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Unveiling the Forces Shaping Natural Gas Demand in the European Union

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ABSTRACT

Following the Russian invasion of Ukraine, European Union (EU) saw a significant drop of over 30% in its natural gas imports from Russia. Despite this challenge, European Union managed to make up for the shortfall by increasing imports of liquefied natural gas (LNG), thus preventing any immediate shortages of this vital resource. While policymakers' efforts are recognized, it's important to highlight that the main driver behind these major changes in natural gas imports was the response of the market to price fluctuations. The surging prices effectively balanced the supply and demand, though they also notably contributed to a period of heightened inflation in European Union. Understanding the dynamics of supply and demand in the European's natural gas market becomes crucial for grasping the current economic landscape. With existing gas import routes nearing their capacity limits, adaptability primarily stems from the demand side. Using applied regression models, we identified the key factors influencing natural gas consumption and changes in demand patterns. Our analysis revealed a significant decrease in demand sensitivity to temperature, as subsidy programs failed to completely offset the impact of higher prices for end consumers. The role of gas in power generation is playing ever more important role, emphasizing that substitution options in power generation, or the absence thereof, could potentially stress the gas market in the event of nuclear outages, aggressive coal phase-outs, or unfavorable conditions for renewable generation. This underscores the imperative for a continuous and robust expansion of new renewable generation sources.

Keywords: Natural Gas Market, Energy Security, EU
JEL Classifications: Q1

1. INTRODUCTION

In the aftermath of Russian invasion to Ukraine, European Union (EU) lost more than 30 % of its natural gas imports that originated from Russia. European Union managed to replace the lost Russian gas with increased imports of LNG and was able to avoid physical shortages of this vital commodity. Even though the efforts of policymakers cannot go unmentioned the primary channel that enabled such massive shifts in imports of natural gas was price driven market reaction. The spot price of natural gas increased from the 2016 to 2021 average of €15MWh to more than €300/MWh at the height of the panic buying during the third quarter of 2022. Such huge price increase was certainly driven by fundamentals, but policies oriented at filling natural gas storages certainly added some fuel to the fire (Frederico, 2024). Impact of this price surge on the wholesale market was, however, twofold. Not only European Union attracted LNG that was destined to supply other nations (IGU, 2023), but the commodity became too expensive even for European Union's retail market and contributed to the inflation woes in European Union (Filip et al., 2023). For instance, the EU import bill for natural gas reached €316 billion (2% of EU GDP) in 2022 compared to €121 billion (0.8% of GDP) in 2021 and average of €67 billion (0.5% of GDP) in previous 5 years (EC, 2023; 2020; 2018). EU's governments did not let these increased costs fully pass on its citizens and firms. Between September 2021 and January 2023 EU governments collectively allocated and earmarked €646 billion, to shield them from extreme price hikes[1].

1 It is important to stress that these figures represent budget allocations and earmarking, meaning that they might not have been entirely used up yet.

In absolute terms, three countries, representing the largest consumers of natural gas in EU, alone accounted for 70% of the overall allocation for households and firms by EU countries: Germany (€264 billion), Italy (€92.7 billion), and France (€92.1 billion). In relative terms, allocations across the EU have ranged between 7.4% of GDP in Germany to <1% in Denmark (Breugel, 2023).

However, the measures taken did not prevent the collapse of demand that occurred in EU in 2022 when increased wholesale market prices began to be felt by retail natural gas consumers. Estimates of demand loss suggest that Europe's consumption of natural gas decreased by 13% or 61 bcm to 427 bcm due to warm temperatures, demand response to record-high prices, and additional energy savings resulting from changes in consumer behavior (Honoré, 2023). This trend continued in 2023, with EU consumption for the whole year averaging 20% below the 2016-2021 average (Dalton, 2024).

Disaggregated figures on natural gas demand, however, offer insights into the dynamics of demand reduction[2].

Natural gas is primarily utilized in three sectors: Industry, residential and commercial (for heating), and power generation. Traditionally, the industrial sector accounts for just over 20% of gas demand in Europe. Gas consumption in residential and commercial sectors, primarily for space heating, represents 35-40% of annual gas demand in Europe and tends to drive the most significant annual fluctuations. Weather conditions play a crucial role in demand within this sector, with variations of ±20-25 Bcm in demand year-on-year depending on the severity of winters.

In Europe, gas usage in the power sector typically constitutes around 30% of total gas demand (Honoré, 2023). The reduction in gas consumption observed in 2022 was primarily influenced by a significant decrease in residential usage, down by 22% compared to 2021. Industrial natural gas consumption also declined, dropping by 18%. However, gas consumption for power generation increased by 2.7% despite high prices, driven by low availability of hydro and nuclear energy, which created financial incentives for greater reliance on natural gas power plants.

These consumption patterns shifted in 2023 due to increased availability of the French nuclear fleet and significantly improved hydrological conditions. As a result, natural gas usage in power generation decreased by 19%. Conversely, lower prices gradually stabilized industrial natural gas usage, which, despite still being 5% below 2021 levels on an annual basis, actually exceeded 2022 levels for the same period since the third quarter. Additionally, gas consumption for space heating in 2023 increased by 2.7% compared to 2022 (Farren-Price et al., 2023).

