Case studies on extreme prices in European energy exchanges

Evidence of the effect of disruptions in demand and supply and the interrelationship of the power and gas markets

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Abstract

In order for the European Union to address major energy problems, including, among others, rising energy costs and the consequent lack of competition, as well as high dependence on specific suppliers, it was considered a necessity to establish an integrated European Energy Policy. Within this framework, specific objectives were defined, with a view to gradually smoothing out these problems. The European Energy Policy is based on five key pillars, namely integrating the European energy market, increasing energy security and solidarity, the gradual decarbonazition of the European economy, increasing energy efficiency to mitigate demand and the development of research, innovation and competitiveness in the energy sector.

As a result of the implementation of this policy, it was considered necessary to restructure the energy market, with a clear distinction between the wholesale and retail electricity and gas markets. Consequently, the establishment of energy exchanges across the continent, operating the wholesale markets has been institutionalized, with a uniform operating model, which facilitates competitiveness, cross-border transactions and the disclosure of fair prices, with the ultimate aim of converging the markets to establish a single European energy market. Exchange market prices reflect the balance between supply and demand. However, there are often strong fluctuations in prices, which in turn reveal significant imbalances in the price formation process. In some cases, disturbances in either the supply, or the demand for energy, and is some extreme cases disturbances in both supply and demand, is followed by the possible occurrence of extreme prices or even the emergence of temporary crises.

The purpose of this study is to examine the facts and the respective factors that contributed to the formation of extreme prices on European energy exchanges during the winter periods of 2016 and 2017. The research is done through the study of cases where the causes of the imbalances are sought, through examining events that have disrupted supply and demand.

In particular, the research focuses on the energy shortage that was observed in the United Kingdom in October 2016, which emerged due to the problems arising from the closure of the Rough Natural Gas Storage Facility, coupled with inadequate LNG supplies from Qatar, due to competition arising from the occurrence of shortages in the Asian market. The second case, refers to the French energy market, where electricity production shortages have led to high prices in the country in December 2016 to January 2017, affecting the entire region of Central and Eastern Europe. In this case, the cause of the phenomenon of extreme prices seems to be the closure of nuclear reactors, coupled with the unusually low temperatures of the period, which led to an increase in demand. At the same time, the price imbalance between northern and southern France is of particular interest, because of the country's inadequate energy infrastructure and the closure of the Manosque natural gas depot. The last case under consideration refers to the period November to December 2017, when events such as the reduced availability of French nuclear power plants and the Baumgarten accident were accompanied by rising energy prices in Italy.

Keywords: electric power, gas, Energy exchange, volatility, price formation mechanism, imbalance of demand and supply curves, extreme prices, case studies

Introduction

Energy Exchanges play a critical role in the implementation of the European Union's energy strategy, which aims to strengthen domestic and cross-border competition, with a long run objective to achieve fair energy prices for consumers and lead to an integrated single market. This process is achieved through the liberalization of the national energy markets across Europe, in order to create conditions of competition and linking individual markets. Energy exchanges provide both spot and derivative products to better facilitate energy trading. Spot markets, include the day ahead, the intraday and the balancing markets, while various types of derivative products are traded on the various forwards markets of the European Exchanges, along with bilateral contracts traded over-the-counter. Forward energy products offer market participants hedging opportunities against short-term price volatility.

Price formation on the energy exchanges is achieved through an auctioning trading system (day-ahead market) or a continuous trading system (intraday and forward markets) that allows prices to be determined freely. The observed prices of the auctions of the day-ahead market represent the equilibrium of demand and supply. Based on the demand theory, the demand curve is shaped in that way, which shows the relationship between the quantity and the price of a product the consumer chooses to purchase, considering that all other factors remain stable (Nicholson, 2008). Demand expresses the exact amount of product the consumer wants to buy at a certain price over the given period of time. While a consumer is interested in both the price of the product and the quality of the product, the issue of quality does not exist in the case of the power market, since power does not show a difference in quality like other goods. Power demand is characterized as inelastic because it is a necessary commodity, therefore it does not change when the price increases or decreases and can be affected by many factors such as weather changes. Weather conditions greatly influence power consumption either by increasing or decreasing temperature (Badr & Nasr, 2001). In addition, power demand exhibits seasonality, both intraday that is attributed to different needs of the consumers during the day and long term seasonality that is attributed to different consumer behavior during holidays and weekends, seasonal patterns such as winter and summer temperature factors. Economic factors such as power prices, gross domestic product, import prices, energy exports and energy efficiency can equally affect power demand.

On the other hand, the supply law shows the positive relationship between commodity prices and the quantity offered when all other factors remain stable (Nicholson, 2008). There are several ways to generate power, but they vary in production costs. More specifically, each production unit is placed at a different position on the power supply curve, according to the short-term marginal cost of production. Renewable Energy Sources, which have minimal marginal costs are placed first, followed by nuclear energy which has higher costs. Next in the line is had fossil and gas with more expensive marginal costs than the previous two forms of energy and finally oil appears to have even greater marginal production costs. This ranking is called the merit order. (Sensfuß, Ragwitz, Genoese, 2007).

The market demand curve is derived from the sum of the individual demand curves of each consumer, while the supply curve is the sum of the individual supply curves of each independent supplier. The equilibrium price of a product is the price at which demand and supply are equalized, with a geometric approach being the intersection of the supply curve and the demand curve (Varian, 2006)

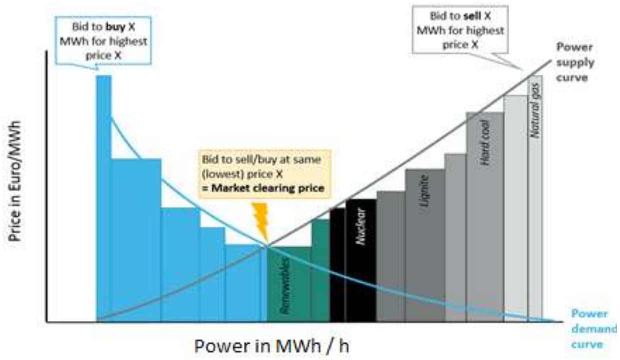

Figure 1: Balance in the wholesale power market.
Source: cleanenergywire

Initially, on the vertical axis of **Figure 1** is the euro price for each MWh, while the horizontal axis shows volumes of power in MWh. At the same time, the graph shows the consumer demand curve, as well as the producer supply curve. These two curves intersect at a point, called market equilibrium, which corresponds to the specific price at which consumers will buy energy, producers will sell energy, as well as the total volume of energy that will be produced and consumed.[1]

Extreme prices, meaning prices that diverge significantly from the average recorded prices, can be observed at times. This divergence can be attributed to significant disturbances in the balance between supply and demand. The existence of extreme prices in wholesale power sales prices is a fact worth exploring and investigating the causes of its creation. Extreme prices changes can be either positive (jumps or spikes), or negative.

In this study we try to identify the causes for the occurrence of abnormally high prices observed in monthly power and gas prices across European energy markets and examine the factors that drive energy prices to diverge from their average trends. It seems that when extremely high prices are recorded, they are related to significant events that had led to the

[1] Energy Regulator Authority, http://www.rae.gr/site/categories_new/electricity/market/wholesale/price.csp

disruption of either the demand or the supply of energy and in some cases both the demand and supply.

Energy Mix

To meet its energy needs, each country uses the types of energy sources available, in differing proportions. This is referred to as the "energy mix", which corresponds to the combination of the various primary energy sources used to meet energy needs in a given geographic region. It includes fossil fuels (oil, natural gas, and coal), nuclear energy, the many sources of renewable energy (wood, biofuel, hydro, wind, solar, geothermal, heat from heat pumps, renewable waste and biogas) and non-renewable waste. These primary energy sources are used, for example, for generating power, providing fuel for transportation and heating and cooling residential and industrial buildings.

For each region or country, the composition of the energy mix depends on the availability of usable resources domestically or the possibility of importing them, the extent and type of energy needs to be met and the policy choices determined by historical, economic, social, demographic, environmental and geopolitical factors.[2]

In effect each country's energy mix is the outcome of a national strategy that involves optimizing the proportions of the available options to produce or import fuels for domestic electricity generation, to provide incentives for investments in renewables, or to import energy. In all cases the competitiveness and the affordability of each option plays a key role in the formation of the energy mix. In most cases the strategy involves not only the need for competitive prices, but other crucial parameters need to be taking into consideration, such as the security of supply and sustainability. Fuel prices tend to be volatile and thus a diversity in the power generation mix is required to a large extend, in order to mitigate the exposure to fuel price risks.

Most countries usually develop power mix based primarily on the availability of domestic resources and then on the availability of resources in international markets. The usage of locally available energy resources to generate power has the advantages of supporting the local industries and provides a great level of independence from outside threats. (Everts, Huber and Blume-Werry, 2016)

It is needless to argue how important are the factors of affordability and competiveness of energy prices for both the economic viability, sustainability and growth of each country.

[2] https://www.planete-energies.com/en/medias/close/about-energy-mix

Both the business and the consumers are influenced by cheap or expensive energy and there have been cases where expensive energy prices have even led to political instability[3].

> *"Since the Paris Agreement on action to fight climate change, virtually every country in the world is now conscious of the need to meet the challenge of the Energy Trilemma: providing households with supplies of energy that are accessible, reliable and affordable, and delivering energy to businesses at competitive prices, while at the same time ensuring that we generate and use energy in a way that protects the environment"*[4]

The need to provide environmental friendly energy has introduced various policy instruments, such as carbon emission pricing or support schemes, which influence the competitiveness of certain technologies directly or indirectly. (Everts, Huber and Blume-Werry, 2016)

These differences can be appreciated by looking at the production and consumption figures for individual countries.

Table 1 demonstrates the energy mix for the generation sources of electric power of 11 selected countries of the total 28 Member States of EU, for 2017 and 2016.

[3] Bulgarian government to resign, PM Boiko Borisov says, BBC, 2013
[4] Sir Philip Lowe, Executive Chair, Energy Trilemma, World Energy Council

	Conventional Energy Sources														
	Lignite			Hard Coal			Other fossil			Gas			Nuclear		
	2017	2016	change	2017	2016	change	2017	2016	change	2017	2016	change	2017	2016	change
EU28	**308**	**306**	**1%**	**358**	**386**	**-7%**	**134**	**133**	**1%**	**649**	**610**	**6%**	**831**	**840**	**-1%**
Austria	0	0		2	2	0%	4	4	0%	10	9	11%	0	0	
Finland	3	3	0%	6	7	-14%	1	1	0%	4	4	0%	23	23	0%
France	0	0		11	8	**38%**	8	8	0%	40	35	14%	400	403	-1%
Germany	148	150	-1%	94	112	-16%	26	27	-4%	88	82	7%	76	85	-11%
Greece	19	17	12%	0	0		6	6	0%	15	14	7%	0	0	
Italy	0	0		33	36	-8%	18	18	0%	138	126	10%	0	0	
Netherland	0	0		35	37	-5%	6	6	0%	57	54	6%	3	4	-25%
Poland	52	51	2%	79	79	0%	5	5	0%	9	8	13%	0	0	
Spain	0	0		44	36	22%	19	19	0%	63	53	19%	58	59	-2%
Sweden	0	0		0	0		3	3	0%	1	1	0%	66	63	5%
UK	0	0		23	31	-26%	7	7	0%	137	143	-4%	70	72	-3%

	Renewable Energy Sources											
	Hydro			Solar			Wind			Biomass		
	2017	2016	change	2017	2016	change	2017	2016	change	2017	2016	change
EU28	**305**	**350**	**-13%**	**118**	**111**	**6%**	**360**	**303**	**19%**	**193**	**187**	**3%**
Austria	38	40	-5%	1	1	0%	7	5	40%	5	5	0%
Finland	15	16	-6%	0	0		4	3	33%	11	12	-8%
France	**51**	**60**	**-15%**	9	8	13%	25	22	14%	8	7	14%
Germany	20	21	-5%	39	38	3%	**104**	**79**	**32%**	51	51	0%
Greece	6	6	0%	4	4	0%	6	5	20%	0	0	
Italy	36	42	-14%	25	22	14%	18	18	0%	26	26	0%
Netherland	0	0		2	2	0%	9	8	13%	5	5	0%
Poland	3	2	50%	0	0		15	13	15%	7	8	-13%
Spain	19	36	-47%	14	14	0%	49	49	0%	6	6	0%
Sweden	65	62	5%	0	0		17	15	13%	11	11	0%
UK	6	5	20%	12	10	20%	50	37	35%	32	30	7%

	Imports			Production			Consumption		
	2017	2016	change	2017	2016	change	2017	2016	change
EU28	**10**	**18**	**-44%**	**3,257**	**3,225**	**1%**	**3,268**	**3,243**	**1%**
Austria	6	7	-14%	67	65	3%	73	72	1%
Finland	20	19	5%	67	69	-3%	87	88	-1%
France	-40	-42	-5%	551	551	0%	511	510	0%
Germany	-52	-51	2%	647	644	0%	595	593	0%
Greece	6	9	-33%	55	51	8%	61	60	2%
Italy	38	37	3%	293	288	2%	331	325	2%
Netherland	4	5	-20%	117	115	2%	120	120	0%
Poland	2	2	0%	170	166	2%	172	168	2%
Spain	9	8	13%	273	271	1%	282	279	1%
Sweden	-19	-12	58%	164	156	5%	145	144	1%
UK	15	18	-17%	336	336	0%	351	354	-1%

Table 2: EU's Energy Mix for selected Member States 2016-2017
Source: Sandbag, Own Illustration

Although the focus of this study is given on the UK, France, and Italy, it is useful to analyze not only the energy mix of those three core countries but also to compare the data with other major countries of the European Union, so that the particularities of each one can be discerned.

Taking a closer look at the volumes of production from each energy source of each country presented in this table, we can observe that each country has a unique profile. Even though most of countries rely on conventional power generation sources, the dominant source is different from one country to the other. We can clearly observe that France is depending on nuclear power, while Italy and the UK record significant volumes of gas to power generation and in contrast Germany, Greece and Poland have considerable volumes of lignite to power generation.

France seems to be a unique case, since from a overall production of 551TWh in 2016 and a consumption of 510 TWh, nuclear power generation reached as high as 403TWh. France's high dependence on nuclear power will be thoroughly discussed later in the study.

Comparing data between 2016 and 2017, we can claim that that despite the modest transition from year to year at overall, significant changes can be identified in the various energy sources and certain countries. To be more specific, as far as the EU28 average is concerned, it seems notable to mention that gas showed a slight increase of 6% and among Renewable Energy Sources, Hydro-electric power showed a decrease of 13% while wind power, on the other hand, showed an increase of 19%. Moreover, imports in total dropped from 18 TWh in 2016 to 10 TWh in 2017 showing a decrease of 44%. To explain these changes, it seems necessary to observe each country of **Table 3** individually.

While there is a general movement away from conventional energy sources in Europe, in accordance to the European energy strategy, in some cases such as Spain, the need to use them had become imperative. In particular, Spain recorded an increase 22% in the use of hard coal, while in the UK and Germany the corresponding volumes decreased by -16% and -26%. As far as gas is concerned, the increased use is recorded throughout the European Union, with Italy and Spain registering a total volume increase by 6%. At the same time, as far as nuclear energy is concerned, while there are no major changes in general, there was a significant decrease of 11% in Germany's production.

In regard to renewable energy sources, it can be noted that 2017 was a relative dry year, with a consequence to record a reduced hydroelectric power generation mostly depicted in Italy, France, and Spain. Notably, Spain decreased its hydroelectric amount by 47%, while Italy and France follow with a 14% and 15% decrease, accordingly. As a result, the EU28 average dropped by 13%. On the other hand wind power generation recorded an increase of 19% in 2017 compared to 2016.

Taking a closer look at Italy's energy mix, we can observe that it is dominated by gas to power generation and followed by power imports and hydropower generation, as it is shown in **Figure 2**, which illustrates Italy's power generation sources in 2016 and 2017. More specifically, in 2017 gas was the dominant source of power generation, as it accounted for 42% of the total consumption, while hydropower follows in domestic production with 11%. The amount of power produced by the various renewable energy sources reaches 32% of the consumption.

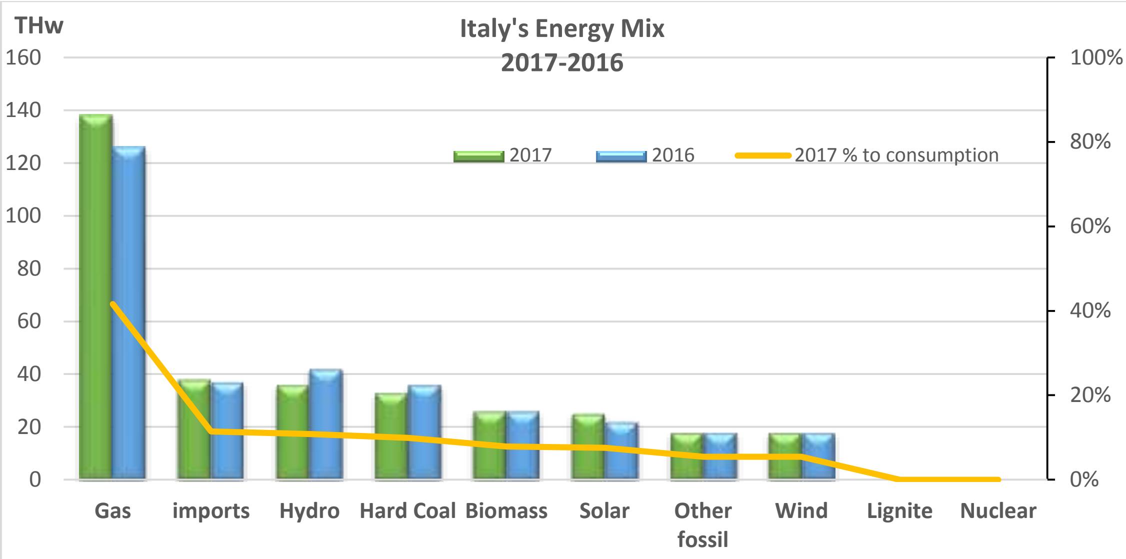

Figure 2: Italy's Energy Mix 2017 – 2016
Source: Sandbag, Own Illustration

Compared to the other member states of the EU, Italy is in the second place when it comes to the use of gas into power generation. On the top of the list is the UK with 143 TWh for 2016 and 137 TWh for 2017, while Italy follows with 126 TWh for 2016 and 138 TWh for 2017, as it can be discerned on Figure 3.

In contrast, for 2017 Italy's gas to power generation accounts for 41.69% of the consumption and 47.10% of the production for, while UK's numbers are a bit lower to 39.03% in the former and 40.77% to the latter. This significant dependency on one source of power generation can make a country vulnerable to perils, related to this source, as it will be described later in the relevant case studies. This is even more important when we refer to gas since Italy and most other European countries need to import gas that is used for power generation, increasing further its energy dependence.

