russia. Notably, 13 countries within Europe received gas exclusively from Russia, indicating a complete lack of diversification. By contrast, France, Germany, and Italy sourced gas from multiple suppliers, primarily from northwestern Europe and southern regions, including Africa.

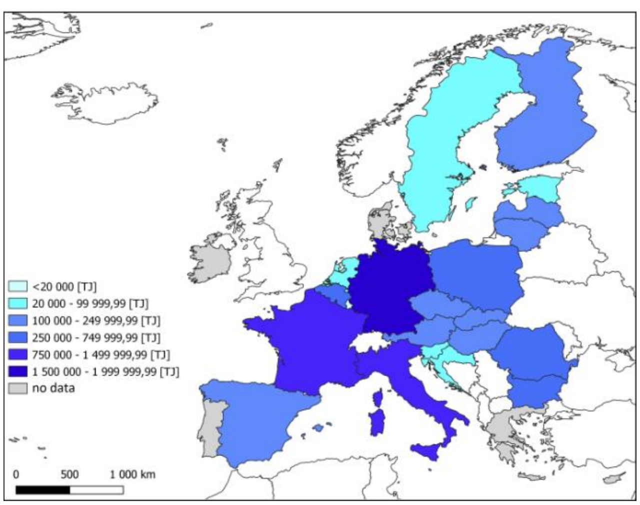

Fig. 5. Values of imported natural gas production in current EU Member States in 1990 (in TJ) (own elaboration based on European Commission data)

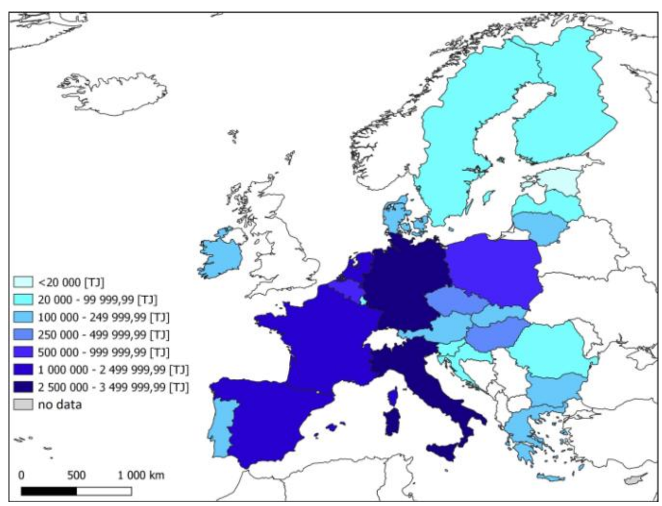

Fig. 6. Values of imported natural gas production in EU Member States in 2020 (in TJ). (own elaboration based on European Commission data)

By 2020, the landscape of gas imports had evolved, with an increase in the volume of imported gas and a broader array of suppliers. Initially dominated by European and African countries, the supply chain expanded to include North America, with the United States and Trinidad and Tobago emerging as significant exporters. The number of African partners also increased, to include Angola, Equatorial Guinea, and Nigeria (Komisja Europejska, n.d.). The development of gas liquefaction technology and the construction of LNG terminals have facilitated the inclusion of remote suppliers from North America and Africa.

In both 1990 and 2020, three major gas-producing countries maintained their leading positions: Algeria (increasing from 1 to 1.5 million TJ), Norway (growing from 700,000 TJ to 2.5 million TJ), and Russia (ranging from 4 to 5.5 million TJ). Projections made in the 2000s suggested that these countries would be the largest gas exporters by 2030 (Rychlicki & Siemek, 2008). However, the geopolitical landscape shifted dramatically following Russia's invasion of Ukraine and the subsequent tightening of trade restrictions against the country. Despite the challenges, Russia continues to represent a significant share of imports, accounting for 14.8% of the EU's total imports in 2023 (Where does the EU's gas come from?, n.d.). Several landlocked states, such as Austria, Hungary, and Slovakia, remain heavily reliant on Russian gas. In this context, diversifying the sources of imports has proven crucial for many national economies. Lithuania exemplifies this transition, having shifted from reliance on Russian gas in 1990 to importing gas from Norway and the United States by 2020, facilitated by the establishment of the LNG terminal in Klaipėda.

