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EU gas infrastructure resilience: Competition, internal changes, and renewable energy pressure

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Abstract

Natural gas security has been at the center of European energy policy in the past decade. The perception of future scarcity drives the intention to expand the gas network. However, many of the gas infrastructure expansion plans went in contrast to the spirit of energy security. Such policies lead to a decreasing diversity and expose the system vulnerability for future disruptions. Given recent developments, another gas supply crisis like 2009 might have a different impact. In this study, we investigate the robustness of the current EU gas infrastructure to withstand potential disruptions. We used a network simulation model to simulate the demand and supply balance of the European gas market. The study includes a climatic feature of the gas hubs, potential consumption profile changes, and supply competition with the East Asian market. Our result suggests that the European gas market is not as sensitive as it has in the 2009 crisis despite these challenges. Increasing pipeline connections and new LNG terminals built after 2009 provide spare capacity as the demand growth is slower than expected due to mild winters in recent years. Furthermore, abundant LNG suppliers offer more options to mitigate the price effect and to avoid demand curtailment.

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Keywords: Energy security; Network model; Crises resiliency; Gas infrastructure robustness

1. Introduction

Energy security is one of the top priorities in European energy policy and an important pillar of the Energy Union strategy [1,2]. European Union (EU) member states use the International Energy Agency's (IEA) definition of energy security as "the uninterrupted availability of energy sources at an affordable price" [3]. Within the EU energy strategy, natural gas supply security is an important topic [1]. The public became aware of the importance of gas security during the EU-Russian gas dispute in 2009, which led to increases of natural gas prices and gas shortages in many eastern European countries [4]. After the dispute, the EU urged its member states to increase

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energy security by increasing natural gas supply diversity. More specifically, the EU stimulates the adoption of renewable energy technologies to improve EU energy independence and the development of LNG capacity in order to diversify gas import sources.

Despite the strong call for increasing supply diversity, many of the EU's major gas projects do not increase supply diversity. Out of 32 natural gas projects on the 2020 European commission list of common interest projects, only 3 projects directly increase the supply diversity. On the demand side, historically mild winters between 2017–2019 and record breaking summer temperature in addition to the increasing gas demand for power production nudge the EU gas consumption profile. An important question is whether considering the trends above, the EU gas network can withstand future shocks without further network expansions and investments especially those that increase the EU gas supply convergence. This paper therefore investigates the effects of supply shocks and demand trends on the robustness of the current EU gas infrastructure with a focus on energy security. More specifically, we provide a model-based evaluation of the EU natural gas sector. The model integrates the four aspects of energy security; the availability, affordability, accessibility, and acceptability of gas supply. We simulate short-run marginal costs for representative locations in each EU country.

We expand on the existing literature in several important ways. First, our simulation models consider the climate conditions at different gas nodes in Europe, enabling us to include regional disparities. Second, we include the gas supply competition between the EU and the East Asian markets both in the pipeline and in the LNG. Third, we also include other major developments, such as the Dutch gas network phase-out and the German nuclear phase-out. Furthermore, by addressing all aspects of energy security, the paper broadens the gas infrastructure discussion to include long-term and strategic considerations. Practically, this study thereby serves as an analytical exercise to evaluate the urgency of gas network expansion in the EU market.

2. Background

The European gas network is a network of several interdependent markets. Each markets (see Fig. 1(b)) aims to fulfill the demand within its system at the lowest possible cost [5] and decides on prices and the development of interconnectivity [6]. This includes major network infrastructure decisions on pipelines, compressor stations, LNG regasification terminals, and gas storage facilities. Although the European Network Transmission Operator for Gas (ENTSO-G) coordinates the effort to maintain stable gas availability across the EU, often times individual markets or national regulators deviates from the strategic roadmap to optimize their supply security [7,8].