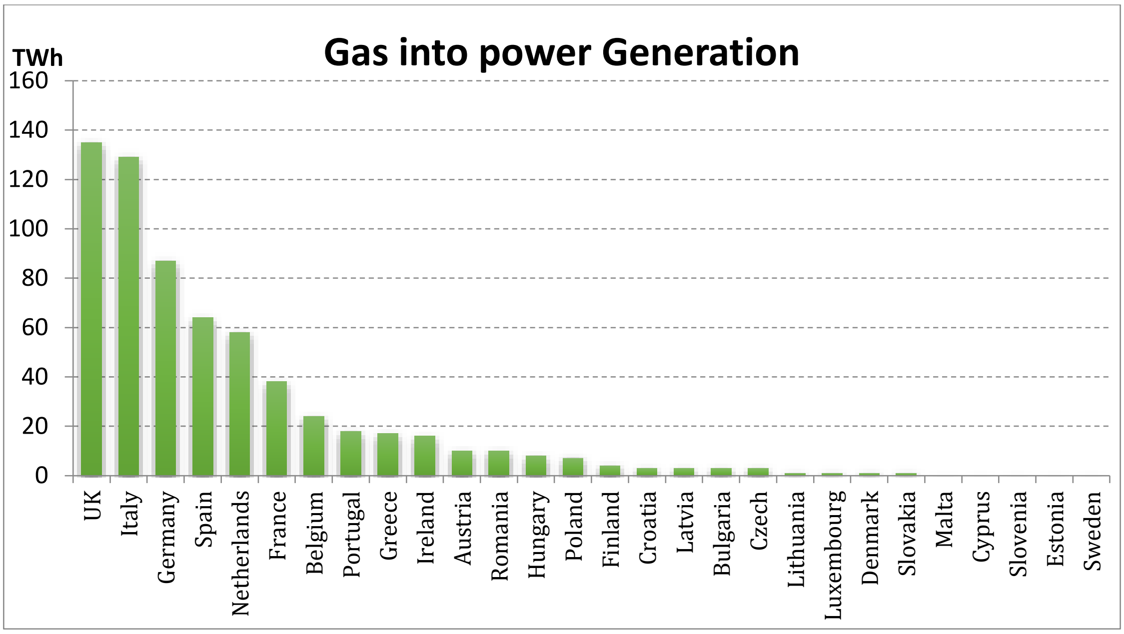

Figure 3: EU's Gas Generation
Source: Eurostat

The second larger contributor to Italy's energy mix is power imports. Italy has the biggest amount of power imports, compared to all of the EU28 member states, as it is depicted in **Figure 4**, which shows the power equilibrium of the countries that constitute the European Union. It is noteworthy that Italy's imports in 2017 reached 38 TWh, while the runner up, which is Finland, had 20 TWh, videlicet less than the half, but slightly increased from 2016 by 3% and 5% respectively. The UK also relies on its power imports. In particular, UK's power imports reached 15 TWh following a decrease of 17% from the past year's 18 TWh.

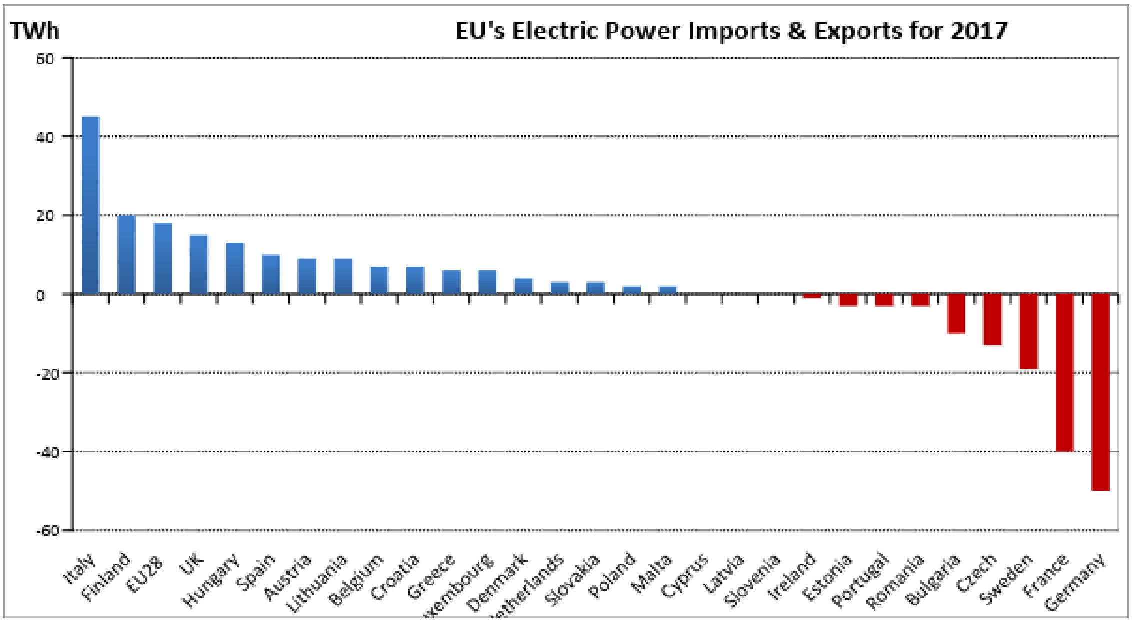

Figure 4: EU's Electric Power Imports & Exports for 2017
Source: Eurostat

Case Studies – Events leading to energy price jumps

As mentioned in the previous sections, achieving the long-term goal of the European policy towards the development of a single pan-European energy market requires the completion of specific intermediate targets. The convergence of the markets can be succeeded through the development of cross-border trading and through the creation of an intermediate stage, which refers to the formation of regional markets with high levels of interdependence and interaction.

The course of integration of Europe's energy markets is reflected indirectly through the convergence of power and gas prices, traded on the various European energy exchanges. However, through the study of the behavior of monthly power and gas prices in the main European markets, extreme prices were observed at certain times and in specific markets, raising questions regarding the efficiency of the model. Therefore, it was considered necessary to further investigate the root causes of the occurrence of these extreme prices, the existence of which, in many cases, is the result of events that led to a steep shift of the supply and demand equilibrium. This fact indicates essentially a distortion of the regularity in the functioning of the market.

As seen in **Figure 5,** which depicts monthly power prices in various European markets, and on **Figure 6** which refers to monthly gas prices across the continent, sharp changes are noted. Specifically, the above-mentioned price hikes were identified at specific time periods, which were isolated for a thorough analysis of the causes.

The first period under review covers the period October - November 2016, focusing in particular on the large increase in UK power and gas prices. Subsequently, the second period begins in December 2016, staggered in January 2017 and concerns most of the countries of Central-Eastern Europe. The chart of gas prices shows that France and especially the southern part of the country played an important role in this crisis. The last period is between November - December 2017, where the two countries with the most intense problems appear to be France and Italy.

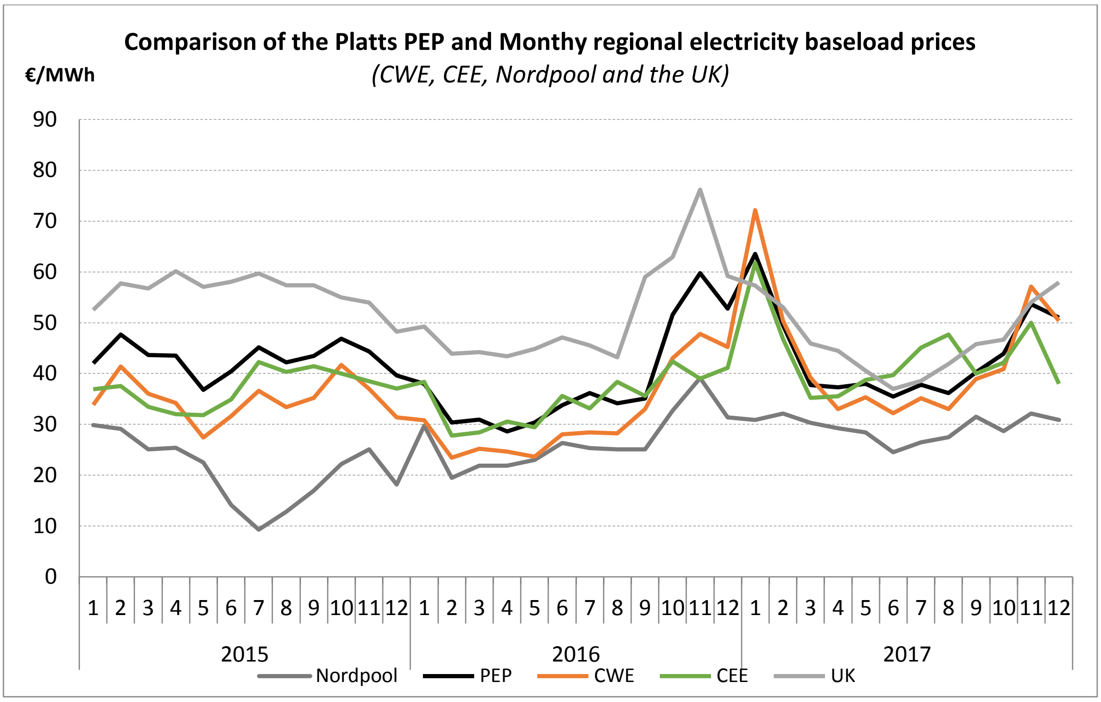

Figure 5: Comparison of the Platts PEP and Monthy regional electricity baseload prices
Source: E.U.

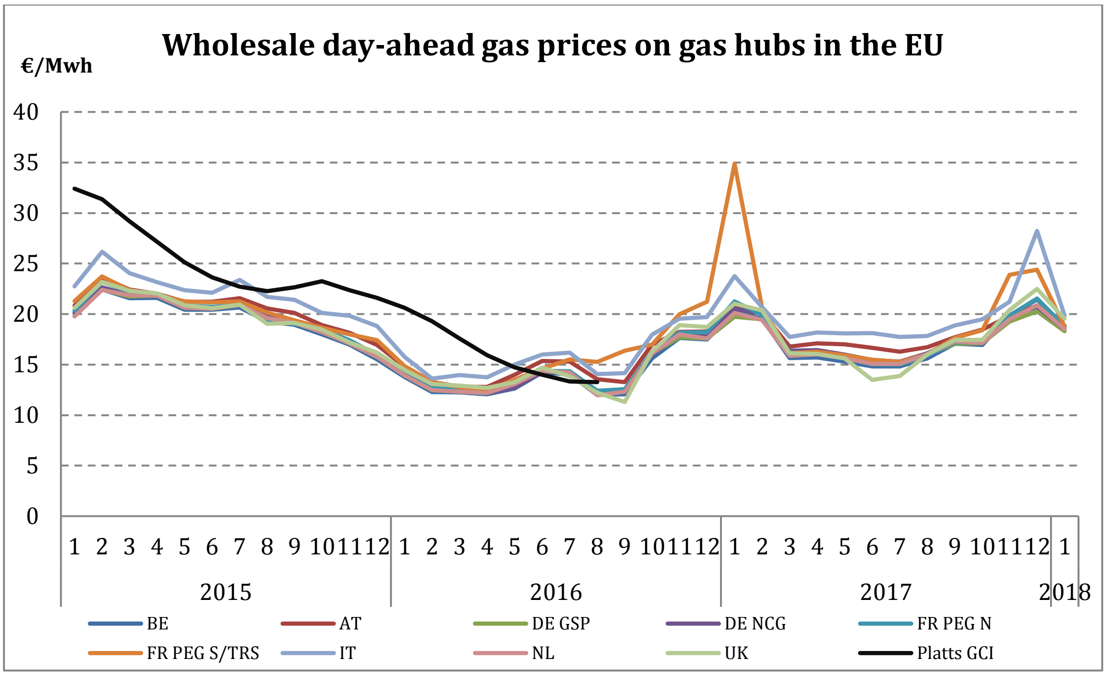

Figure 6: Wholesale day-ahead gas prices on gas hubs in the EU
Source: E.U.

First Period: October - November 2016 – U.K.

Starting with the first period, as noted above, United Kingdom has experienced strong fluctuations in power and gas prices, as is shown at the relevant monthly price charts. This volatility is even more evident and steep when we focus on daily and hourly price charts, represented by **Figures 8, 9** and **10**, where jumps and spikes have emerged.

Figure 7, below, depicts the UK's daily power prices for the period of interest noted above in the study. Until August of 2016, prices were lower than 50€/MWh, but in September the average price started to increase. The first jump of the daily prices was recorded on the 11th of September at a price of 61.17 €/MWh, followed by a spike reaching at 145.38 €/MWh on the 14th of September and then again, the highest spike was recorded on 27th of September at 199.17 €/MWh. At the same time hourly day-ahead prices have reached as high as 990 GBP/MWh.

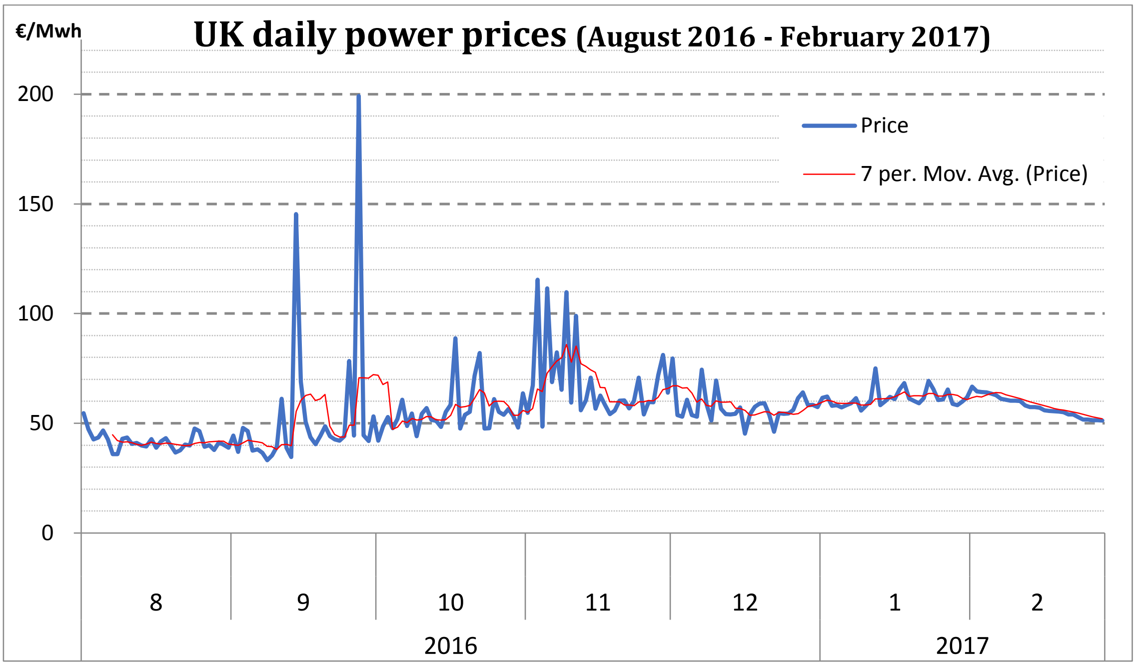

Figure 7: UK daily power prices
Source: Nordpool

Figures **8**, **9** and **10**, below, depict the UK's hourly power prices for the period of interest noted above in the study. The first spike of the hourly prices was recorded on 15th of September reaching at 990 GBP/MWh. Then on 19th of September there was another spike at 960 GBP/MWh and on the 21st Of October another one at the prce of 400 GBP/MWh.

In October, the daily Day-ahead prices were more stable as the greater divergence was at 73.68 GBP/MWh at the 24th of the month and the next day at 79.41 GBP/MWh. The highest hourly price reached up to 304.94 GBP/MWh at the 21st of October and followed by two more jumps at 24 and 25 of the month at 300 GBP/MWh and 259.97 GBP/MWh respectively.

Observing the figure related to November, the period of 7 to 9 of November can be distinguished as the daily Day-ahead prices were higher than the rest of the month averaging at around 100 GBP/MWh. Each day, the hourly Day-ahead prices peaked at 796 GBP/MWh, 775.92 GBP/MWh and 600 GBP/MWh respectively.

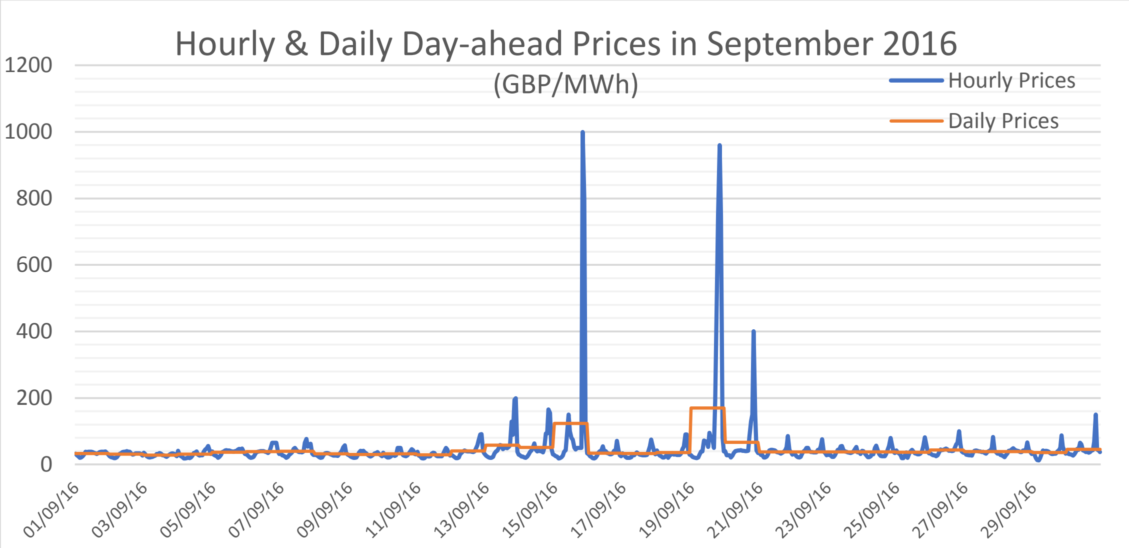

Figure 8 : Hourly & Daily Day-ahead Prices in September 2016, UK
Source: Entso-e

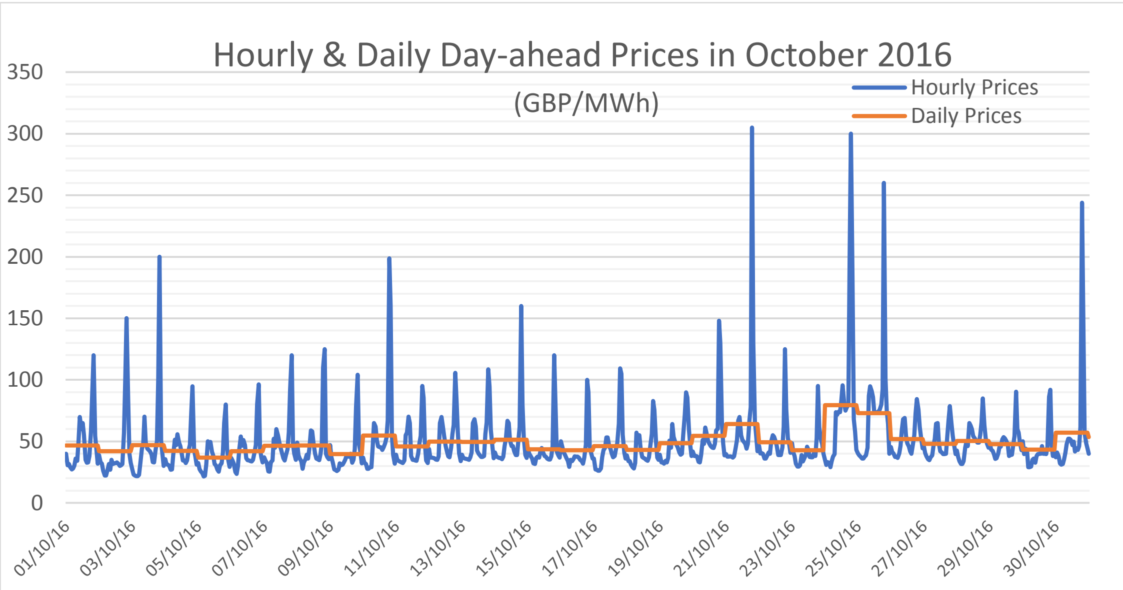

Figure 9: Hourly & Daily Day-ahead Prices in October 2016, UK
Source: Entso-e

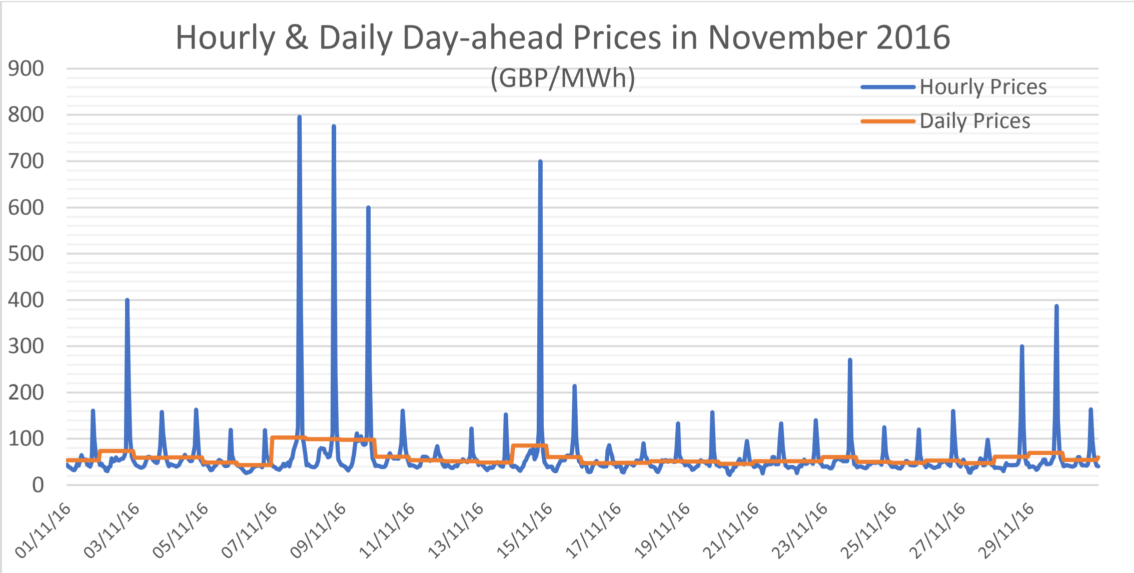

Figure 10: Hourly & Daily Day-ahead Prices in November 2016, UK
Source: Entso-e

This volatility is highly correlated to the idiosyncratic characteristics of the energy profile of the county and more specifically it refers to the power production mix. As already mentioned earlier, the UK is highly depending on covering its power demand on power production from gas. A predominant role in this phenomenon, as it emerges by the study of the relevant events of the period, was played by the uncertainty caused by the irregular operation of the Rough gas storage facility.