Throughout the period under review, there has been a general improvement in the European gas supply situation, with anticipated growth in participation from regions such as Africa, the Middle East, and the Near East in the diversification process (Rychlicki & Siemek, 2007). Currently, suppliers such as Qatar, Trinidad and Tobago, the United States, and Nigeria are strengthening their positions in the European market. Moreover, during this period, European companies have entered into new gas supply agreements with Angola, Congo, and the United Arab Emirates.

6. Diversification of natural gas supply modalities

Gas imports to European countries occur through numerous offshore and onshore entry points. This section examines the spatial characteristics of these imports, considers new methods of gas supply and their significant role in enhancing supply security.

6.1. Traditional routes

The infrastructure facilitating the transport of natural gas within the EU is predominantly designed for imports (Kovač et al., 2021). Most of the natural gas demand is met through pipelines. By the second decade of the 21st century, over 600 gas pipelines were in operation across Europe. Figure 7 highlights a disparity between eastern and western regions. The pipeline network is denser in western and central Europe, whereas those originating from the east tend to have greater capacity. This subsection briefly discusses the most strategically important gas import routes from three main directions (northwest, south, and east), as well as the role of interconnectors in redistributing gas between EU countries.

Fig. 7. Spatial distribution of gas pipelines in Europe, as of September 2024 (Source: redrawn and adapted from Global Energy Monitor, n.d.)

6.1.1. Northwestern direction

Gas pipelines from Norway, a country with strong economic ties to the EU, play a key role in gas imports. Two major pipelines are the Zeepipe and Europipe II. The Zeepipe pipeline originates from the Sleipner gas field in the North Sea and extends to Zeebrugge in Belgium. Its construction took place in three phases between 1993 and 1997, with a gradual increase in capacity and length (Zeepipe Gas Pipeline, 2024). The Europipe II pipeline, operational since 1999, has a capacity of 21 bcm. It begins at the Kårstø processing plant north of Stavanger and transports natural gas to Dornum in northern Germany (Europipe II, 2024).

6.1.2. Eastern direction

Russian gas reaches EU countries through several routes, though most are currently out of service or operating at limited capacity due to ongoing hostilities. The exception includes pipelines passing through transit countries, primarily Turkey. Among these is the Turkish Stream pipeline, which transports gas from both Azerbaijan and Russia to Southern and Central Europe. The Trans-Anatolian Natural Gas Pipeline (TANAP), whose first phase was completed in 2019, enabled the transmission of gas from Azerbaijan to Europe via Turkey. Together with the Trans Adriatic Pipeline (TAP), it forms part of the Southern Gas Corridor, a project supported by many EU nations as an option to reduce dependence on Russian gas. This pipeline has been operational since 2020, facilitating gas transmission from Azerbaijan through Turkey, Greece, and Albania to Italy. The first billion cubic meters (bcm) were transported in March 2021, and by the following year, this figure had reached 10 bcm (Voytyuk, 2013; Trans-Adriatic Gas Pipeline Website, n.d.).

The Urengoy-Pomary-Uzhhorod pipeline, also known as the Brotherhood pipeline, is the largest of the eastern gas transport routes, having been launched during the Cold War. Its annual capacity is estimated at around 30 bcm. The pipeline begins in northwestern Siberia and passes through Ukraine to the Slovakian border, from where gas is distributed to the Czech Republic and Austria (Urengoy-Pomary-Uzhhorod pipeline, 2022). Other key pipelines built during the same period include the Soyuz and Progress pipelines, which are part of the Brotherhood's transcontinental infrastructure. Post-1990, additional pipelines such as the Torzhok-Smolensk-Mazyr-Dolyna and Yamal pipelines (running from Western Siberia through Belarus and Poland to Germany) were constructed. Nord Stream I, another project with significant geopolitical implications, was commissioned in 2011. It is the world's longest underwater pipeline, linking Russia's Vyborg to Greifswald in Germany (Sobieraj, 2022). This pipeline heightened the EU's vulnerability to Russian gas supplies, particularly for Central and Eastern European countries, which became acutely aware of the risks of relying on a single supplier after Ukraine was cut off from Russian gas (Szul, 2011; Tomaszewski, 2017; Kosewicz, 2019). The final major EU-Russia gas transport project, Nord Stream II, was planned to have a capacity of 55 bcm, matching that of Nord Stream I (Sobieraj, 2022). Completed in 2021, the project was not commissioned. In September 2022, the pipeline was damaged (Adomaitis, 2024).