In its quest to secure supplies, large countries and individual markets have opted for expanding the role of major suppliers. For example, by expanding the eastern gas network in Slovakia and Germany, the Russian share of EU gas supply has been a stable 40%–45% between 2010–2018. EU gas imports predominantly come from five countries, namely Russia, Norway, Libya, Algeria, and Qatar. The EU northern Africa supply poses a different risk. Pinkerton [9] put the EU large gas suppliers' political stability outlook in the North African region as volatile and risky in the foreseeable short-horizon the same outlook was also given to the major EU gas hubs Russia, namely Ukraine and Belarus. Such a condition increases the EU risk exposure on any major supply disruptions.

2.1. Changes in the EU gas supply

The Nord Stream pipeline directly connects Russia to Germany and supplies 18% of the German gas demand [10]. Similarly, the expansion of the Greenstream pipeline in Libya, coupled with an extra pipeline connection, further increases the share of natural gas from Northern Africa in the southern European gas supplier mix [11] by, on average, 18%. As a result, the European LNG sector, one of the main sources of diversification, faces increasing price competition from pipeline gas. The average utilization of the LNG terminal in Europe was only 27% in the period 2015–2018 [12]. The relatively high LNG prices in the Asian market further contributes to the low utilization of European LNG terminals [13]. Additionally, the Chinese pipeline expansion to Turkey and Russia adds an extra challenges to the EU gas supply security [14]. At the same time EU gas import dependency has increased from 70% in 2009 to an all-time high of 77.9% in November 2018 [15]. With Brexit, the EU loses its biggest domestic pipeline gas producer. Additionally, the Netherlands, another major EU gas producer, will cease its gas production activities in 2022, due to the earthquake risks of gas extraction. With the higher import dependency and the loss of significant gas producers, the availability of EU long-term gas supply is vulnerable [16].