Rough was the only long-range storage site and the largest gas storage facility in UK, used by market participants to store gas in the summer and deliver that gas to meet peak demand in the winter. The Rough reservoir is a depleted gas field located approximately 29km (18 miles) off the east coast of Yorkshire, in Rotliegendes sandstone, 2.7km (9,000 feet) under the Southern North Sea bed. The Rough field commenced gas production and processing in 1975. In 1985, the gas field was converted by its then owners (British Gas) to store gas to meet seasonal supply/demand imbalances. There are seasonal variations in demand, which are a consequence of overall demand for gas in the winter being higher than in the summer. Variations in demand are particularly pronounced in relation to domestic customers. CSL (Centrica Storage Limited), which owns and operates the facility, reported that Rough can meet approximately 10% of the UK's peak day demand.

According to data included in the National Grid's Ten-Year Statement on the national gas network published in 2015[5], Rough alone could make up 72% of the UK's existing gas

[5] https://www.nationalgridgas.com/sites/gas/files/documents/44047-GTYS_2015_Full%20Document.pdf

storage capacity. With a storage capacity of 3.31 billion m^3, Rough, to the maximum of its storage capacities could cover the United Kingdom's gas needs for nine consecutive days.

The uncertainty about Rough began in March 2015, as Centrica announced that it would begin maintenance work, resulting in its under-operation, according to a relevant Platts article[6]. In 2016, while the facility was still partially operational, due to maintenance, the company announced its temporary shutdown during the summer season, from June to August 2016, according to a BBC radio station article[7]. Moreover, in a subsequent statement, the company notified about the all-embracing closure of facilities with effect from August of that year, as mentioned in a related article by The Financial Times[8]. Nevertheless, Centrica, later that year, announced that the gas storage facility will be operational again on the 1st of November 2016, but operating at one-third of its capacity, although six of the thirty storage wells would be permanently closed. This decision was taken because of concerns that the shutdown would increase the UK's dependency on imports and would create a rise in domestic gas prices, as Telegraph published[9]. Due to the high uncertainty about the effective coverage of energy demand in the United Kingdom, Liquefied Natural Gas (LNG) was expected to fill the gap created with regular deliveries, according to The Guardian[10]. Instead, between October 2016 and February 2017, LNG imports were down 77% from the previous year. In **Figure 11,** which lists the quantities of LNG imports per country, the abovementioned reduced flow is clearly depicted. Specifically, as we observe in October 2016 there is a major reduction in the LNG imports to the United Kingdom, which were maintained until February 2017. This fact can be seen in the chart since at that time the red line concerning the UK becomes thinner.

6 http://blogs.platts.com/2015/03/24/uk-gas-storage/

7 https://www.bbc.com/news/business-36604520

8 https://www.ft.com/content/564a1ec0-8288-11e7-a4ce-15b2513cb3ff

9 https://www.telegraph.co.uk/business/2016/09/09/part-of-britains-main-gas-storage-site-permanently-shut-down/

10 https://www.theguardian.com/business/2017/jun/20/uk-gas-storage-prices-rough-british-gas-centrica

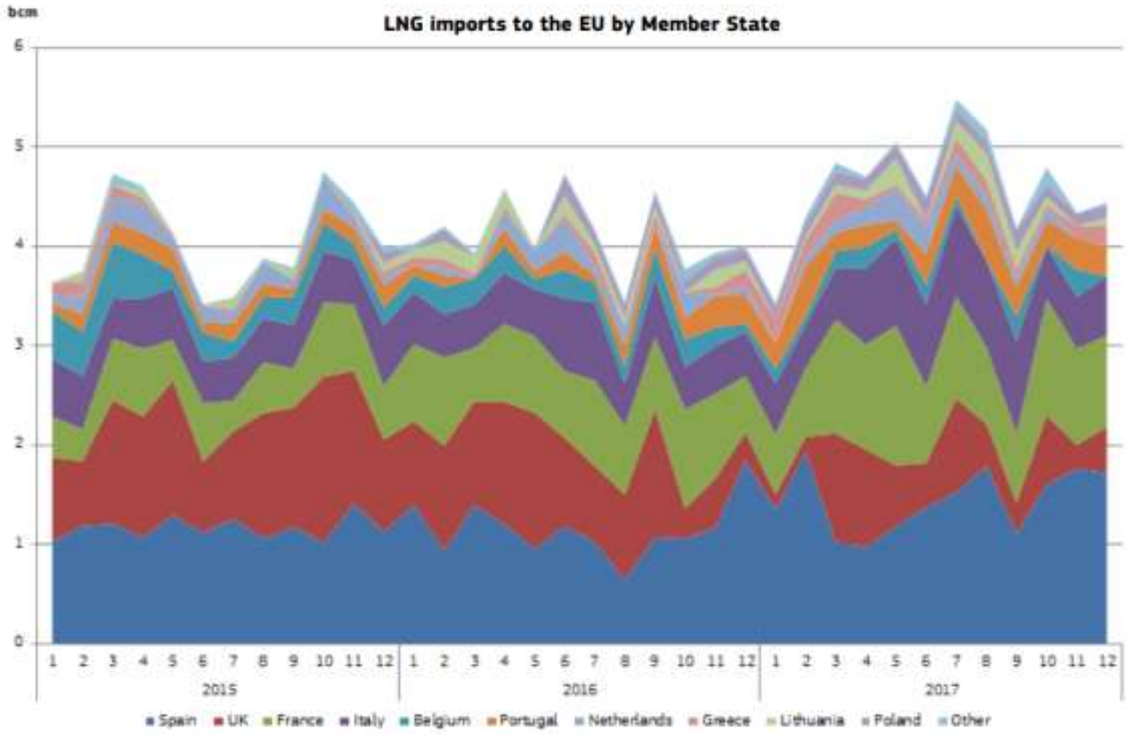

Figure 11: LNG imports to the EU by Member State
Source: E.U.

The main reason that explains the decline in imports of LNG in Britain seems to be the failure of Qatar to cover the shortage at a time when UK gas traders were dealing with volatile markets and the forthcoming peak winter demand. Qatar is UK's largest supplier of LNG and it accounts for one-third of total gas imports to the country. However, during that period it had re-routed certain tankers, originally intended to be delivered in the UK, to Asian markets that offered higher prices, as Reuters analyzed[11].

As mentioned in the article of Maritime -Executive[12], an unexpected increase in liquefied gas demand in Asian markets had caused prices to increase considerably, turning these markets into a more attractive destination for the Qatari LNG than the UK. **Figure 12**, presents monthly LNG imports from Qatar to the UK. As it can be seen there, the decline which is depicted as a deep fall of monthly LNG imports is evident in the last four months of 2016 and continues in the early months of 2017.

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[11] https://www.reuters.com/article/us-qatar-lng-idUSKBN19Q0YX

[12] https://www.maritime-executive.com/article/qatar-diverts-lng-from-britain-to-asia#gs.KLkF8_g

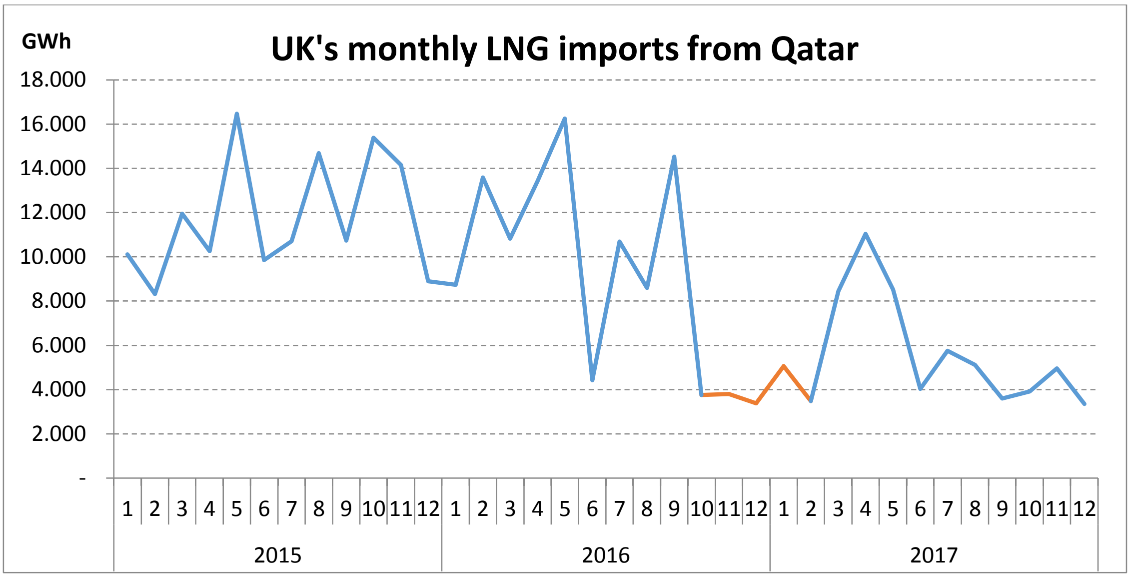

Figure 12: UK's monthly LNG imports from Qatar
Source: UK's Department for Business, Energy & Industrial Strategy

The sudden rise in demand in Asian markets resulted from specific incidents in South Korea. In December 2016, there was an increase of 13.5% of imports of LNG in South Korea, driven by low temperatures and several other factors, as mentioned in an article in ICIS [13]. Earlier, in August of the same year, four nuclear reactors suspended their operation due to seismic phenomena, with a capacity of 2779 MW, a 10% total capacity of the country. Seismic vibrations, size 5.1 and 5.8 on the Richter scale, were the strongest ever recorded in South Korea, according to Reuters[14]. At the same time, three reactors were already out of service for maintenance, resulting in seven out of a total of twenty-five nuclear reactors in the country being shut down. Inactive reactors began to re-operate in December 2016, according to data published by Energy Aspects [15]. To highlight the importance and interdependence between South Korea and Qatar, it is worth noting that South Korea is one of the world's largest LNG buyers and one of the largest LNG importers of Qatar. [16]

This is illustrated in **Figure 13,** which shows the LNG exports from Qatar and as shown, there is an increase in shipments to South Korea, along with a reduction to other trading

[13] https://www.icis.com/explore/resources/news/2017/03/16/10088469/qatari-volumes-continue-to-boost-south-korean-lng/

[14] https://www.reuters.com/article/us-southkorea-quake-nuclearpower-idUSKCN11I1X5

[15] https://www.energyaspects.com/publications/view/2017-01-17-natural-gas-south-korea-dec-2016

[16] https://www.reuters.com/article/us-china-lng/china-becomes-worlds-no-2-lng-importer-in-2017-behind-japan-idUSKBN1EK09C

countries. All the above events contributed to the increase in LNG prices in Asian markets in the months of October 2016 - February 2017, as observed in **Figure 14**.

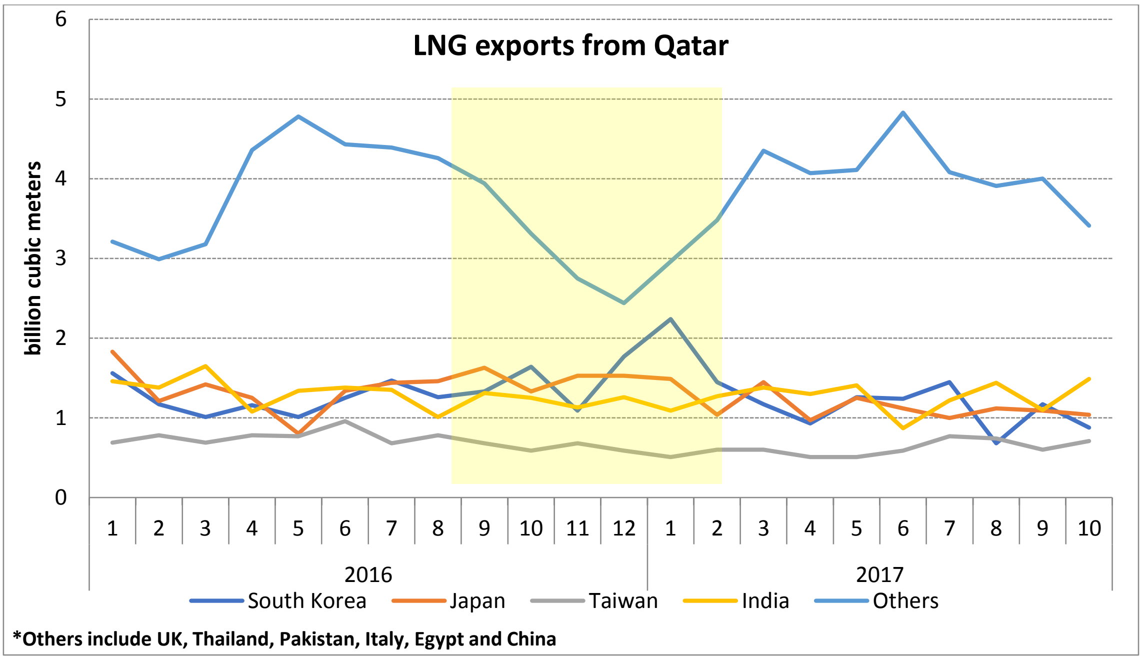

Figure 13: LNG exports from Qatar
Source: Reuters

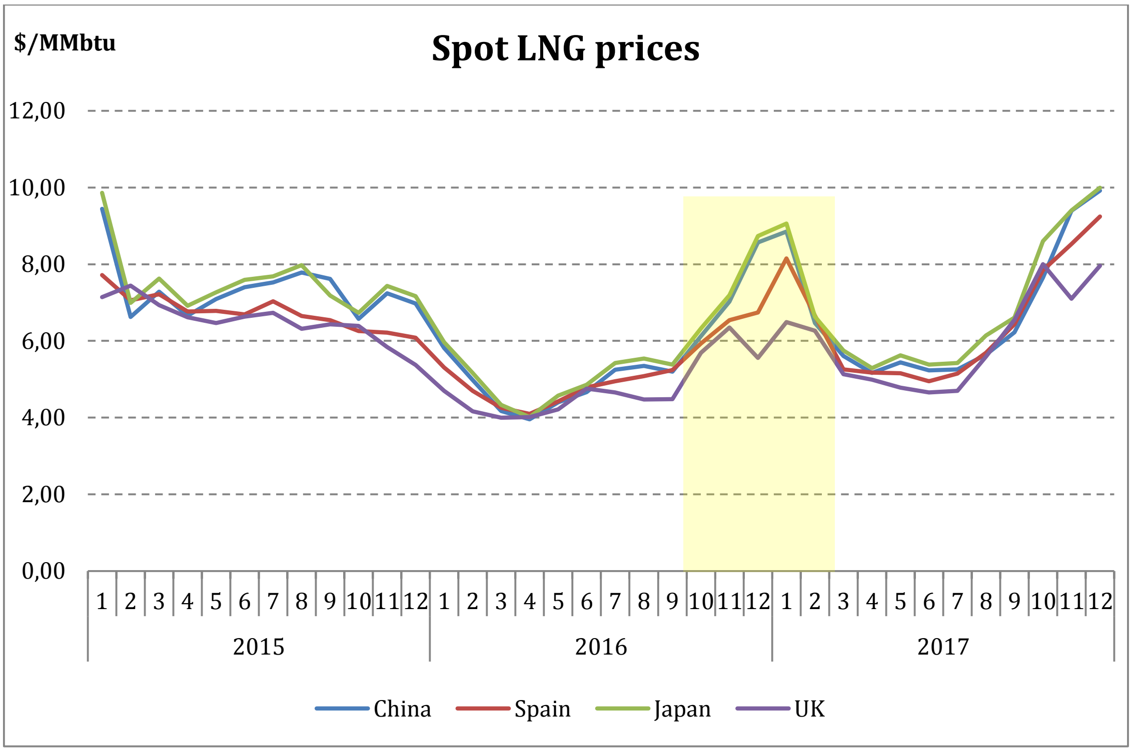

Figure 14: Spot LNG prices
Source: E.U.

Regarding the LNG supply from Qatar to the UK, it is important to note that Qatar does not guarantee regular deliveries within a firmly structured timetable to the United Kingdom. In many cases freights can be diverted at will, if the better-priced markets arise and need support.

All this is a result of the agreements governing relations between the UK and Qatar which have been ratified among Centrica and Malaysian Petronas companies.

Centrica is the UK's largest domestic gas supplier and one of the largest suppliers of electricity. It has 3 long-term agreements from 2011 to 2023 with Qatar, but these are not strict agreements, as the supplier can divert LNG deliveries to markets offering higher prices by paying a pre-agreed diversion charge. Centrica also is not required to provide the imported LNG in the UK, according to articles from Telegraph and Reuters [17].

Similar are the agreements with the Malaysian Petronas company which owns 50% of the liquefied natural gas terminal, Dragon, located in Wales, with a total storage capacity of 4.4 mtpa (million tonnes per year). The company has entered into two deals with Qatar between 2014 and 2023, but contracts are flexible enough to operate in a similar way, as reported by Reuters and Arabian Business[18.]

UK had maintained a cooperative relationship with Norway since 1977, when the first pipeline connecting the two countries was inaugurated, according to the company monitoring this connection, Norwegian Petroleum[19]. In this case, the main factor in resolving the problem was that in October of 2016, exports to the UK had increased to cover the loss of Qatar. Significant is the fact that exports to the UK had reached the highest level of the last 20 years, as seen in **Figure 15**, where gas imports from Norway are observed.