6.1.3. Southern direction

Another group of pipelines supplies natural gas from North Africa. The most significant are the Trans-Mediterranean Pipeline, the Greenstream pipeline, and the Medgaz pipeline. The Trans-Mediterranean Pipeline has been in operation since the early 1980s.It originates in Algeria, runs through Tunisia, crosses the Sicilian Channel and Sicily, and reaches mainland Italy, with a branch extending to Slovenia (Trans-Mediterranean Pipeline, 2021). The Greenstream pipeline starts in Mellitah, Libya, and terminates in Gela, Sicily (Greenstream pipeline, 2021). The newest of these pipelines, the Medgaz pipeline, was commissioned in 2011. It transports gas from Laghouat province in Algeria to Almeria, Spain, via the Mediterranean Sea (Medgaz pipeline, 2023).

6.1.4. Interconnectors

To conclude this section, it is worth addressing the rapid development of interconnector networks in recent years. These critical infrastructures, built at national borders, enable the flow of energy between networks of different countries. They increase the number of suppliers and help create a unified energy system. Key examples include the Baltic Pipe, which transports gas from Norwegian reserves to Denmark, Poland, and neighbouring countries. Poland also benefits from the Poland-

Slovakia interconnector, with a transmission capacity of 5.7 bcm, granting access to gas from the southern region. This interconnector provides Slovakia access to gas from the Baltic Pipe and the LNG terminals in Świnoujście and Klaipėda. In May 2022, the Poland-Lithuania interconnector was launched, ensuring supply security for the Baltic states (GAZ-SYSTEM, n.d.). All of these projects were crucial to the EU and received backing from the European Commission. Among the operational interconnectors, those in Hungary stand out, connecting the country's system with Ukraine, Austria, Slovakia, and Croatia (HUNGARY NATURAL GAS SECURITY POLICY, 2022). The Czech Republic also has an extensive network of interconnectors – seven in total – allowing the import of 129 bcm and the export of 86 bcm of gas (CZECH REPUBLIC NATURAL GAS SECURITY POLICY, 2022). Among the 'old' EU Member States, Belgium leads in interconnector development, with 17 facilities connecting it to other European countries (BELGIUM NATURAL GAS SECURITY POLICY, 2022).

6.2. The growing role of LNG terminals

LNG terminals are becoming increasingly important for diversifying natural gas supplies in the global and European economies (MAXWELL & ZHU, 2015; LONT, 2020; PALAIOS ET AL., 2024). Their significance has been amplified by the negative experiences of many countries during gas supply disruptions caused by emergencies, such as the Libyan conflict in 2011 and the ongoing tensions and conflicts in Eastern Europe since the mid-2000s. Thus, the development of new LNG terminals enhances independence from conventional pipeline supplies, thereby reducing the limitations inherent in models based on fixed supplier(s) and buyer(s).

Even before the current international crisis, LNG terminals were recognised as strategic infrastructure that "enhances supply flexibility" and increases "the number of entry points into the gas system, which, in the event of geopolitical conflict, strengthens the energy security of the integrated EU energy market" (RUSZEL, 2014, p. 54). According to 2016 data, LNG imports amounted to around 350 bcm, representing approximately 10% of global natural gas consumption (JANUSZ ET AL., 2017). This section outlines the locations of key LNG facilities and the prospects for the development of this infrastructure in EU countries. The distribution and construction of LNG terminals underscore the importance of geography. The concentration of such infrastructure is significantly higher in Western Europe, thanks to its proximity to bodies of water like the Mediterranean Sea, the North Sea, and the Atlantic Ocean (Fig. 8). The LNG era in Western Europe began in the 1960s, with the first deliveries of gas coming from Algeria to France and the UK, and from Libya to Spain and Italy (VAN DE GRAAF & SOVACOOL, 2020). Spain and Italy, along with Norway, have the highest number of terminals.