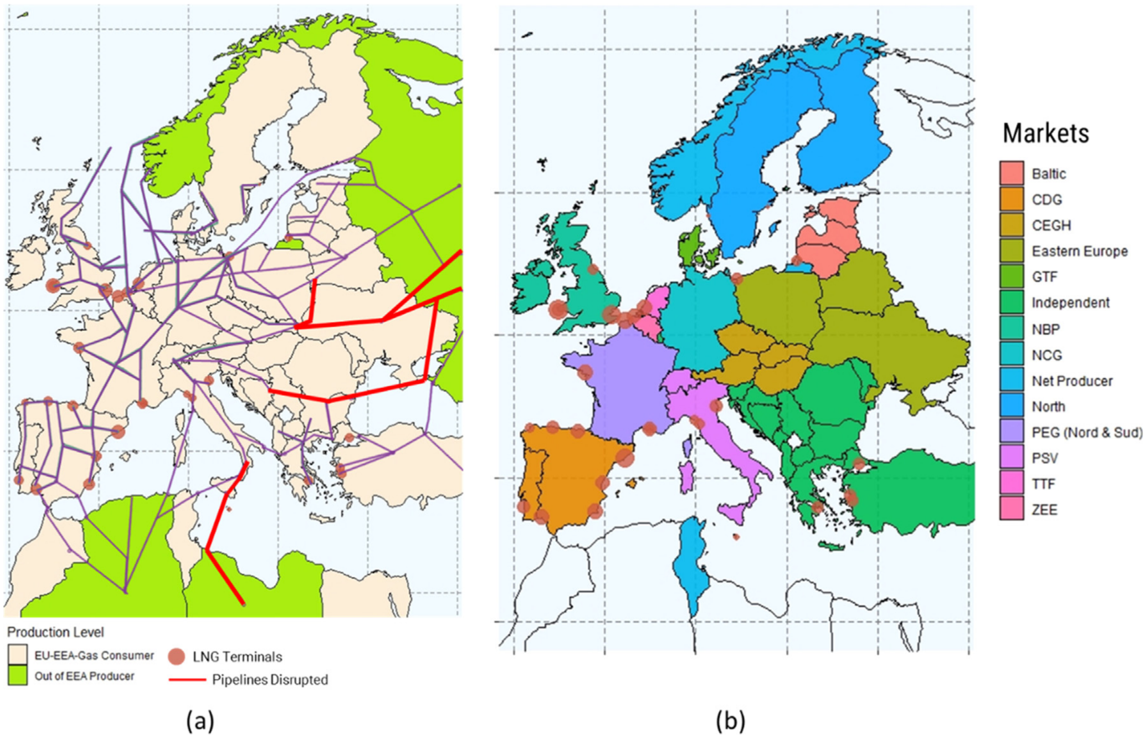

Fig. 1. (a) Gas Pipelines Infrastructure Europe (b) Gas Market Europe and LNG Terminal Locations.

While the decreased diversity of supply creates long term risks for energy security, the expansion of the eastern gas network benefits the affordability aspect of the EU energy security in the short run. Dieckhöner et al. [11] finds that the Nabucco and South Stream Pipelines will reduce disruption for consumers and stabilize prevent price increases. Similarly, Erbach [10] states that the expansion will trigger more internal markets connection as countries seek to secure a relatively cheap source of energy. Increasing connectivity within EU members in the east increases the resiliency of the entire system.

If the main agenda of energy security is to improve supplier diversity, then the previous eastern bound pipeline expansion goes against this agenda. Increasing volume of the pipeline gas will further lower its price and making it more price-competitive against LNG. Naturally, the LNG unit prices are higher than the price of pipe-borne gas due to other liquefaction and regasification processes. Since LNG is one of the most capital-intensive energy projects, it needs a higher degree of usage and predictable unit delivery. As a result, many investors see the infrastructure expansion of pipeline gas as an additional risk in the LNG investment.

2.2. Changes in the EU gas demand

On the demand side, the gas consumption pattern in Europe is changing. The highest consumers of natural gas in the European market are industrial, gas-fired power plants, and residential heating [17]. These sectors made up 86% of the total European gas consumption. The consumption profiles in these sector changes at least in two ways. First, there is a shifting in the seasonal gas consumption and increasing summer heat [17]. This leads to a continuously decreasing number of gas flows especially in the winter to the residential markets and increasing gas usage in the power plant for summer. The growth trend in the recent years are driven by the increasing usage in the electricity generation instead of the heating consumption ([13]; European Gas Markets 2017). There is an accelerated change due to mild winter temperature in many individual countries that leads to significant gas demand drops. Coupled with the changes in the electricity mix, it increases the gas usage during the summer that traditionally has not been the case in 10 years prior to 2016. ENTSO-G observed up-ticks of around 5%–8% increase in the summer gas delivery mainly to region below the 35 degrees of northern latitude. On the one hand, the mild winters reduce gas storage facilities' financial efficiency in many central and northern European countries. Germany and Austria invested heavily in storage facilities to mitigate the surge of gas consumption in the wintertime. However, due to mild winters in the period 2016–2019, the average storage utilization in Germany fell to around 56% of its 270 TWh capacity [18]. On the other hand, increasing summer heat increases the financial attractiveness of using gas as the primary electricity source due to the low gas price in the summertime for countries like Spain and Portugal.

Second, the European gas market will also see structural change in its major players. Traditionally the Dutch is a major gas producer and consumer in the region. Together with Russia, both of them supplies 80% of the total gas consumption of the continent in its peak 1976. Gas-fired plants may replace nuclear power plants in some of the large European countries. The German Energiewende plans to decommission 17 reactors with a total capacity of around 20 GWe between 2011–2022 [19]. France's EDF will decommission 14 reactors to reduce the nuclear share of the French electricity mix to 50% from 75% following the 10-year energy plan of president Macron [20]. In addition, natural gas becomes increasingly financially attractive as base load replacement for nuclear power plants compared to other primary energies such as coal. The second trend is the push to increase the share of renewables in the energy mix. These plans not only focus on power generation but also include the electrification of heating and cooling. An example are the Dutch plans to phase out natural gas for heating and cooking by 2050 (Ministry of Economic Affairs and Climate Policy, 2016).