[17] https://www.reuters.com/article/centrica-qatar-lng/update-2-centrica-inks-long-term-qatar-lng-deal-idUSLDE71M0X820110223

https://www.telegraph.co.uk/finance/newsbysector/energy/10430701/Centrica-signs-4.4bn-gas-import-deal-with-Qatar.html

https://www.telegraph.co.uk/business/2016/09/05/centrica-extends-gas-import-deal-with-qatar/

[18] https://uk.reuters.com/article/britain-lng-dragon/uks-new-dragon-lng-deal-no-guarantee-of-supply-qatargas-idUKL5N0HJ0YE20130923

https://www.arabianbusiness.com/qatargas-inks-lng-supply-deal-with-uk-unit-of-petronas-649600.html

[19] https://www.norskpetroleum.no

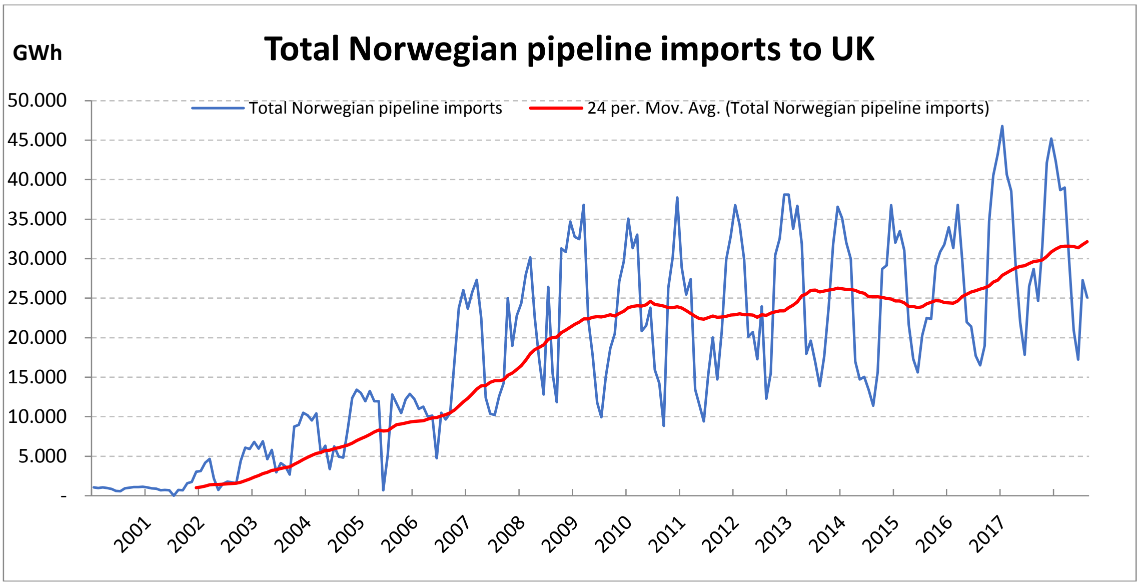

Figure 15: Total Norwegian pipeline imports to the UK
Source: UK's Department for Business, Energy & Industrial Strategy

Additionally, as noted in **Figure 16**, which quotes gas imports to the UK, at the same time as Qatar interrupted its liquefied natural gas supply, Britain relied on Norway, which responded to mitigate the magnitude of the problem. As market forces were looking for alternative ways to meet demand, two additional countries that contributed to alleviate the problem were Belgium and the Netherlands.

Particularly, imports of those two countries to the UK were on the rise. In October the increase begins to be evident and specifically, the combined imports of the two reached 26% of the UK's total inflows in November. The present rate is noteworthy, given the unprecedented high levels recorded in the imports from the Norwegian pipelines. In addition, Qatar's imports fell from 43% to just 9% in a time span of a month, from September to October 2016.

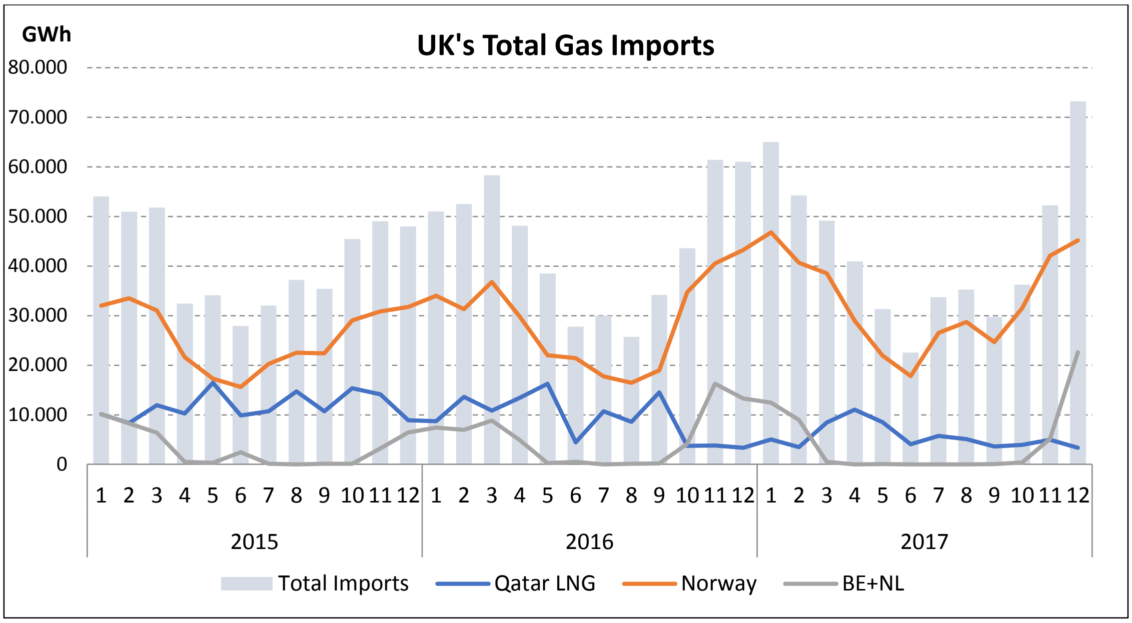

Figure 16: UK's total gas imports
Source: UK's Department for Business, Energy & Industrial Strategy

Another factor that contributed to the deterioration of the situation was the lack of electricity imports from France. As can be seen in **Figure 17**, which demonstrates the imports and the exports between France and the UK, France is used to be the exporter and supplier of electric power to the latter country. However, there was a significant decrease, starting of September 2016 and which lasted until February 2017. During this period, exports from France to the UK reached the lowest of the whole period depicted. Specifically, there was a 73.91% decrease as the UK's electric power imports from France went from 1173 GWh in August 2016, to 306 GWh in October 2016. The reason for this situation was the nuclear power outage that France had to face during that period and could not meet its own power needs.

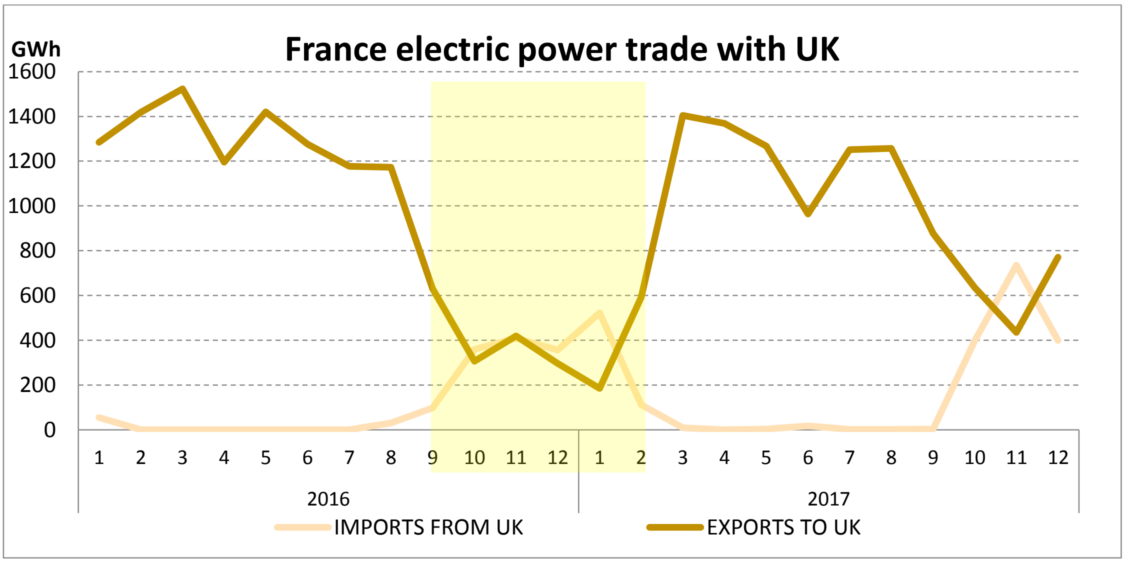

Figure 17: France's electricity trade with the UK
Source: European Network of Transmission System Operators for Electricity (ENTSO-E)

As it was mentioned earlier, in the energy mix section, UK relies, to a great degree, on gas. Except for its profound direct use for heating and other uses, it is largely used for power generation. The clean spark spread represents the profit for the producer of power, given the price of power, gas and emission allowances. When the earnings result to be positive, then the producer has a motive to generate power. Respectively, dark spread represents the profit of the producer of power with the use of coal as a raw material. For the case of the UK, **Figure 18** represents the clean spreads for the UK for the period of 2014 to 2017. As can be observed, throughout the whole period of 2014-2017 gas to power generation in the UK is profitable, in contrast to their German peers, where the profitability is positive only after the second half of 2016 and for a limited time period. This difference is highly related to the characteristics of the profile of the energy mix of each country. The UK and Germany have a totally different energy mix profile. On the one hand, the UK relies of gas production, nuclear, hard coal and imports. On the other hand, Germany relies more on lignite and hard coal units, wind power and much less on gas to power production. It is noteworthy, that during the period of September 2016 January 2017, when the problems, described above, emerged and the imports were limited, and the profitability of gas to power generation exhibited a sharp increase. In fact, as described earlier, even though the availability of gas was limited and the prices of gas increased, the clean spark spread increased, since the rise of power prices was such that offset the rising cost of production, creating increased profits.

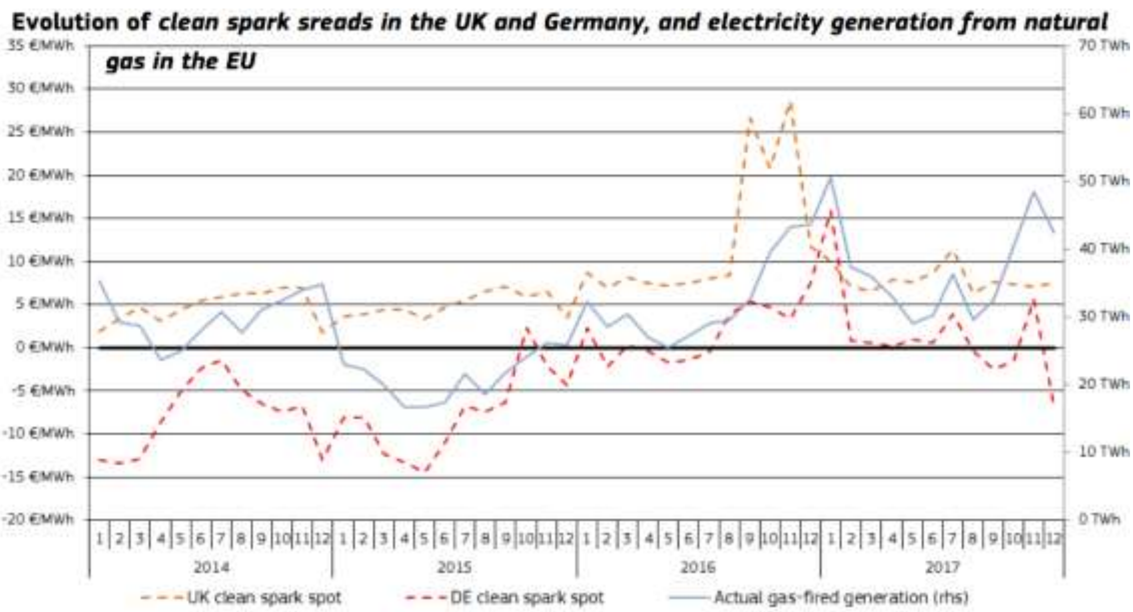

Figure 18: Evolution of clean spark spreads in the UK and Germany and electricity generation from gas in the UK
Source: EU

Second Period: December 2016 – January 2017 – France

Continuing on the second reference period, the analysis focuses on the period December 2016 – January 2017, when a significant jump in the observed monthly prices was observed in all the European energy markets. Specifically, there was a rise on the wholesale electricity prices in the central western (CWE) and central eastern (CEE) region, as it is shown in **Figure 5,** causing the European Power Benchmark index, to reach the highest monthly day-ahead baseload wholesale prices since February 2012, at the value of 64 €/MWh. An equally admirable increase was observed in the gas market prices, as it is shown in **Figure 6**, which implies that the core factor that has generated this disruption was production shortages and energy availability in both electricity and gas in France, in a period of high demand, and especially in the South part of the country, where wholesale prices exceeded every other recording since December 2013, according to the EU data[20].

Nuclear Outage

The nuclear power outage observed in that period in France played a significant role. Nuclear power is the largest source of electric power in France. With 58 power reactors, France manages to cover its own energy demands and also covers part of the energy needs of neighbouring countries. In the fall of 2016, 21 of France's 58 reactors were offline, mostly for inspections. On January 11, 7 reactors were still offline which accounts for 14 percent of the fleet, as it is shown in **Figure 19**, which depicts the quantity of the unavailable nuclear reactors, along with the percentage of that amount in the total. In that time, France had to cover increased heating demand, rendering the energy system vulnerable to other factors that could pose a challenge.

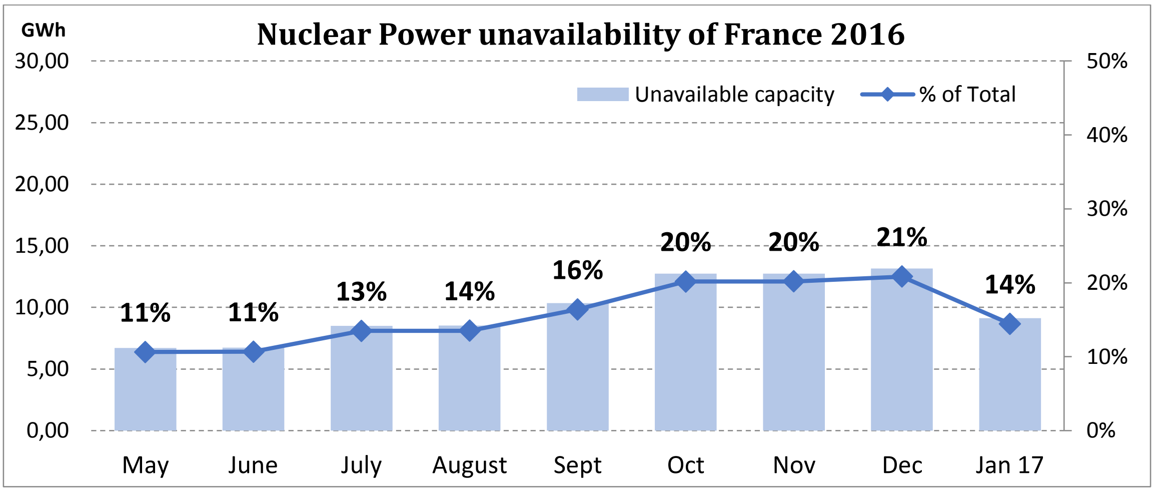

Figure 19: Nuclear power unavailability of France
Source: EDF

[20] European Commission quarterly Gas and Electricity market reports

Low temperature

In January 2017, a cold spell shocked Europe. In particular, average daily temperatures were 10 degrees Celsius below the long-term daily averages as it is projected in **Figure 20**Figure 20, which shows the degrees of deviation from the average temperature of the period 1975-2016 for France, Germany, and Belgium.

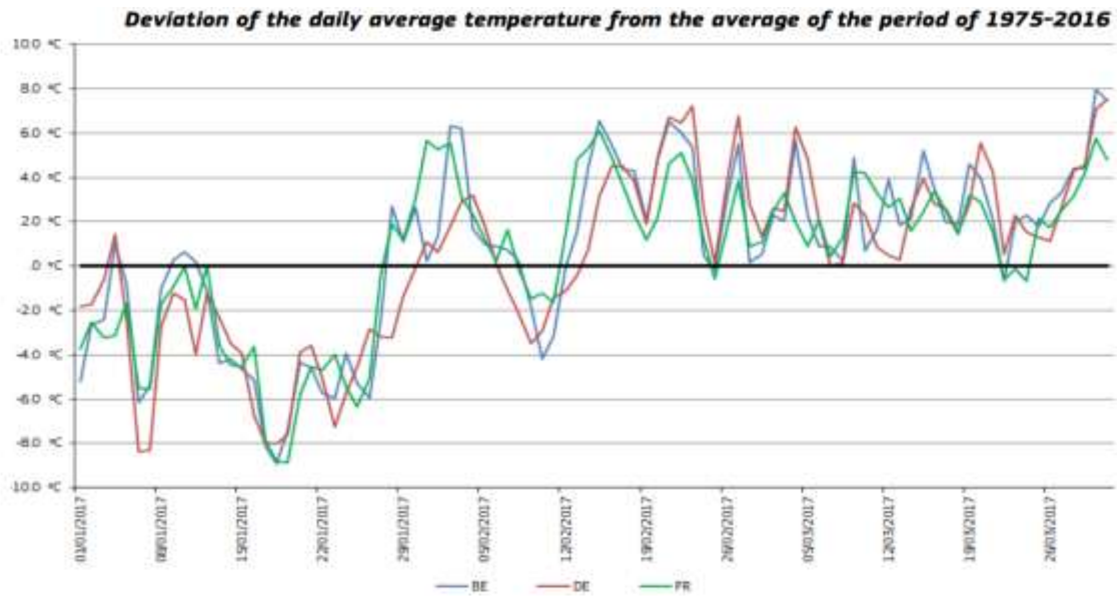

Figure 20: Deviation of the daily average temperature from the average of the period of 1975-2016
Source: E.U.

Increased Gas Demand

As an aftereffect, demand for energy consumption, especially heating, peaked in January. **Figure 21** projects the divergence of the Heating Degree Days (HDD) from the long-term average for the first three months of 2017. Heating Degree Days (HDD) and Cooling Degree Days (CDD) are a measurement for the energy demand needed to heat or cool, respectively, a home or a business, according to the European Environment Agency[21]. Therefore, the HDDs are inversely proportional with the low temperatures. So, it is shown that in most of the countries in the European continent low temperatures dominated and electricity prices were affected accordingly.

[21] https://www.eea.europa.eu/data-and-maps/indicators/heating-degree-days

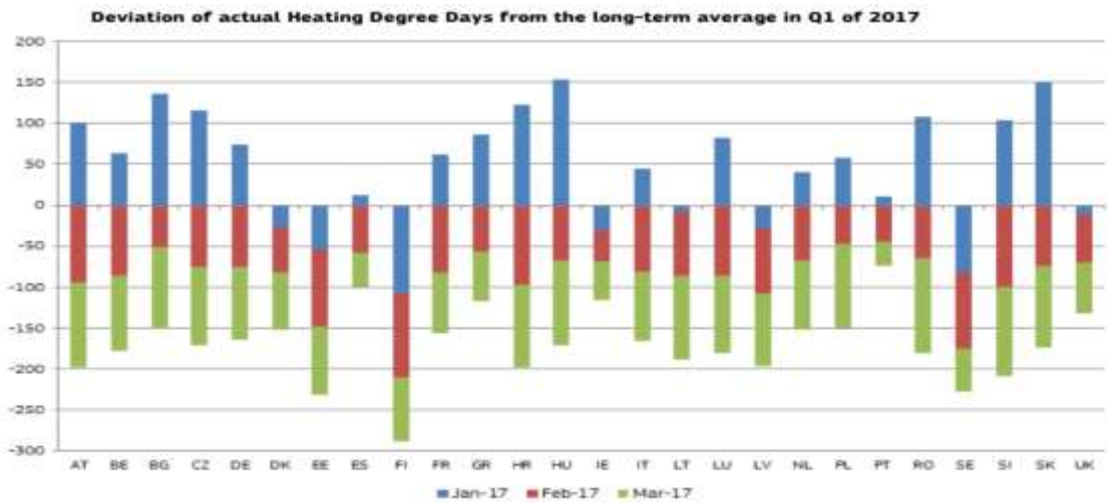

Figure 21: Deviation of actual Heating Degree Days from the long-term average in Q1 of 2017
Source: E.U.