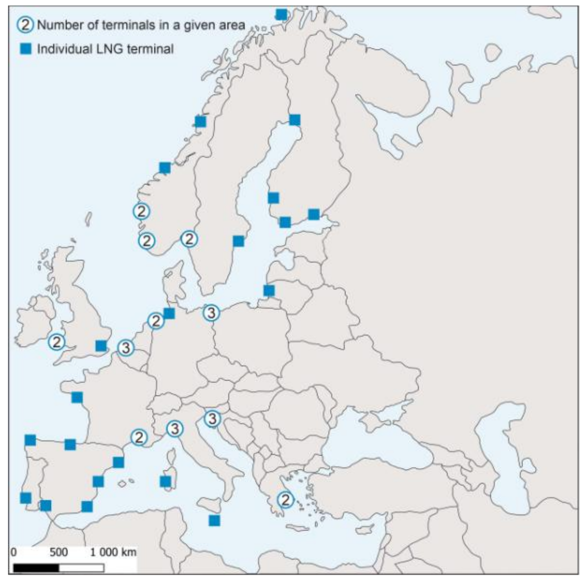

Fig. 8. Distribution of LNG terminals in Europe in 2023 (Source: redrawn and adapted from Global Energy Monitor, n.d.)

A notable recent development is the Krk LNG terminal (FSRU) on Croatia's northwest coast, which was commissioned in 2021 and continues to expand. The Croatian terminal is also viewed as a strategic asset by Hungary, which aims to source gas through it, providing geographical diversification for its supply. Initially, the terminal's capacity was 2.6 bcm per year, enough to meet Croatia's annual demand. By 2022, its capacity had increased to nearly 3 bcm per year (KRK FSRU, 2023; KRK LNG, n.d.).

Terminal Gate in South Holland Province in the Netherlands is one of the largest LNG terminals in Europe, strategically located in Rotterdam, one of the world's largest ports. Construction began in 2008, and the terminal became operational in 2011, with an initial capacity of 12 bcm per year, expandable to 16 bcm. It plays a crucial role in supplying gas to the Netherlands and northeastern Europe (GATE LNG, n.d.).

Another key facility is the Zeebrugge LNG terminal in Belgium (West Flanders). Construction started in 1982, and the terminal became operational five years later. Its connection to the Dunkirk terminal allows access to the German, Dutch, and UK gas markets. Initially, Zeebrugge had a capacity of 9 bcm, which has been expanded several times. Future plans include increasing its capacity by 6.4 bcm by 2024, and an additional 1.8 bcm by 2026 (Zeebrugge LNG Terminal, 2022). In Western Europe, the Dunkirk gas port is particularly important due to its proximity to France's gas network. Operational since 2017, it is now the largest LNG regasification terminal in continental Europe, connected to Zeebrugge via the Dunkirk-Zeebrugge Pipeline. The terminal has an annual capacity of 9.6 bcm, making it the fifth largest in Europe (Dunkirk LNG Terminal, 2023).

In Spain, the largest and oldest gas port is the Barcelona LNG terminal, which has been operational since 1969 and includes six tanks. With an annual capacity of 13 bcm, it ranks third in Europe. In 2016, a proposal was made to expand the terminal into an LNG distribution hub (Barcelona LNG Terminal, 2022). In 2022, the number of vessels delivering liquefied gas to the terminal doubled compared to the previous year (Faus, 2023).

The LNG terminal in Świnoujście, Poland, has played a crucial role in diversifying gas supplies to Central and Eastern Europe. Launched in 2016, it is considered one of the most modern terminals in the world and was classified by the European Commission as a project of community interest (Laskowicz, 2016). The expansion of the Świnoujście port further strengthens the stability of gas supplies, ensuring that Poland's energy needs are met (Gaz-System, 2020). The terminal is bi-directionally connected to the Baltic Pipe, allowing for gas export to Denmark in the event of a surplus. In 2017, a decision was made to expand the port with an additional storage tank, which was completed four years later. This expansion increased the terminal's regasification capacity from 5 bcm to 6.2 bcm per year. In January 2025, the port's expansion was finalized with the installation of a third tank, thereby enhancing its regasification capacity to 8.3 bcm (Gaz-System, n.d.; *Wreszcie! Trzeci zbiornik terminala LNG w Świnoujściu gotowy*, 2025).