3. Methods

To analyze the impact of supply disruptions on the gas network we build a simulation model of the European gas network. Our model integrates and extends three earlier modeling efforts: the TIGER market model of the European gas infrastructure [21], and the Gemflow [22] and Nemo models of gas supply security [23]. These models serve different objectives and use different methods (see Table 1). We extend these models by including (1) competition on the LNG market with the East-Asian market and (2) refined demand profiles based on nodal climatic conditions. Our model consists of 420 number of nodes based on the ENTSO-G gas hub (see Fig. 1(a)). We run the simulation on a daily basis for 730 calendar days starting from 1st of January of the reference year.

Table 1. Reference Models.

Model	Developer	Focus	Modeling Approach
Tiger	EWI / EGRG	Investment Decision	Hydraulic model
Nemo	ENTSO-G	Stress Test - Demand curtailment	Hydraulic Model
Gemflow	Monforti / Skzikasai	Gas Supply Security	Monte Carlo Optimization Model

Our model is based on an extensive database of the European gas market infrastructure containing all relevant high-pressure long-distance transmission pipelines, LNG import facilities, and natural gas storages. The full dataset of the historical capacity, storage, and flow in each node can be accessed through the ENTSO-G data transparency platform.[1] The model optimizes the expected total cost of gas supply in the European gas market at the nodal level. The optimization is subject to the relevant technical constraints of the infrastructure. This includes location, connections to other infrastructure, and capacities (pipeline transmission, working gas volume/injection and withdrawal rates for storage facilities, import, and monthly regasification capacities for LNG terminals).

The objective of this paper is to analyze the robustness of the current EU gas infrastructure given the changes in the gas markets. Therefore, we tested the availability and the affordability of gas by simulating a disruptions by setting the pipeline capacity to 0 in the two largest pipeline gas connections in both the eastern and the Mediterranean markets for three months (90 continuous days) in the winter months starting on October to test the supply loss during the peak consumptions simultaneously. The gas corridor pipeline disruptions in this paper are:

- The "Brotherhood" (Urengoy–Pomary–Uzhgorod route) pipeline. This main pipeline with its branches is the single largest gas supplier for the European market, serving Germany, the Czechia and Austria directly and other countries indirectly.

1 https://www.entsog.eu/maps#

- The Libyan–Italy gas connection. This pipeline connection serves the Italian and Southern France (PEG-Sud) market.

We use a regional temperature dataset to model the nodal temperatures within the gas hubs. Traditionally, residential heating dominates gas usage. However, as the winters become mild and the summers becomes increasingly hot, natural gas usage shifted more to power production in some countries (Energy Information Administration, 2020). The regional distinction on the temperature. Every node that fall into a certain region will follow the demand curve that region. Using the modified Thornthwaite climate classification we assign each node to a climate region. In this model, we follow a stochastic demand modeling based on regional temperature. Cox [24] found that the temperature dynamics closely resemble a seasonal pattern, the temperature tend to revert to the average number and there is an autoregressive component in the deviation of the average temperature. We used an autoregressive model of the historical average monthly temperature as the gas demand in each node. The model utilize a stochastic linear optimization with an objective function to minimize the expected total cost of gas supply in the European gas market. The objective function of this model is shown in Eq. (1)

$$minimize \sum_{i,t} Total\ Cost = \sum_{i,t} Q_{i,j,t}.p_{j,t} + \sum_{i,t} \left(\phi_{i,t}.\overline{p_{j,t}} - \delta_{i,t}.\overline{p_{i,t}}\right) \tag{1}$$

where Q is the total supply of gas received by node i from supplier j at time t at price p determined by the supplier j. The second part of the equation deals with the injection and withdrawal of natural gas. Where φ shows the injection volume and δ shows the withdrawal volume with average price of $\overline{p}$ to meet the demand ($D_{\{i,t\}}$).