<u>Use of gas in power generation</u>

Wholesale consumers contributed consequential to the increase in demand for gas, as well. In order to cover efficiently the nuclear power unavailability that occurred, France had to produce more power from alternative sources. Thus, gas was used more in power generation, in order to cover the country's increased energy demand. Specifically, gas deliveries to power generation in France were increased by 97% in the first quarter of 2017, according to the EU[22]. Also, the aforementioned increase is illustrated in **Figure 22** as it depicts the quantity of gas that was used to power generation for the period of 2015 – 2017 for selected Members of the EU.

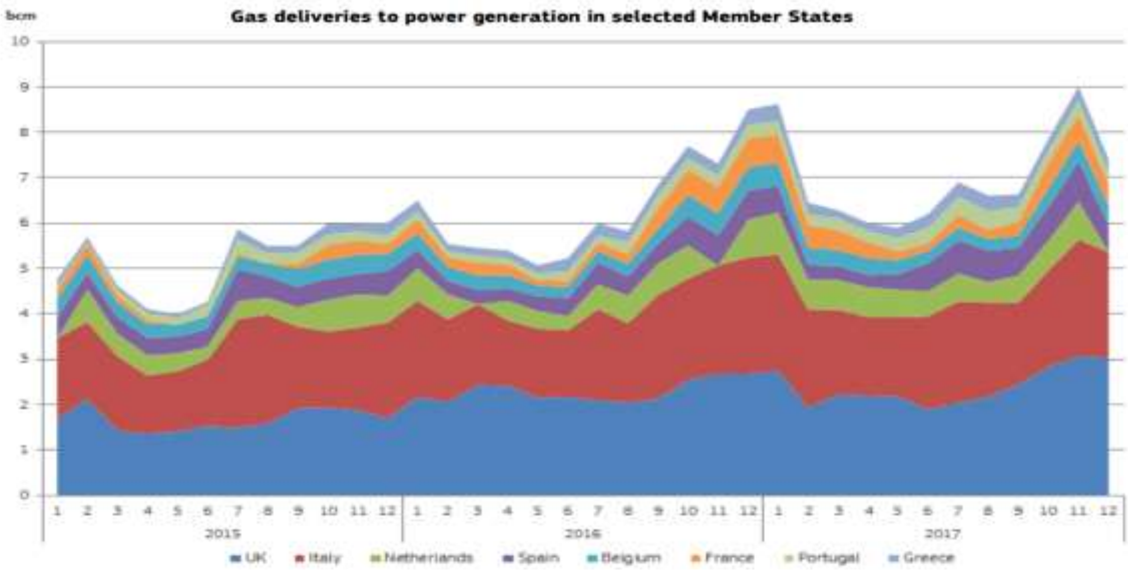

Figure 22: Gas deliveries to power generation in selected Member States
Source: E.U.

[22] European Commission quarterly Gas market reports

Those decisions about France's alternative method of power generation affected most of the European countries, because of the inability of France to export electric power, due to its lower nuclear capabilities. The increased use of gas into power generation was observed in the European energy mix as a whole, which, according to the EU, was the highest in more than seven years. **Figure 23** shows the quarterly increase in gas consumption in the EU as a whole, which reflects the demand for gas. It can be observed that in the fourth quarter (Q4) of 2016 the increase reaches almost 20%, the highest percentage increase witnessed for the whole period illustrated in the graph. **Figure 24** illustrates the difference between the gas consumption of 2016, compared to 2015 by the countries in the E.U. In particular, for the sake of comparison, the period is divided into four quarters, which are depicted in different colors, while the dots represent the total annual change in percentage points.

As it can be discerned, UK, Germany, France and Italy had a noteworthy increase in gas consumption in the last months of 2016, compared to the same period of 2015, while Greece had the most significant annual increase reaching 30%, almost double from the runner-up. Altogether, there was an increase in gas demand in the EU in 2016 especially in the last quarter of the year.

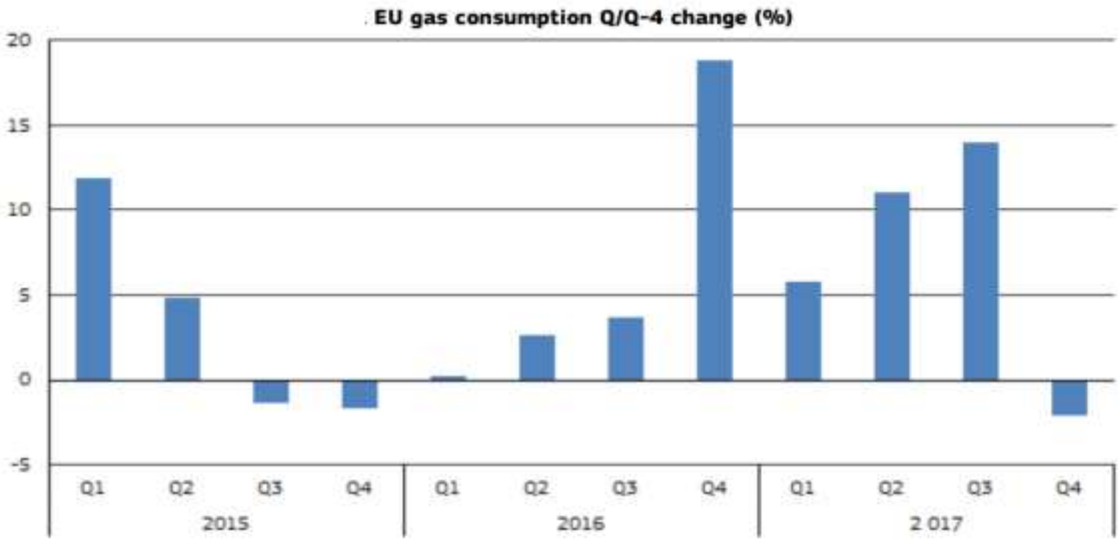

Figure 23: E.U. gas consumpion Q/Q-4 change (%)
Source: E.U.

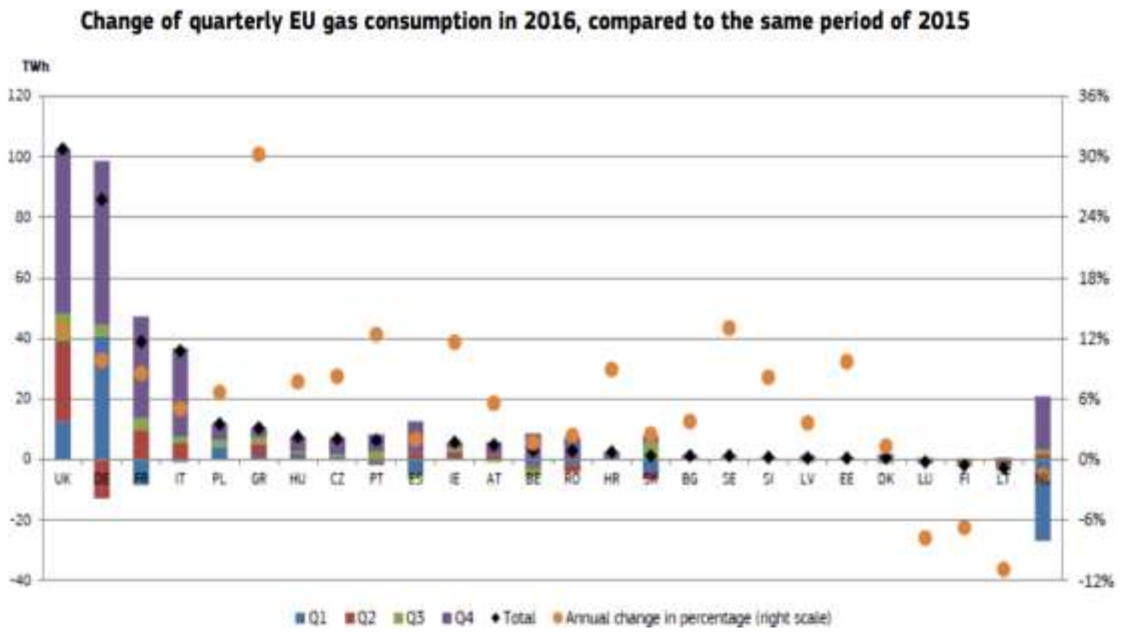

Figure 24: Change of quarterly E.U. gas consumption in 2016, compared to the same period of 2015
Source: E.U.

Electric Power Imports-Exports

In order to mitigate the problem, in December 2016, France had to become a net importer of electric power, for the first time in five years, as it is projected on **Figure 25,** which shows the total electric power imports and exports in France for 2016 to 2017. Observing the course of the electric power flows, it is worthy to examine the rate of exports' attenuation. Specifically, while the exports in June 2016 were 7 TWh, they progressively fell to 3.2 TWh in October 2016, meaning a 54.11% decrease. From that point, up to the turnaround of the equilibrium, the exports were more stable but remained at low levels and ended up to 2.9 TWh in January 2017. As a consequence, the entire Central Western Europe region decreased its electric power exports to the neighboring markets, due to the increased demand arising from France for the period December 2016-January 2017. According to Reuters[23], during January 2017 France imported the highest amount of power on a net basis since 1980. Specifically, France, starting on June 2016 from 0.41 TWh electric power imports, reached 2.54 TWh in October 2016 meaning 517.38% increase. Until January 2017, imports continued to rise and peaked in January 2017 at 3.74 TWh.

[23] https://www.reuters.com/article/us-france-election-power-analysis/france-likely-a-frequent-power-importer-in-years-to-come-idUSKBN16K1CX

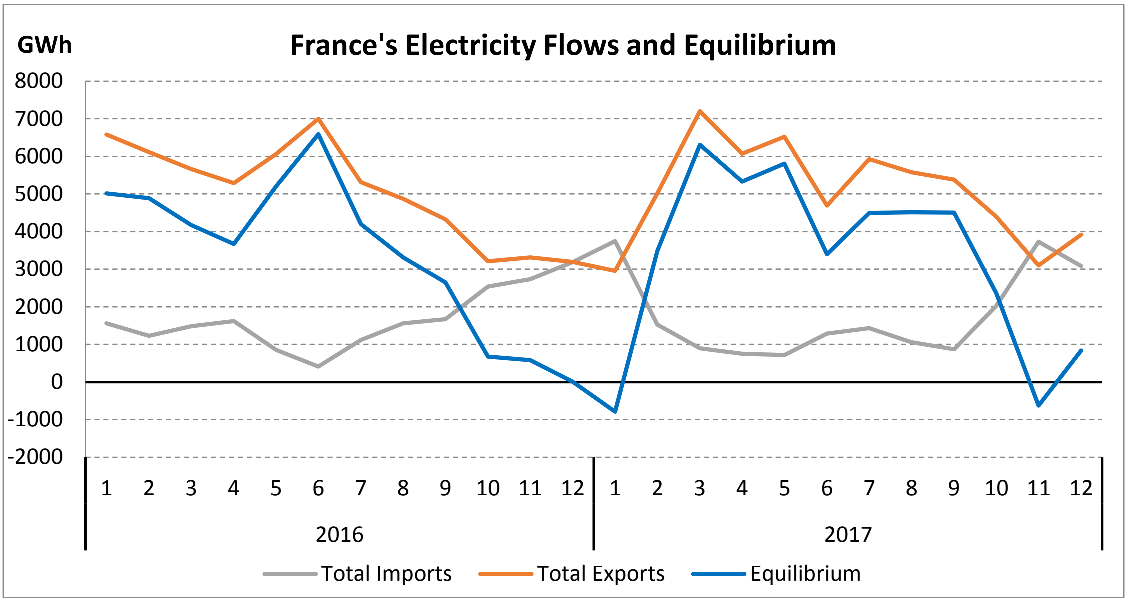

Figure 25: France's electricity flows and Equilibrium
Source: ENTSO-E

Figures 26,Figure 28**27,Figure** 29**28,Figure** 30**29,Figure** 31**30** and **31** show the electricity flows between France and the neighbor countries for the period 2016-2017. As far as the individual exports are concerned, during the winter of 2016/2017, they record a significant decrease as mentioned earlier. Exports towards Italy, Germany and Belgium progressively fell to low levels during the period of the energy crisis. Exports to Spain decreased, as soon as the problem began to develop, but there was an increase during the last two months of 2016, reaching levels similar to those of September. It is noteworthy to focus on the exports towards the UK since they reveal an additional factor that contributed to the deterioration of the situation in November. With a closer look, it can be noticed that the exports "dived" to the lowest of the whole period depicted, and more specifically from 1173 GWh in August 2016, to 306 GWh in October 2016, meaning a 73.91% decrease. On the contrary, exports to Switzerland remained at high levels.

In respect to imports, most of the above countries contributed largely to the conversion of France as a net importer. Belgium was the main contributor, followed by Spain and Switzerland. The electric power flows from the UK and Germany were affected and there was a change to their net equilibrium, turning the two aforementioned countries into net exporters towards France. On the other hand, Italy which was highly affected by the crisis, because of its energy structure and the high dependency on imports from France, and consequently could not manage to invert the situation.

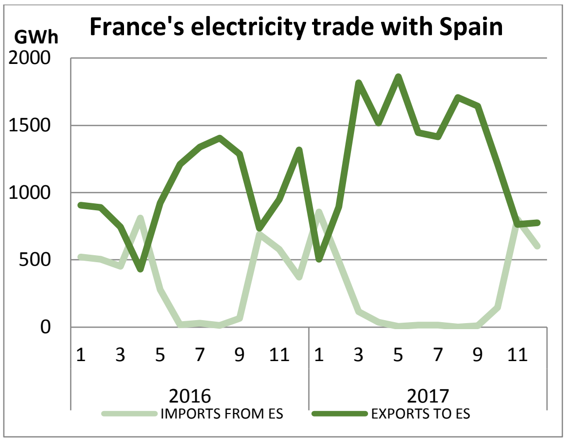

Figure 26: France's electricity trade with Spain
Source: European Network of Transmission System Operators for Electricity (ENTSO-E)

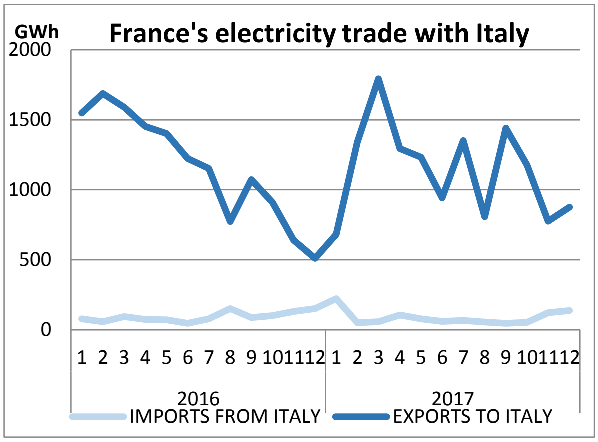

Figure 27: France's electricity trade with Italy
Source: European Network of Transmission System Operators for Electricity (ENTSO-E)

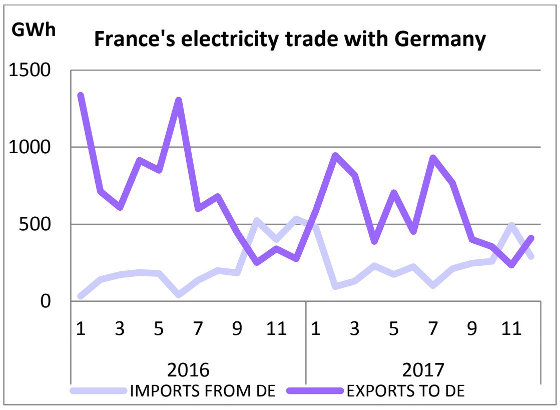

Figure 28: France's electricity trade with Germany
Source: European Network of Transmission System Operators for Electricity (ENTSO-E)

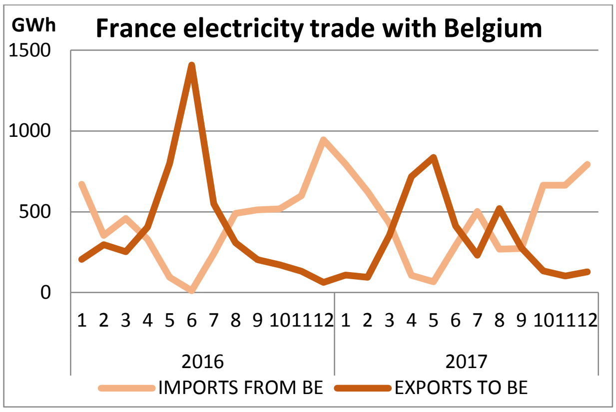

Figure 29: France's electricity trade with Belgium
Source: European Network of Transmission System Operators for Electricity (ENTSO-E)

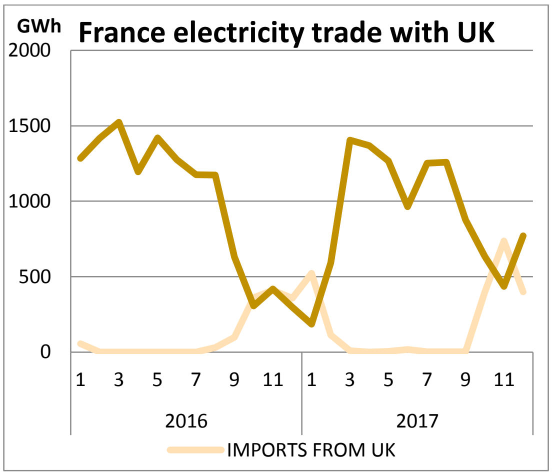

Figure 30: France's electricity trade with UK
Source: European Network of Transmission System Operators for Electricity (ENTSO-E)

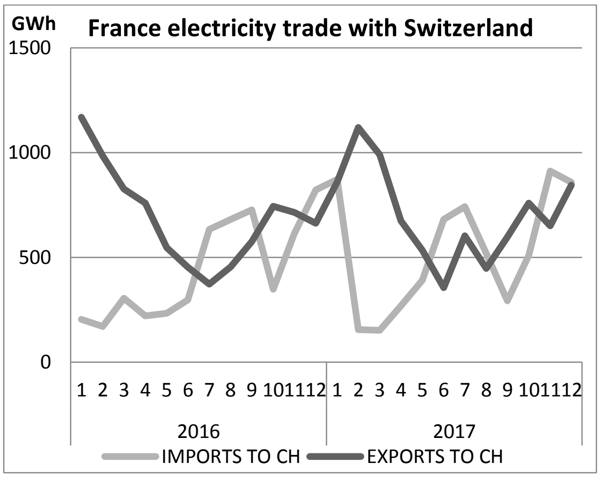

Figure 31: France's electricity trade with Switzerland
Source: European Network of Transmission System Operators for Electricity (ENTSO-E)

The role of Gas Deliveries to power generation

France is divided into three large regions regarding its gas transmission grid. GRTgaz is the grid operator for the North and for a part of South France, which operates independently. Within the northern area, PEG Nord provides a virtual point for gas transfer. The southern part of the country was divided into two smaller districts. TIGF was responsible for the Southwestern part of France while GRTgaz South, named Peg Sud, was accountable for the rest, according to Selectra[24]. Following an agreement between GRTgaz and TIGF, the PEG Sud and PEG TIGF have merged into TRS (Trading Region South) on April 1, 2015, providing a virtual point for the southern market area, according to relatable information provided by GRTgaz[25]. The aforementioned information can be depicted in **Error! Reference source not found.**, which shows the areas of the gas distribution grid.