7. Discussion

Over the 30-year period studied, the main sources of natural gas imports for the EU were Russia, Norway, and North African countries (Godzimirski & Nowak, 2018). These regions have been the primary suppliers of natural gas to EU member states. An analysis of gas production between 1990 and 2020 reveals a decline in natural gas output due to the gradual depletion of reserves and challenges associated with extracting gas from low-lying seams, where production becomes uneconomical due to high costs. The Netherlands and Romania stand out as the countries with the highest production levels during this period. In contrast, natural gas imports increased, reflecting growing reliance on external supplies.

By the late second and early third decade of the 21st century, the EU and its member states began to adapt their energy policies, seeking greater flexibility in sourcing natural gas. Although these changes varied across countries and regions, efforts to diversify supply routes, construct interconnectors, and explore alternative sources intensified. One positive trend during this period was the increase in gas storage capacity, which has enhanced energy security, particularly in the face of complex international situations. Despite Romania's relatively better position, a noticeable decline in self-sufficiency rates was observed between 1990 and 2020. With rising consumption, many EU countries have been compelled to import natural gas from other regions. Looking ahead, the common policy of the European Union should strive to better utilize the capabilities of countries with extensive storage facilities, particularly Ukraine and Germany.

Over the past decade, the expansion of LNG terminal infrastructure has played a key role in boosting energy security, allowing countries to diversify their gas sources. By investing in LNG infrastructure, nations can enhance their energy independence and reduce the risk of supply interruptions. As demand for natural gas continues to rise, investments in LNG infrastructure have become increasingly profitable (Palaios et al., 2024). Consequently, LNG terminals are being built at a growing rate across the EU and in other regions (Lont, 2020; Van de Graaf & Sovacool, 2020). Countries that once relied heavily on a single gas supplier now have access to multiple sources, improving energy supply security and increasing their resilience to geopolitical shifts and changes in global trade. The construction of new LNG terminals, particularly in post-socialist EU countries like Poland and Croatia, has been a game-changer, enabling greater supply flexibility and expanding the pool of potential suppliers. Many nations capable of building LNG/FSRU terminals are either doing so or planning to in the near future.

8. Conclusion

In the second decade of the 21st century, many EU countries experienced growing challenges in securing their natural gas supplies, especially those with limited domestic gas reserves or heavy reliance on Russian imports. This has been particularly true for Eastern and Central European nations (Laskowicz, 2016; Szul, 2011; Kosewicz, 2019). Past experiences have shown that diversifying gas supply sources and enhancing energy security are crucial for national security and remain top priorities for most member states and EU institutions (Szulecki, 2018; Selei & Tóth, 2022). Given their limited natural gas and oil reserves, EU countries meet only a small portion of their energy needs through domestic production, making the diversification of supply sources and routes essential. In light of EU strategies focused on low-carbon development, it is reasonable to expect a reduction in the demand for natural gas.

Government approaches to natural gas import diversification have historically varied across Europe due to differences in geographic location, economic development, and energy structure. However, recent events – particularly following the Russian invasion of Ukraine on 24 February 2022 – have led to greater alignment among member states, driving joint efforts to seek alternative gas markets. The rapid changes in investment, infrastructure, and geopolitics over the past few years have highlighted the key directions for diversification. Areas like the Middle East and the Persian Gulf have significant potential to become leading natural gas exporters to Europe, provided they can overcome infrastructure challenges and maintain political stability. Additionally, ongoing and planned investments in LNG infrastructure will likely increase the importance of two more regions for supply diversification: North America (notably the United States, and Trinidad and Tobago) and Africa (Nigeria, Cameroon, Equatorial Guinea).

The issues discussed in this article underscore the complexity of natural gas supply diversification in Europe. Notably, apart from certain countries like Hungary, advancements in transmission technologies and the initiation of new projects have significantly diversified the pool of suppliers. The European Union's adoption of a more flexible gas policy, in line with the principles of the Third Energy Package and the European Energy Union, has mitigated the major energy and geopolitical security risks and uncertainties of the current complex international environment.

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