We employed-fold cross-validation tests to fine tune the model result with the historical data [25]. The test takes different random sets of flows at time t and insert these sets into the reference case analysis. Using this validation method, we cross checked the behavior of the model on different time horizons. We used the cross-fold validation result to fine tune the flow preferences in the model.

4. Discussion and results

This paper simulates the disruptions by setting the "Brotherhood" and the Libyan – Italy pipeline gas capacity to zero simultaneously for three months since October. Disruptions in the east and south gas corridor will cut 34% of the total European gas supply. As a result, the average daily LNG utilization across Europe increases to 46% at the end of the year. Furthermore, alternative gas supply routes such as Nordstream and Norwegian gas flows increase significantly (see Fig. 2(b)). Regarding availability and affordability, our simulations indicate the importance of internal connections within the western European market. The supply drop in pipeline gas will be compensated by LNG supply from different sources, especially those closer to Germany's large consumer. Sudden increasing activity in the LNG receiving facility will increase the average gas price throughout the region, driving the gas price to a record high. On the other end of the market, there is an increasing likelihood of demand curtailment in Romania, Bulgaria, and Slovakia in early December. The internal connection is not as strong as on the other side of the market. However, the demand is fulfilled again in the first week of January with an increasing 6% price. The price spike remained until May, when the demand dampened.

The crisis effect does not occur at the same time. Instead, it propagates and finds new equilibrium in terms of supply and demand regarding the prices (see Fig. 2(a)). The immediate effect of the price spike fell in the vicinity of the Brotherhood pipeline. In the next month, the effect propagates to the west side of Europe. Germany's gas price surges to a record-breaking high for 15 consecutive days at the crisis height. This led to increasing demand from the Belgian connection to mitigate the supply loss through the Norwegian pipelines or the LNG utilization in the Zeebrugge.

Furthermore, the southern corridor gas also will supply more to the German market because the German spot price is much more attractive than the Italian price. This then drives the Italian PSV price up and creates affordability issues in the Balkan region, Slovakia, Czech Republic, and Slovenia. On average, the LNG utilization will significantly increase as a direct response to the crisis. The German power sector will consume an extra ∼63.98 TWh to compensate for the nuclear phase-out. However, eventually, gas consumption dropped because of the price increase, and the power producers switched back to coal. To compensate for the loss of supply, Germany increases inflows from the Yamal and Nordstream pipeline as an alternative to the Brotherhood. Both pipeline corridors manage to replace 47% of the brotherhood loss capacity. With the decommissioning of the Dutch gas facilities,