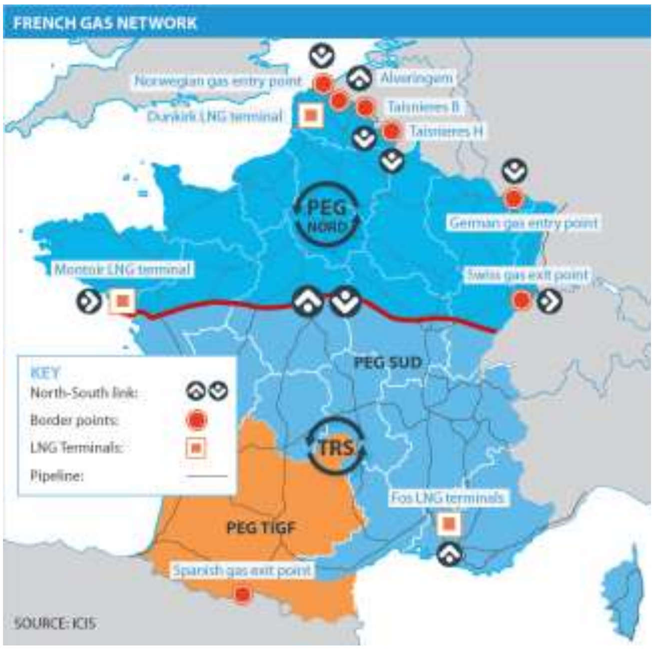

Image 1: France's gas transmision grid regions
Source: ICIS

In general, it is notable that South France has fewer gas imports compared to North France. For example, as it is shown in **Figure 32** which illustrates the total gas imports of North France compared to the total gas imports of South France, in January 2017 the gas imports in South France were 207mcm/h, when in North France the quantity of the imports reached 4.468mcm/h.

[24] https://selectra.info/energie/guides/comprendre/points-echange-gaz
[25] https://www.grtgaz.com/fileadmin/clients/documents/fr/5.TRS.pdf

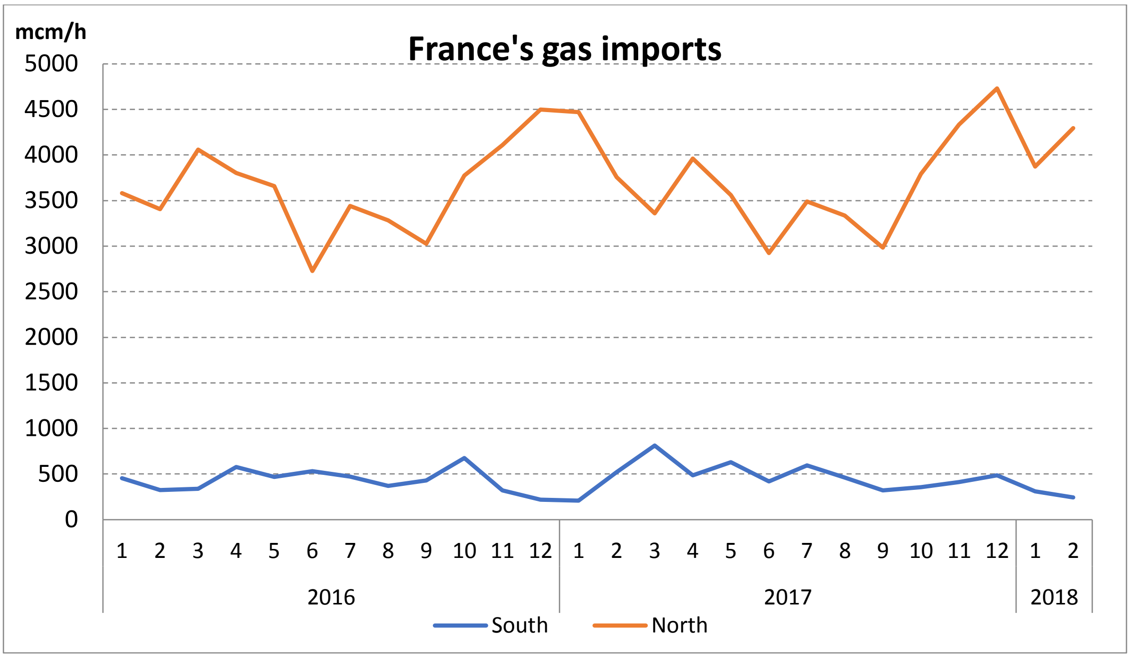

Figure 32: France's total gas imports
Source: IEA (International Energy Agency)

In particular, North France pumps gas from Belgium, Germany, Norway and a small part of the total from Switzerland. Furthermore, two LNG terminals operate in North France, as it is shown in **Figure** 33**32** which depicts the total gas and LNG imports in North France. On the other hand, South France depends on its sole LNG terminal, Fos sur Mer, and the north-south link pipelines, connecting its grid with North France. Spain also trades with South France, but the latter is mainly an exporter. The main supplier of the southern LNG terminal is Algeria, which made only one delivery in January, according to ICIS[26]. **Figure** 34**33** projects the total gas and LNG imports in south France and the difference in the number of imports and the number of importers between the two regions, compared with **Figure** 33**32**, can be noted. Observing **Figure 33**, the significant decrease of South France's imports can be distinguished. More specific, in October the Fos sur Mer deliveries reach 676 mcm/h while the next month falls to more than half, to 320 mcm/h. Imports diminished further until January, a fact that resulted in South France being unable to sustain adequate gas supply for the required gas to power generation. So, in order for France to be in a position to fulfill the required power supply, power imports from neighboring countries increased. At the same time, its exports remained stable at low levels, as it is projected in **Figure 25**. Under those circumstances, the country became a net electric power importer for the first time in five years, as mentioned before.

[26] https://www.icis.com/explore/resources/news/2017/01/31/10074627/trs-gas-prices-to-fall-on-back-of-lng-influx-relief-for-french-ccgts/

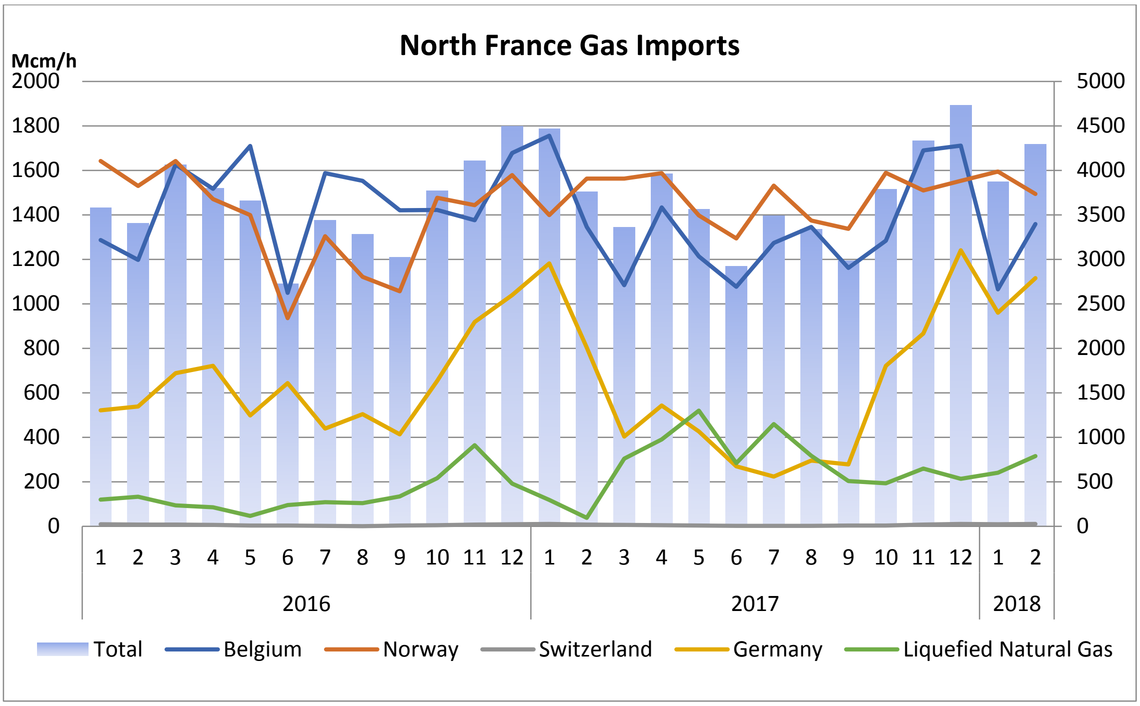

Figure 33: North France gas imports
Source: International Energy Agency (IEA)

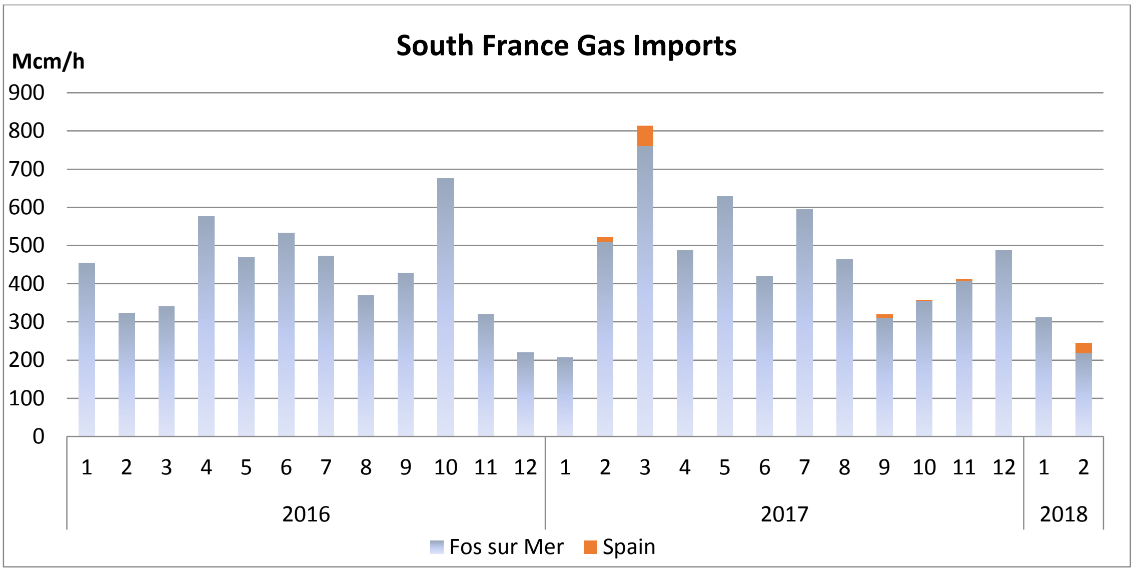

Figure 34: South France gas imports
Source: International Energy Agency (IEA)

Because of the structure of the French gas transportation system, a strange irregularity was observed in the French gas market. The disparity between TRS over PEG Nord reached exceptional levels, averaging 13.5 Euro/MWh in January 2017. Specifically, on the 20th of January, the premium of TRS over PEG Nord reached a record 23.0 Euro/MWh as it can be discerned on **Figure 35.**

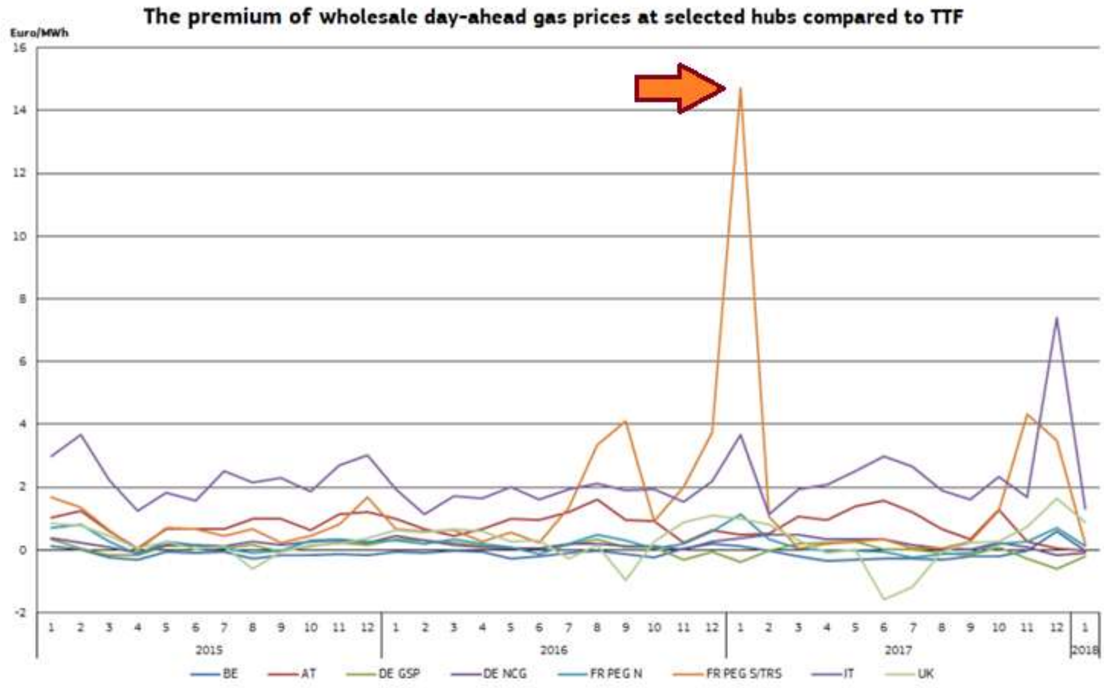

Figure 35: Premium of wholesale gas prices compared to the TTF
Source: Europa Energy market analysis

The spread in gas prices between the two regions started increasing as of the end of December 2016. The TRS zone, as a whole, was running at a deficit of around 25mcm/day. Total consumption, of the southern part, was at around 115mcm/day, with an additional 10mcm/day exported to Spain. On the supply side, around 35mcm/day was being imported from North France via a set of pipelines called the north-south link, just shy of maximum capacity while storage withdrawals had ramped up to around 46mcm/day, according to articles by the ICIS[27]. Moreover, gas deliveries, on the only LNG terminal of south France, were reduced in January. The outage of the Manosque gas storage facility played a significant part in this deficit of the TRS zone.

The Manosque underground natural gas storage site is located in the municipality of Manosque in the Alpes-de-Haute-Provence region. The facilities are distributed across two sites roughly 2.5 kilometers apart, separated by a hill and interconnected with two high-pressure pipelines. In operation since 1993, this storage site is owned by Géométhane, an Economic Interest Group specialized in underground natural gas storage and shared equally by Géosud and Storengy. The operation and commercial services for this site are managed by Storengy. The site contributes to the gas supply for the South East of France. The

[27] https://www.icis.com/resources/news/2017/01/03/10067228/trs-natural-gas-premium-over-peg-nord-soars-on-lng-shortage/

maximum storage volume is 496 million m^3 at STP[28] and is used for storage of high calorific gas. The storage facility uses salt caverns in the ground and the depth of the salt layer is around 1,000 meters, as the Géométhane says in the corresponding publication about the storage facility[29]. Also, the salt caverns type of gas storage can be shown on **Image 1** which describes the Manosque storage site.

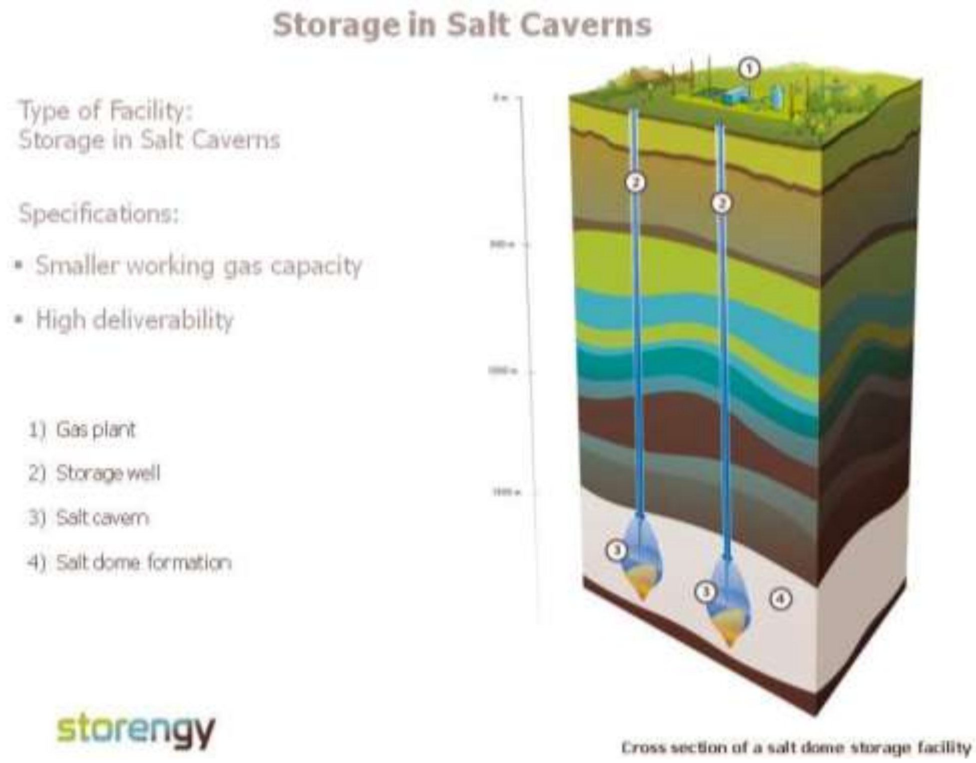

Image 1: Salt Caverns type of gas storage
Source: Storengy

Manosque storage site has had its operations decreased by 50% since the start of the winter, due to maintenance. The operator decided to increase the withdrawal capacity from the Manosque storage site, so as to help alleviate the shortage of gas in the system. Nonetheless, it was necessary by the operator to undertake maintenance work, prior to the boost, to guarantee the availability of full withdrawal capacity, but it would cost the full shutdown of the site for a period of three days, namely 3-5 January. During this period of time, gas supplies in South France were depending from the send-out from the Fos sur Mer LNG terminals, which are used to supply the TRS zone, according to the relevant article by ICIS[30].

28 m^3 at STP (cubic metres at standard temperature and pressure: quantity of natural gas which at 0°C and under atmospheric pressure occupies a volume of one cubic metre)
29 https://www.storengy.com/countries/france/en/nos-sites/manosque.html

30 https://www.icis.com/resources/news/2016/12/30/10066611/more-lng-needed-to-avert-french-gas-shortage-operator/

Due to the high demand for gas in the Asian markets, there was a lack of supply in the southern part of France as the LNG cargoes were drawn on, as it is shown in Figure 34 above. The system operator, GRTgaz, made requests of shippers to bring more LNG into the area but they didn't respond in time [31].

Third Period: December 2017 – January 2018 –Italy

Moving on to the next case, which refers to the observed increase of monthly energy prices in most European countries, we focus on Italy, in order to analyze the country's energy structure and record its reaction to the events of both chronological periods previously discussed.
As described earlier, in the energy mix section, Italy's power generation is dominated by gas to power production and power imports, which inevitably obliges the country to rely on imports of both power and gas to a large extent. The high dependency on its country neighbors makes the country vulnerable, not only to domestic perils but also to discrepancies of Italy's importers. Therefore, the aforementioned incidents regarding France's energy crisis highly affected Italy's power supply. Enhancing the tempered situation, an explosion at the Austrian pipeline hub in Baumgarten, a main gas transit pipe for Europe, on the 12th of December 2017, skyrocketed gas prices in the European market exchanges. While the neighbor countries managed to overcome the crisis more effectively, Italy struggled to cope due to its inherent weaknesses.

Italy first showed its energy weaknesses in December 2016 – January 2017, when the incidents in France, regarding its unavailability to cover its own energy needs, took place. The strong impact of those events in the CWE region forced electric power and gas prices in the Italian market to jump. Since France, a key source of imports for Italy became a net power importer in December 2016, Italy observed reduced electricity flows than usual, which were later followed by an increasing import need for Italy in the winter season. Particularly, on the 10th of January 2017, the gas prices increased to the highest level since 2012, reaching 40.0 Euro/MWh resulting in a declaration of an alert state by the Italian Ministry of Economy which requested the monitoring of the storage level, according to E.U. data[32].