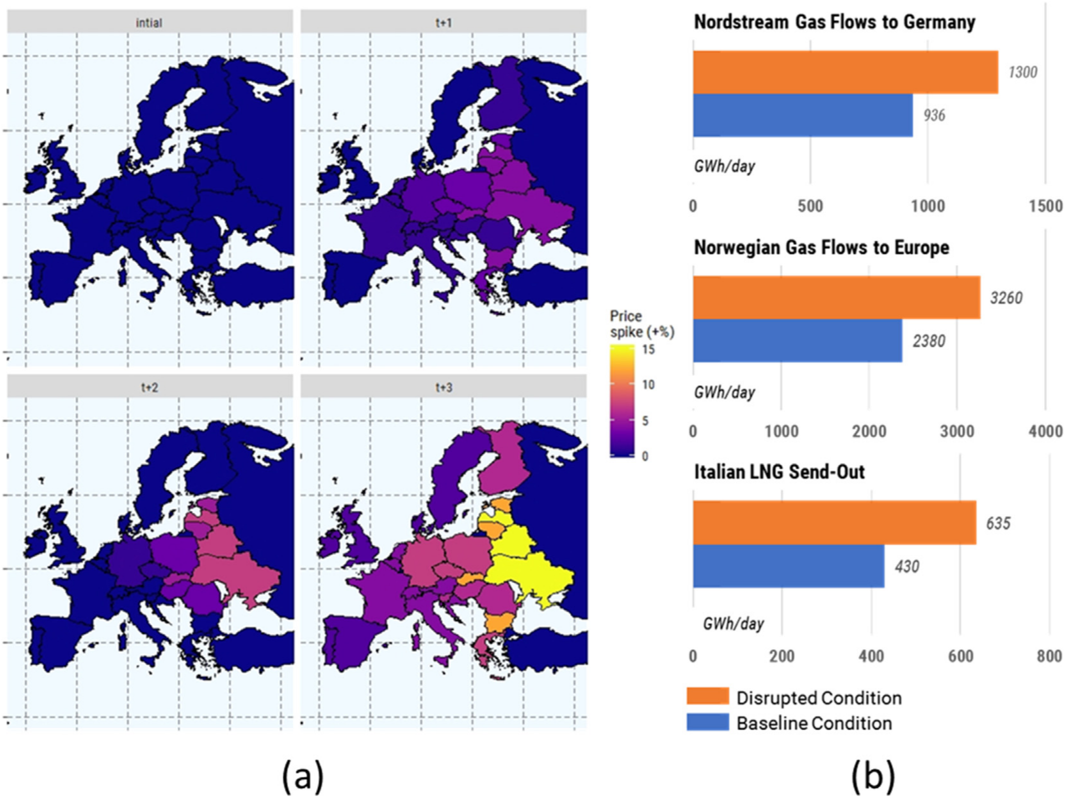

Fig. 2. (a) Time Development of Supply Disruptions and (b) alternative routes of gas supply.

the Belgian and Southern corridor gas fulfill Germany's extra demands (42% of the total capacity loss). Additional supplies are coming from the Norwegian and British pipe with a small addition from the Polish Floating Storage & Regasification Unit (FSRU).

Natural gas is still the most attractive primary energies to support the Nuclear powerplant phase-out in France. In the current condition, France's potential gas power plant capacity is only around 1.2 GW. While the total Nuclear phase-out capacity needed is 18 GW, more than ten times the current capacity. Since most French gas power plants are situated in the north of the country, the increasing consumption will happen in the northern French market. The crisis increased the annual average Italian LNG utilization from 18% to 27% (see Fig. 2(b)). The increasing utilization in the LNG drives prices up in the Italian PSV market and the Southern French market. Availability will remain intact in the French markets. Most of the lost French gas supply will be fulfilled by the British, Norwegian, and LNG supplies from different terminals. Furthermore, the Southern French market connection to the Spanish market allows them to tap into the Algerian gas supply and limiting the price spike effect.