[31] www.icis.com/resources/news/2017/01/31/10074627/trs-gas-prices-to-fall-on-back-of-lng-influx-relief-for-french-ccgts

[32] European Commission quarterly Gas market reports

Later that year, in the early second quarter of 2017, France had once again an outage of some of its nuclear reactors after the French Nuclear Safety Authority (ASN) spotted a weakness at the pumping station pipes, as far as the earthquake withstanding is concerned. Consequently, EDF, the operating company, began repairing procedures, on 20 out of its 58 nuclear reactors[33], around 30% of France's nuclear capabilities. As shown in **Figure 36**, which depicts the amount of nuclear unavailability expressed in GWh and the percentage of the full unavailability, the problem peaked in October 2017. The company admitted that it had failed to resolve the situation on the planned timeline, so it announced that the speeding up of the maintenance, in order to reach the final target. That target was to have the full fleet operating before the end of the year, 2017, so as to avoid the energy crisis that struck the country the previous year, according to relevant articles by Reuters[34].

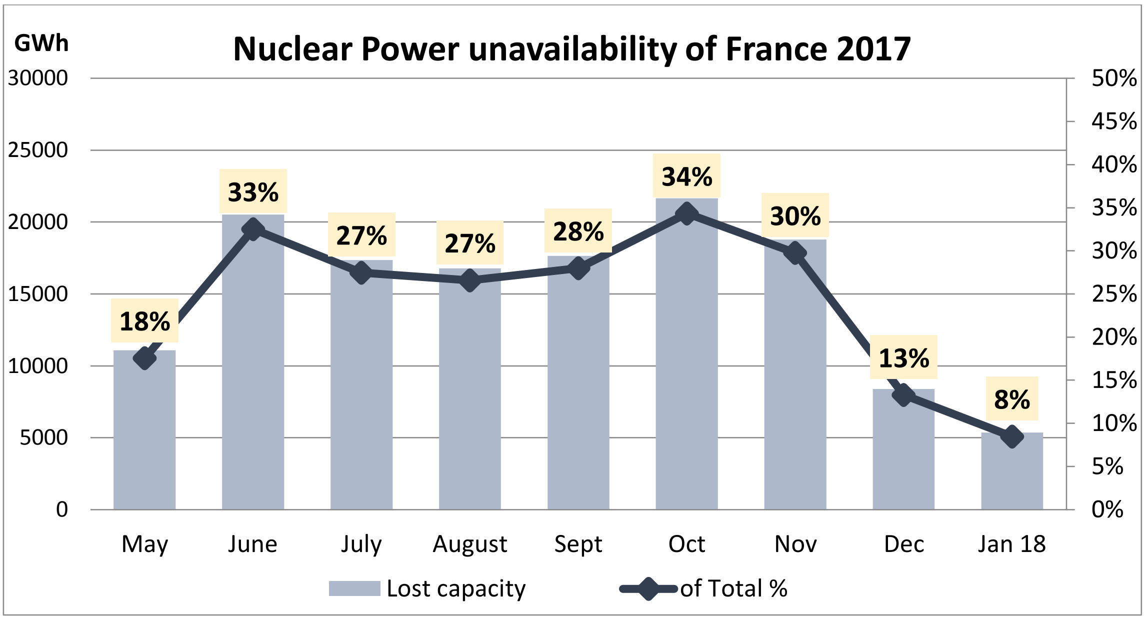

Figure 36: Nuclear Power unavailability of France in 2017
Source: EDF

In November 2017, France had to cover its high demand, so it became a net importer of electric power once again, as it is shown in **Figure 36**. The aforementioned figure shows the electric power imports and exports for France for the period of 2017 to 2018. Because of

[33] https://www.reuters.com/article/us-france-nuclearpower/frances-edf-fixing-pipe-problem-at-20-nuclear-reactors-idUSKBN1CG10M
[3] https://www.reuters.com/article/edf-output/update-1-frances-edf-to-miss-nuclear-output-target-as-restart-dates-slip-idUSL8N1OF1M5
[34] https://www.reuters.com/article/us-france-nuclearpower/frances-edf-fixing-pipe-problem-at-20-nuclear-reactors-idUSKBN1CG10M
[3] https://www.reuters.com/article/edf-output/update-1-frances-edf-to-miss-nuclear-output-target-as-restart-dates-slip-idUSL8N1OF1M5

the fact that France couldn't cover its domestic demand by the domestic supply, it wasn't possible to make regular deliveries to its neighbors, as usual. As a result, the exports to Italy, which are generally characterized by high volumes, fell significantly.

Another factor that was crucial in combination with the deficiency of electric power imports from France was the increased power demand in 2017. As can be shown in **Figure 37**, which displays the electric power demand in Italy for 2016 compared to 2017, it was on higher levels for the most part of 2017, starting on April 2017 until the end of the year, with the exception of October in which the numbers didn't exceed the previous period.

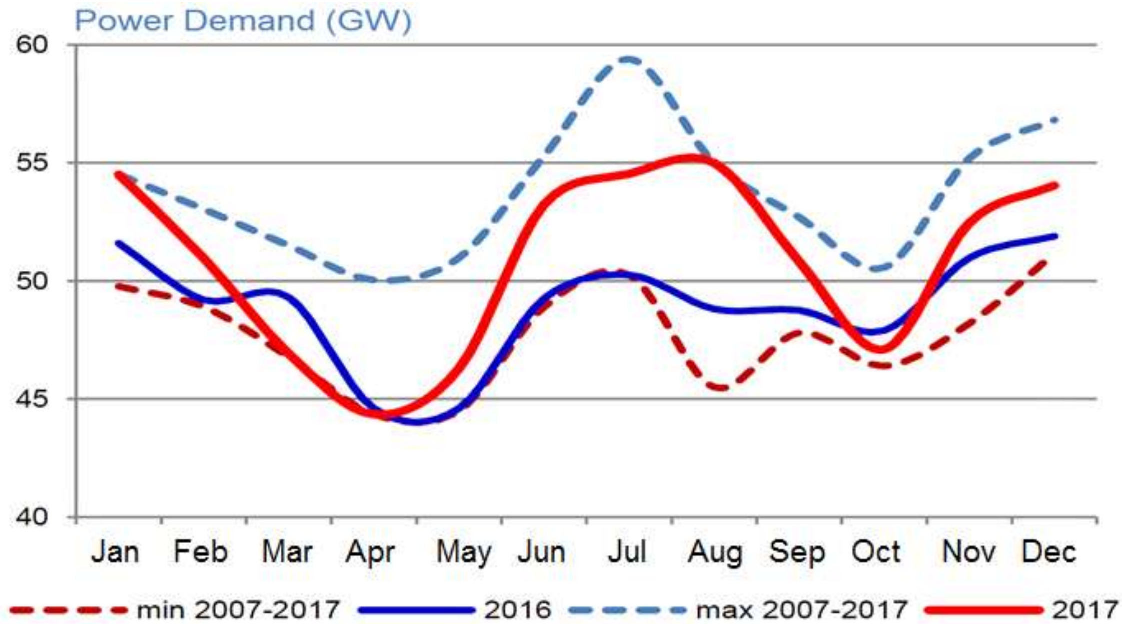

Figure 37: Italy's electric power demand
Source: Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)

As mentioned in the previous section, Italy, apart from the renewable energy that it produces, has two options to cover the domestic needs, depending on the cost of each one. It either produces its own power using mainly imported gas, or it imports electricity directly from its neighbors. Because of the fact that France, a major exporter of electricity towards Italy, dealt with the abovementioned problems with its nuclear reactors, the option of trading was not cost effective. As a result, Italy had to import the gas needed in order to generate power.

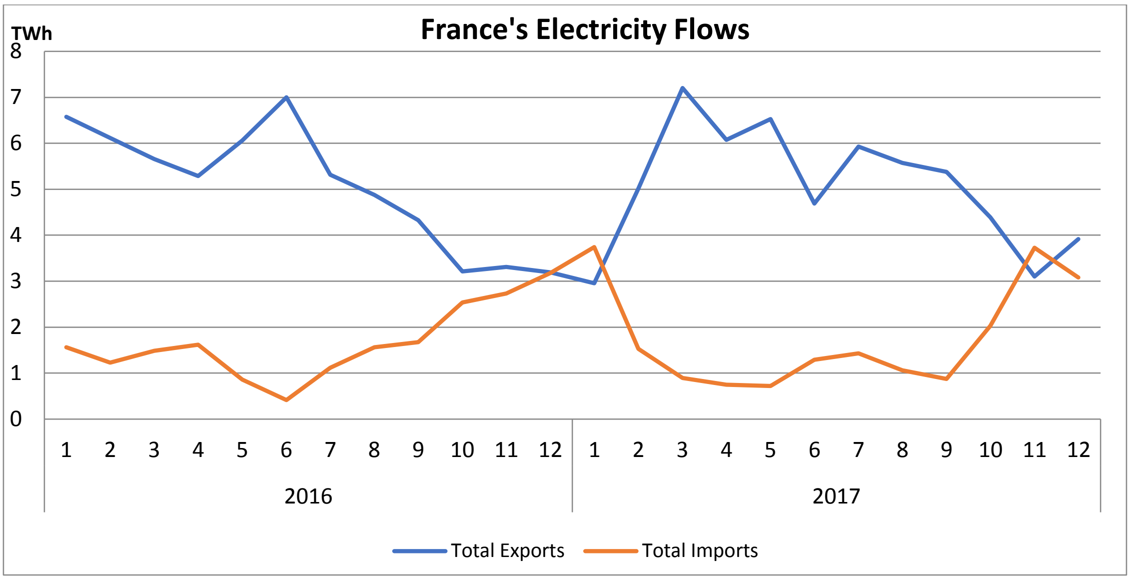

Figure 38: France's Electric Power Flows
Source: ENTSO-E

In the first period of September 2016 to January 2017, the power exports from the CWE region fell, as previously mentioned, and are portrayed in **Figure 39,** in which the EU regional electricity flows equilibrium is depicted. The fact that the physical flows of Italy follow the opposite direction can be distinguished, meaning that Italy's electric power imports decreased, while the CWE region flows noted the foregoing fall, and its needs were covered with an alternative way. After the crisis was suppressed in February 2017, there was a significant rise in the CWE's flows and a simultaneous increase in Italy's flows. In September 2017, when the French nuclear stations closed once again, the CWE's flows decreased once again, until November 2017. The difference in that case, as illustrated in the relevant figure, was that Italy's flows were not as much affected compared to the previous period of time. Specifically, in January, the deviance of the CWE's physical flows from those of Italy was 126 digits. On November 2017, during the peak of the second under examination crisis, the deviance was much larger at 582 digits. During the first period, while the CWE equilibrium was decreasing the rest of the European countries were affected. The influence was reflected on the physical flows which increased in order to close the gap that was formed. The difference during the second period was the countercurrent reaction of Italy to the rest of Europe. While the market seemed to converge the rest of the regions toward the fall of the CWE's flows, Italy stayed more stable to its precedence course.

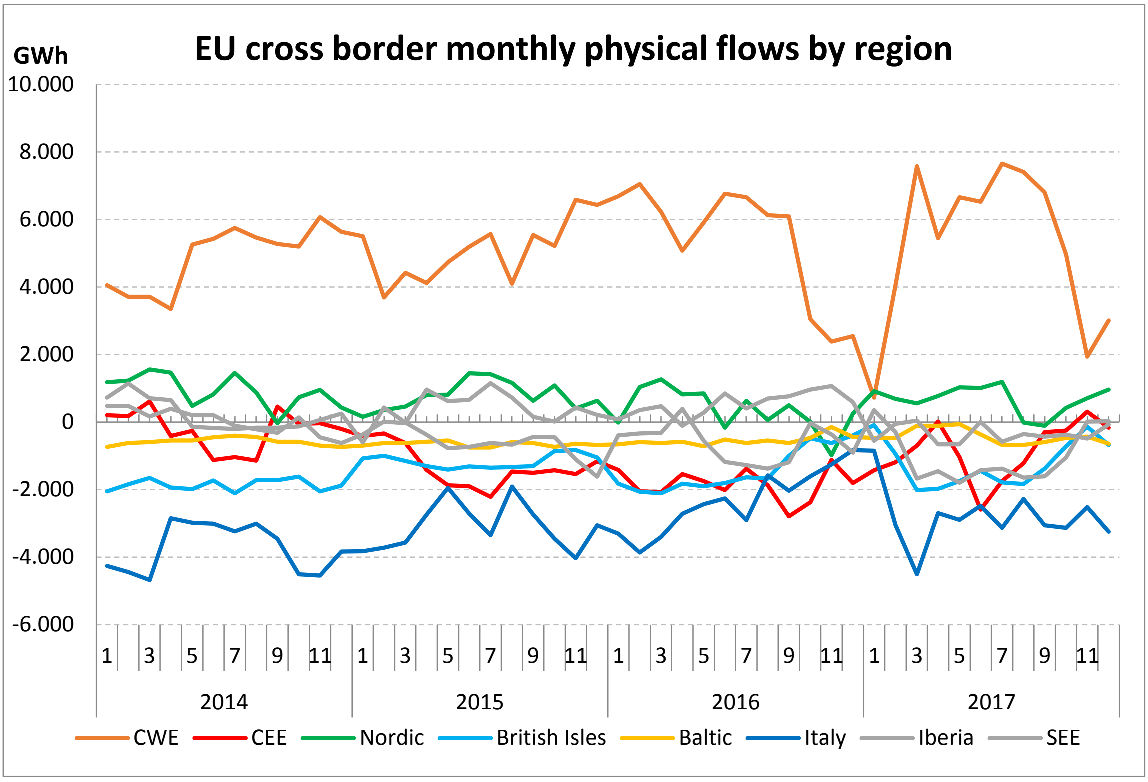

Figure 39: EU cross border monthly physical flows by region
Source: ENTSO - E

The explanation for this phenomenon can be found by observing the European wholesale baseload prices. **Figure 40** shows the European monthly regional electricity baseload prices for 2017. It seems that Italy had the second highest power price in Europe in November 2017, meaning that in order to be able to cover its high demand, Italy had to keep the imports on the same level as before. Because of the fact that the European flows this period were limited, Italy had to pay their imports more expensive than their competitors in order to maintain the required quantities.

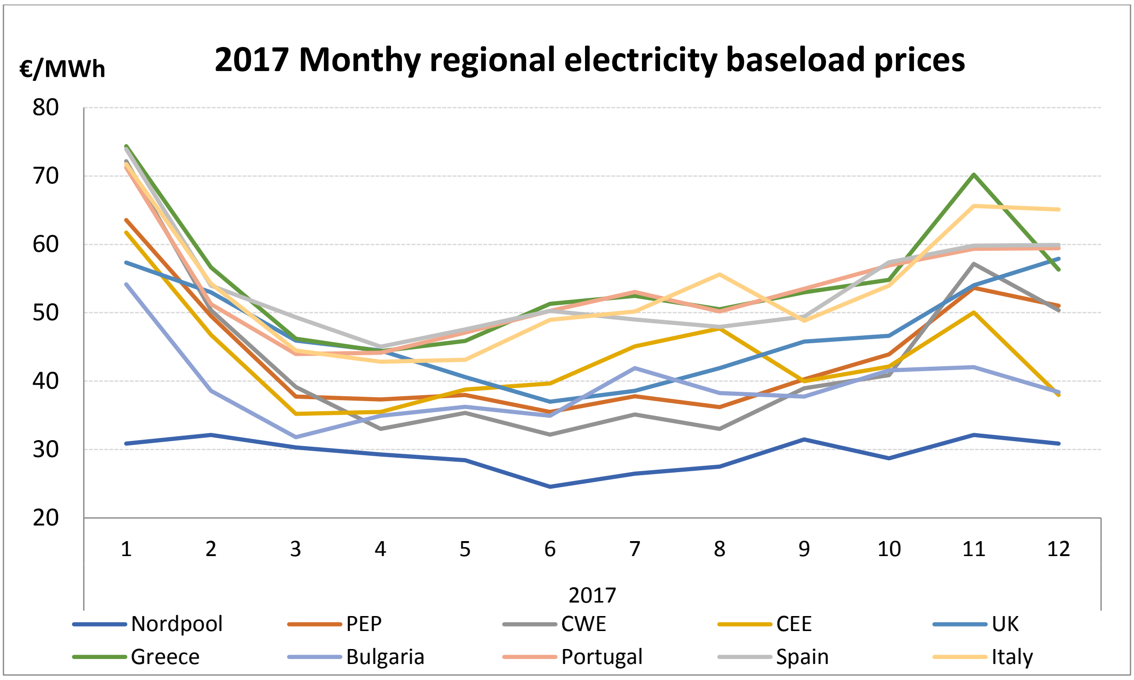

Figure 40: 2017 Monthy regional electricity baseload prices
Source: E.U.

Taking a closer look in Italy's electric power imports in **Figure 41**, some conclusions can be made. As can be seen, in the period of September 2016 to January 2017, there was an overall decrease in electric power imports towards Italy. On the contrary, in the second period under examination, starting of September 2017 as mentioned above, there was a decrease in France's flows but it seems that the imports coming from Switzerland remained on normal levels while the smaller contributor, Slovenia, noted a slight increase.

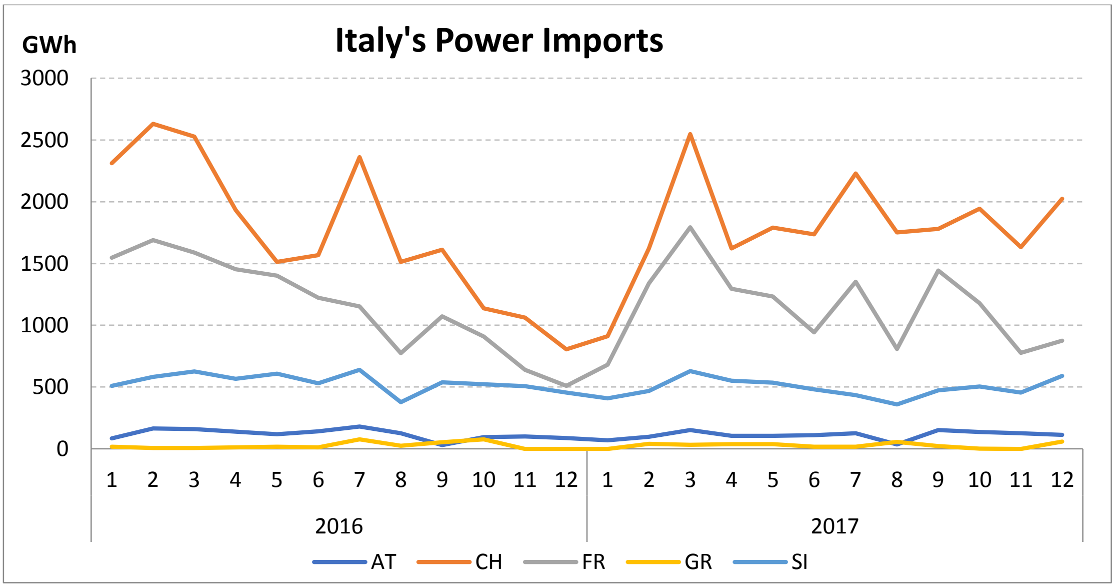

Figure 41: Italy's electric power imports
Source: ENTSO-E

In order to cover its increased power demand, Italy only cost-effective option was to increase the use of gas into power generation. A key role to the utilization of the capacity was played by the increase of the clean spark spreads, meaning the profit of the producer, given the price of power, gas and emission allowances. Once again, similar to the case described earlier regarding the UK, the increase of power prices, despite the simultaneous increase of gas prices guaranteed enough profits for the gas to power generation to be operational and thus cover the domestic energy needs. As shown in the following **Figure 42** the spark spreads for Italy (PSV) during the winter of 2016 and the winter of 2017 held a positive value and even signaled high spikes. The extreme price drop in December 2017 caused by the explosion in Austria's Baumgarten, which resulted in a halt of gas supplies for a short period of less than 24 hours.

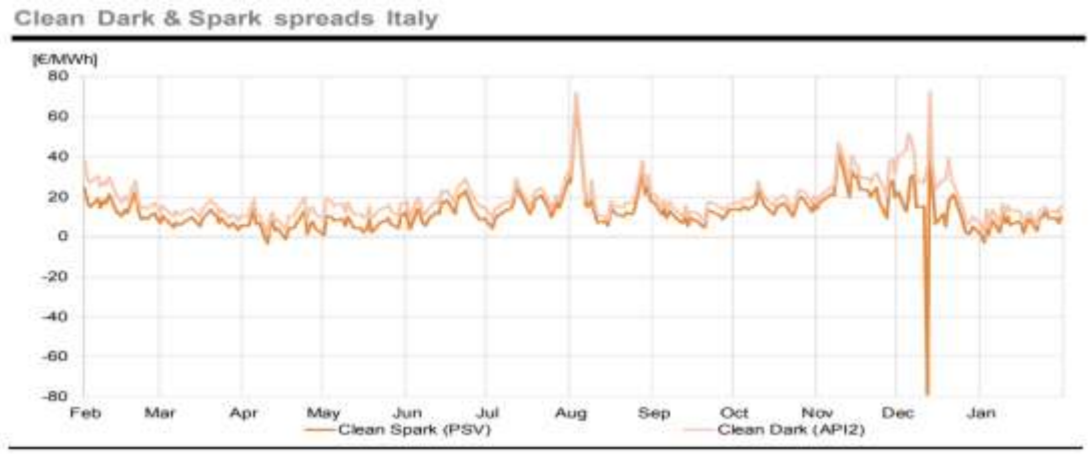

Figure 42: Italy's clean dark and spark spreads
Source: Terna

Except for the gas that was required for power generation, Italy needed to cover the ascended gas demand. Specifically, as can be observed in **Figure 43**, which compares the quarterly gas demand for the time period of 2014 to 2017, it is clear that for 2017 an increased gas demand was recorded during the whole year, compared to the previous years. However, Italy continued to import gas at the same levels as before, as it is shown in **Figure 44**, which displays the total gas imports to Italy compared to imports by entry point. It can be observed that in the last three months of 2017 there is an increase in gas imports, which however can be attributed to seasonality deriving from higher demand in winter periods.

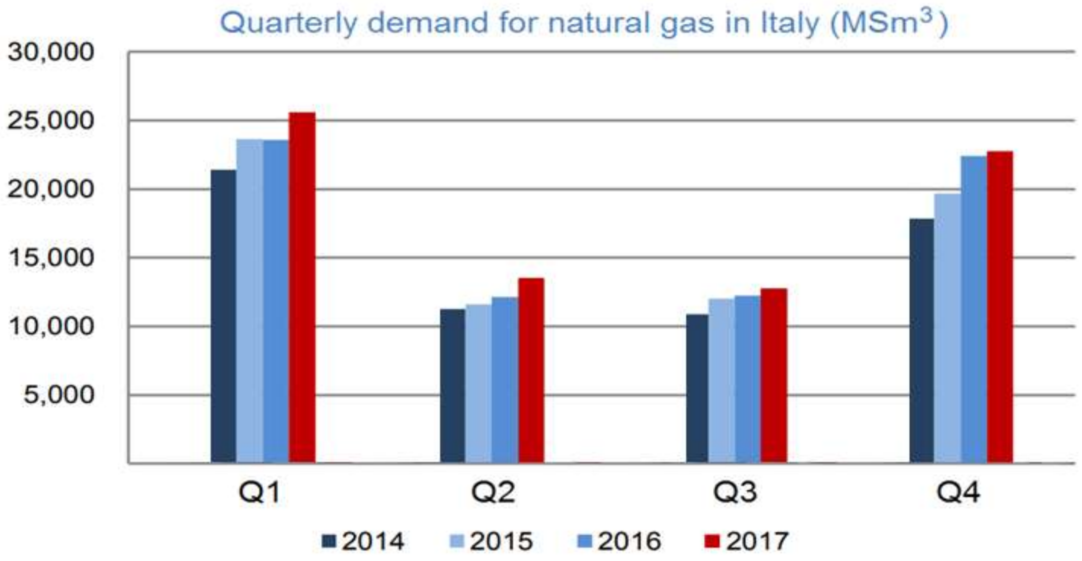

Figure 43: Quarterly demand for natural gas in Italy
Source: ENEA

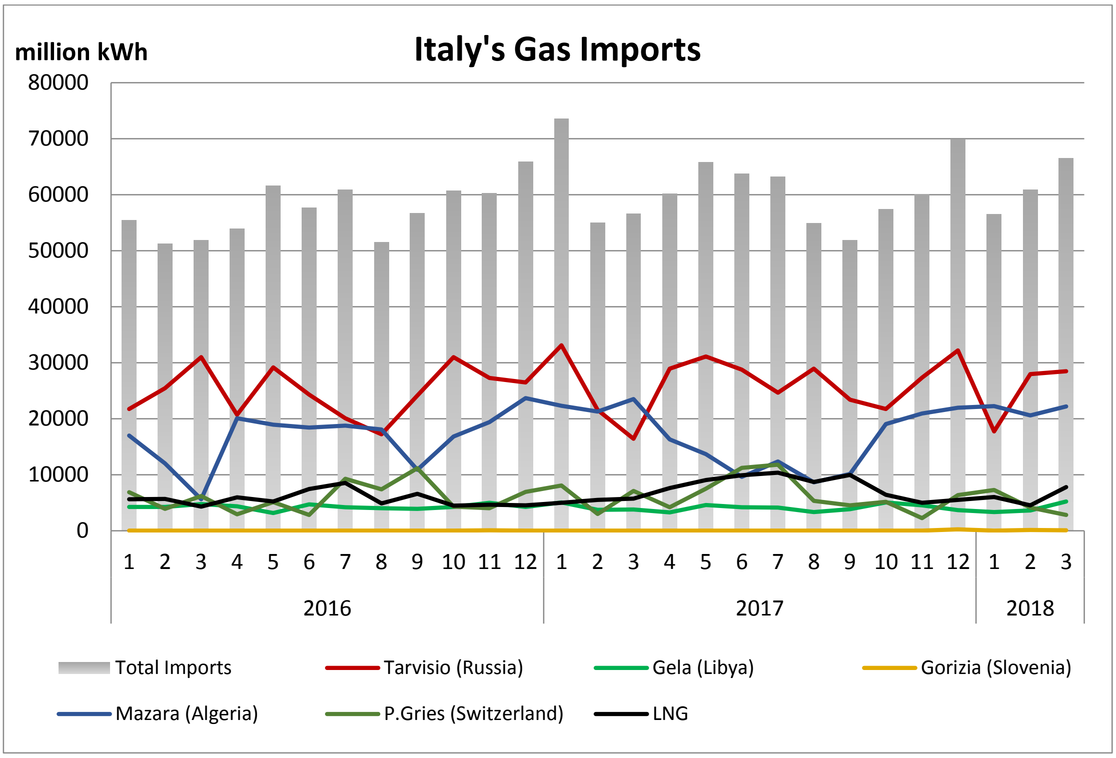

Figure 44: Italy's gas imports
Source: Snam

In particular, the peculiarity of the Paso Gries entry point, meaning the connection between Switzerland and Italy, needs to be examined. The forenamed gas entrance combines two natural gas pipelines, the Trans Europa Naturgas Pipeline (TENP) and the Transitgas Pipeline which use Switzerland as a passage to deliver gas to Italy. The former pipeline connects Belgium and Netherlands to Germany through which, the gas destined to Italy is exported to Switzerland, as can be seen in **Image 3**. The latter combines the aforementioned quantity of gas with supplemental imported from France and through Switzerland delivers to Italy, as it is depicted in **Image 4**. The additional gas from France is involved because there is a difference in maximum capacity between the two entry points and needs to be filled. The one between Germany and Switzerland has 53 mcm/day while Switzerland - Italy has 59 mcm/day. The above information is based on the research by ALBA SOLUZIONI[35].

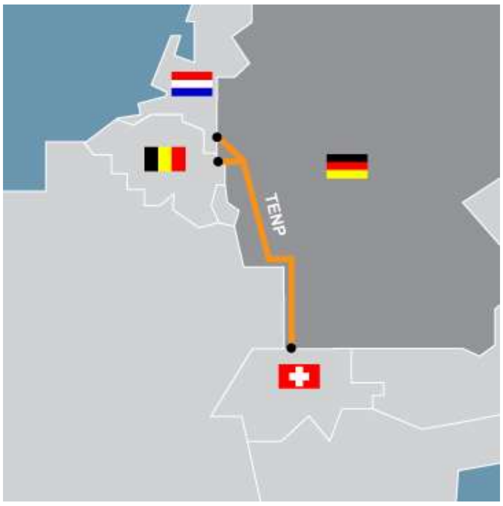

Image 3: Trans Europa Naturgas Pipeline (TENP)
Source: Fluxys

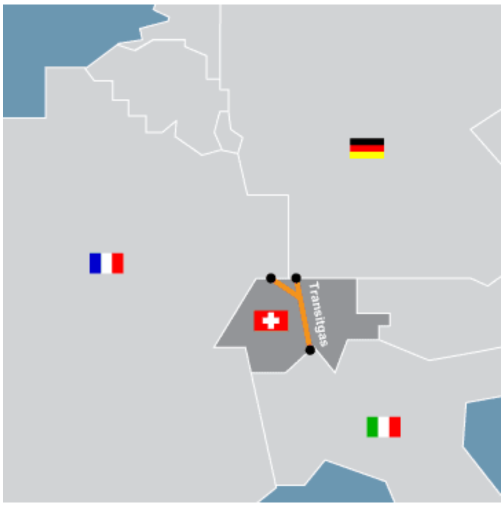

Image 4: Transitgas Pipeline
Source: Fluxys

As it is portrayed in **Figure 45** which shows the monthly gas that is used into power generation for the period of 2015 to 2018, it can be discerned that in November 2017 there was a peak that was the second highest value in the whole period depicted. Specifically, there was a 42.5% increase from September to November as from 19033 million kWh of gas used reached 27133 in a time span of two months.

[35] https://www.albasoluzioni.com/

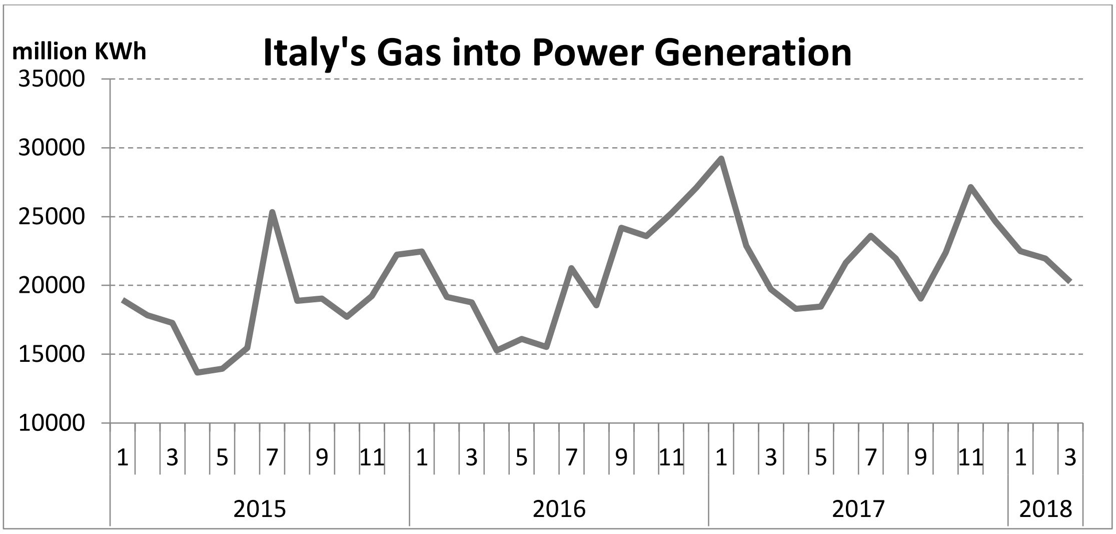

Figure 45: Italy's gas into power generation
Source: Snam

Figure 46 displays the comparison between 2016 and 2017 for hydroelectric production. It is safe to say that except January and September the whole year of 2017 the hydroelectric production was lower than the previous year. Specifically, hydroelectric production in Italy in 2017 was at the lowest levels in the decade, which has a significant effect, since Italy occupies one of the first three places in hydroelectric power generation in Europe. In 2017, production has fallen from 14% to 10% in total, according to the relatable article from Plats[36].

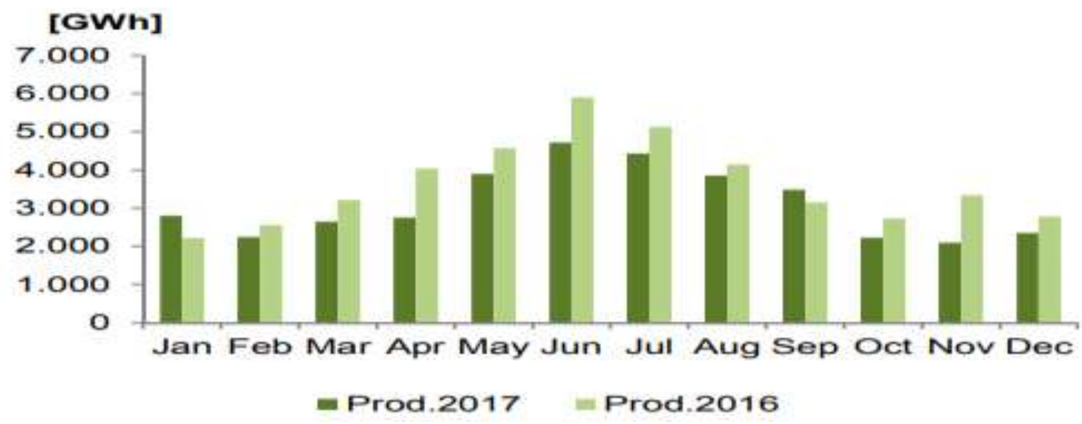

Figure 46: Italy's Hydroelectric Production and Capacity
Source: Terna

In conclusion, as was mentioned above, the demand for gas was increased while the imports remained stable and the power generation was increased, Italy was depending too much on gas and was vulnerable to other perils that may change.

[36]https://www.platts.com/latest-news/electric-power/london/europe-faces-supply-tightness-this-winter-under-21681911

Baumgarten

On 12 of December 2017, there was an explosion at Austria's Baumgarten natural gas hub which led to the interruption of Russia's supply to Austria and transit flows to Italy. Although Austria managed to invert the situation because of its domestic storage that was enough to cover its needs, Italy had a lack of supply. The latter was too dependent on gas for the last months as was described earlier that the disruption was apparent right away. Specifically, Italian wholesale day-ahead power prices rose from 23.7 to 80 €/Mwh in a time span of 24 hours. The time of the explosion, Italy declared an emergency and proceeded into some actions. They doubled the domestic storage withdrawals while increased the supply from Switzerland, Algeria and the LNG deliveries from the Adriatic. These actions can be seen in **Figure 47** which displays the gas and LNG imports to Italy during the day of the incident. As can be observed the flow was restored by the end of the day but the impact was depicted on the monthly wholesale day-ahead power prices which jumped.

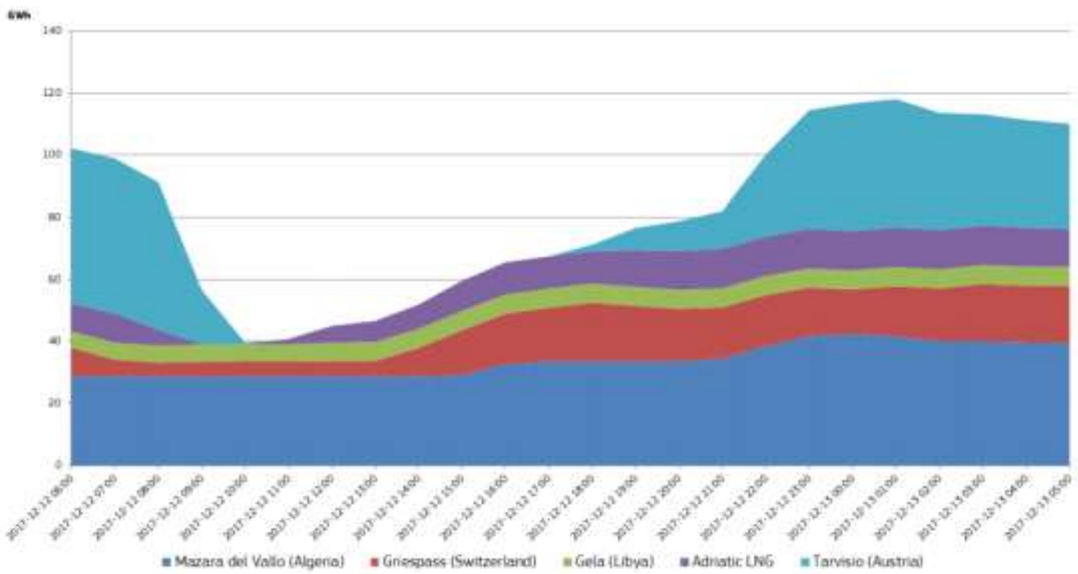

Figure 47: Italy's Gas & LNG imports on 12/12/2017
Source: EU

Conclusion

The events described in the cases presented in this study, show that the process of creating an integrated energy market is vital for the energy security, the security of supply and the efficiency of the markets for the whole European Union and for each member state involved. The process of creating an energy union is still ongoing and there are still a lot of steps that need to be taken, in order to achieve the desired single energy market. These case studies described the conditions that form a stress tests for both the markets and the transmission systems to their ability to deal with extreme conditions and situations. The examination of the events related to that period provide a root cause analysis of the fundamental reasons that led to the increased volatility of the market prices spreading across energy markets in Europe.

It is obvious that each country has different energy needs and different capabilities to produce the power needed to cover the domestic demand. There are always limitations to what each country can do with the resources it owns, in order to produce and consequently use that energy for its own purposes. In the European Union, there are countries such as France, which are self-sufficient to a certain extent, but there are also countries like Italy which are to a large extent relying on imports from other countries. However, these different markets are linked to each other and usually in the event of a crisis they are affected accordingly.

In all cases that we examined in this study the issue of security and availability of supply has emerged in a critical manner. In order to ensure a reliable supply of power, the energy mix needs to provide adequate incentives to provide sufficient and flexible generation capacity. This is an imperative to guarantee a high level of security of supply because fluctuating output of renewable energy sources, sudden power plant outages or unexpected high demand can otherwise cause power shortages.

The presence of extreme values over time is an inevitable phenomenon, which can be caused by various factors, both natural, like low weather temperatures and economic or geopolitical. So when extreme events occur, the prices of the various sources of energy are affected to a great extent.

The equilibrium of supply and demand is a sensitive equation affected various factors, both in the demand and the supply side. The ability to predict the equilibrium price is crucial for all the involved parties and of course to final consumers. On the one hand, various prediction models have emerged through the years, trying to forecast volumes and prices in the short and long term. Events described in this cases and similar scenarios are hard to predict and may occur at any time, rendering the whole market and system vulnerable to the repetition of such phenomena. The root cause analysis of the fundamental reasons for the observed turbulence of the market prices proves that, in order for the volatility to be mitigated, it is necessary to deal with the real reasons that created these phenomena. Utilizing forecasting models that do not incorporate fundamental factors of the market may be inadequate in their ability to predict the emergence of such situations.

On the other hand, these case studies have also shown that the interconnection of the systems and the markets are still inadequate to address issues of security of supply in stress situations and further investment and upgrade is required. Furthermore, the increased capability of power storage, the introduction of smart grids and demand response schemes and measures can help mitigate the threats of security of supply and simultaneously help in reducing volatility of prices and the emergence of extreme prices, both positive and negative. However, all these will be further stress tested in the future under the prism of the further introduction of renewable energy, which is influenced by weather conditions, together with the planned phase out of fossil fuels and the increasing prices of CO^2 emissions.

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