5. Conclusion

This paper aims to analyze the robustness of the current EU gas infrastructure, given possible disruption scenarios. We presented the supply disruptions of the two most significant gas corridors to the European gas market's availability and affordability. Although we saw an increase in the gas price at the height of the crisis, it does not last for a long time. Most of the gas demand is still fulfilled even on a limited amount of demand curtailment in some countries. Despite the German and French power plants' increasing consumption due to the Nuclear phase-out plans, the current gas infrastructure manages to withstand the loss of major suppliers in the eastern corridor. The buffer comes from the second largest gas corridor in both markets (Algeria–Europe for the Mediterranean and Nordstream for the eastern market). The increasing LNG utilization, especially in the Belgian and Italian sides, is connected to the German, France, and Austrian markets. The scenario results show that the current EU gas infrastructure is robust enough to withstand major disruptions. Despite significant disruptions, the projected LNG utilization is still limited, and most supply still comes from a converging set of countries.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] European Commission. Regulation (EU) 2017/1938 concerning measures to safeguard the security of gas supply and repealing Regulation (EU) No 994/2010. Off. J. Eur. Union 2017/1938. 2017.
[2] Sencar M, Pozeb V, Krope T. Development of EU (European Union) energy market agenda and security of supply. Energy 2014;77:117–24.
[3] Umbach F. Global energy security and the implications for the EU. Energy Policy 2010;38:1229–40.
[4] Cherp A, Jewell J. The concept of energy security: Beyond the four As. Energy Policy 2014;75:415–21.
[5] Hedenus F, Azar C, Johansson DJA. Energy security policies in EU-25-the expected cost of oil supply disruptions. Energy Policy 2010;38:1241–50. http://dx.doi.org/10.1016/j.enpol.2009.01.030.
[6] Melling AJ. Natural gas pricing and its future: Europe as a battleground, vol. 129. 2010.
[7] Brutschin E. Targeting infrastructure. In: EU Gas Security Architecture. Palgrave Macmillan UK; 2016, p. 67–83. http://dx.doi.org/10.1057/978-1-137-51150-8.
[8] Schubert SR, Pollak J, Brutschin E. Two futures: EU-Russia relations in the context of Ukraine. Eur J Futur Res 2014;2:52. http://dx.doi.org/10.1007/s40309-014-0052-7.
[9] Pinkerton. Business risk ranking. Ann Arbor; 2017.
[10] Erbach G. The Nord Stream 2 pipeline project. Strasbourg; 2016.
[11] Dieckhöner C, Lochner S, Lindenberger D. European natural gas infrastructure: The impact of market developments on gas flows and physical market integration. Appl Energy 2013;102:994–1003. http://dx.doi.org/10.1016/j.apenergy.2012.06.021.
[12] CEER. How to foster LNG markets in Europe. 2019.
[13] ENTSOG. Gas market report quarterly. 2018.
[14] Rui X, Feng L, Feng J. A gas-on-gas competition trading mechanism based on cooperative game models in China's gas market. Energy Rep 2020;6:365–77. http://dx.doi.org/10.1016/j.egyr.2020.01.015.
[15] ENTSO-G. Gas market qurterly. 2019.
[16] Sutrisno A, Nomaler Ö, Alkemade F. Has the global expansion of energy markets truly improved energy security?. Energy Policy 2020;148:111931. http://dx.doi.org/10.1016/j.enpol.2020.111931, Part A.
[17] Henderson J, Programme NG. Quarterly gas review: Analysis of prices and key themes for 2020. 2020.
[18] Paper O, Honor A. Decarbonization and industrial demand for gas in Europe. 2019.
[19] Jarvis S, Deschenes O, Jha A. The private and external costs of Germany'S nuclear phase-out. J Chem Inf Model 2019;53:1689–99. http://dx.doi.org/10.1017/CBO9781107415324.004.
[20] Schneider M, Froggatt A, Hazemann J, Katsuta T, Lovins AB, Ramana MV, Hirschhausen Cv, Wealer B. The world nuclear industry status report, vol. 2019. 2019, p. 1–38. http://dx.doi.org/10.1177/0096340213517215.
[21] Lochner S. Modeling the European natural gas market during the 2009 Russian–Ukrainian gas conflict: Ex-post simulation and analysis. J Nat Gas Sci Eng 2011;3:341–8. http://dx.doi.org/10.1016/j.jngse.2011.01.003.
[22] Szikszai A, Monforti F. GEMFLOW: A time dependent model to assess responses to natural gas supply crises. Energy Policy 2011;39:5129–36. http://dx.doi.org/10.1016/j.enpol.2011.05.051.
[23] ENTSO-G. Security of supply simulation report. 2017.
[24] Cox E. Opening the black box of energy security: A study of conceptions of electricity security in the United Kingdom. Energy Res Soc Sci 2016;21:1–11. http://dx.doi.org/10.1016/j.erss.2016.06.020.
[25] Xiang X, Kennedy R, Madey G. Verification and validation of agent-based scientific simulation models. Agent-Direct Simul Conf 2005;4:7–55.