The global supply-demand balance in the natural gas market remains tight until the next significant supply wave arrives, projected between 2025 and 2028. With pipeline import routes nearly maximized and flexible LNG already accounting for 36% of European non-storage supply, there is minimal potential for further increases unless there is a significant decline in demand elsewhere in the world at current price levels. Consequently, the demand side remains the primary source of flexibility in this market. Understanding the key drivers of natural gas demand in Europe within this supply-tight regime is crucial (Timera, 2023).

The global natural gas market is currently susceptible to price spikes, which could further complicate the state of the European Union's economy. Therefore, our article aims to expand upon the presented findings and deepen understanding by quantifying the drivers that led to the reduction in EU demand following war-induced changes in the European Union's natural gas market. We analyze the period between 2016 and 2023, for which we have collected data, with the objective of determining what factors drove these changes and how the demand side evolved after 2020.

2. LITERATURE REVIEW

The exploration of natural gas demand has long captivated researchers' attention. This interest stems from the strategic positioning of natural gas as a transitional energy source from the fossil fuel era to the age of carbon-free energy resources, as well as its implications for energy security within international trade dynamics. These factors have spurred numerous inquiries and warranted extensive research efforts.

Dilaver et al. (2014) forecasted the natural gas demand in OECD-Europe, recognizing the significance of such predictions for policymakers, energy companies, and financial institutions. They estimated long-term income and price elasticity at 1.19 and 0.16, respectively, projecting OECD Europe's natural gas consumption to range between 572 and 646 bcm by 2020. However, these forecasts ultimately overestimated demand, as evidenced by the peak in natural gas consumption in the EU occurring in 2010 (BP, 2023), contrary to predictions from the early 2000s' (IEA, 2008), which were not able to capture the impact of increasing energy efficiencies and penetration of renewable energy sources.

Jones et al. (2015) echoed this sentiment, noting a systematic tendency to overestimate gas consumption projections. They highlighted the adverse impact on the economic viability of new gas import infrastructure due to declining demand. Moreover, they observed reductions in demand across all sectors, including industry, power, and residential segments. Notably, Jones emphasized the concentration of 75% of EU gas demand in six Western European Union's countries, with only 7% highly reliant on Russian imports, primarily in Eastern European Union's nations, specifically Bulgaria, Estonia, Czech Republic, Greece, Finland, Hungary, Latvia, Lithuania, Slovakia, and Slovenia. This highlights the potential for safeguarding the most exposed countries through targeted actions in Eastern European Union's nations.

The influence of natural gas consumption on economic growth in EU was investigated by Balitskiy et al. (2016). Their research revealed a long-run connection among economic development,

2 The data on such granularity are not publicly available and are results of calculations of researchers, therefore we suggest to reader to understand them in wider context of presented data.

natural gas consumption, labor, and capital. The multivariate model results indicated a positive, albeit statistically insignificant, impact of natural gas consumption on economic growth. In the short term, a bi-directional causality existed between natural gas consumption and economic growth. Specifically, the positive relationship between economic growth and natural gas consumption was evident, with a 1% increase in GDP leading to a 0.13% rise in natural gas consumption. Surprisingly, a negative relationship emerged between natural gas consumption and economic development, suggesting that a 1% increase in natural gas consumption could lead to a 0.02% decrease in GDP. The inverse relation between gas consumption and GDP growth was not confirmed by IMF (2022) study that suggested that reduction in Russian gas exports to Europe poses challenges for meeting demand, and that the GDP of Central and Eastern European countries could be significantly affected in case of gas shortages, highlighting the importance of energy security for economic stability.

The challenge of accurately forecasting natural gas consumption is evident in Tabagari's analysis (2022), which predicted European Union's continued dependence on Russian gas until 2025. However, by 2023, Russian pipeline exports comprised only approximately 6% of EU gas imports, down from 40% in 2021.

Tzeiranaki et al. (2019) examined energy consumption patterns in the EU's residential sector from 2000 to 2016, focusing on the impact of energy efficiency policies. Overall, EU primary and final energy consumption decreased, with a notable decline in final energy intensity and per capita consumption. Despite a temporary increase in residential energy consumption in 2015 and 2016, the article suggests that, when normalized for economic, climatic, and dwelling-related factors, residential energy consumption is on a declining trend, indicating the effectiveness of energy efficiency policies. While long term analysis such as this usually considers factors as population growth, income elasticity, GDP or energy intensity as main drivers of gas consumption, shorter term analysis mostly focuses on weather related factors, fuel substitution or industrial output as a major factors affecting energy usage (WIFO, 2024).

In response to Russian aggression, the European Commission initiated measures to reduce gas consumption within the EU, aiming for a voluntary 15% reduction from August 01, 2022, to March 31, 2023, subsequently extended to March 31, 2024. However, monitoring EU natural gas consumption faces challenges due to delayed data availability and limited granularity.

Fernández-Blanco et al. (2024) methodology offers a solution, enabling the estimation of daily EU natural gas consumption using publicly available sources like Eurostat, ENTSOG, GIE, and the JRC's ENaGaD database. This facilitates the monitoring of demand reduction efforts on a weekly and monthly basis, enhancing the EU's ability to respond to energy security challenges.

In studying the impact of the COVID-19 pandemic on natural gas consumption, Cias et al. (2021) observed significant reductions in industrial and residential gas use, particularly in Italy (25%), France (16%), and Spain (14%). Germany and Poland also experienced significant but shorter-term decreases due to lockdown measures.

Erias and Iglesias (2022) analysed natural gas demand in 15 European countries from 2016 to 2020, focusing on daily own-price, cross-price, and income elasticity. They found that demand includes a strong seasonal component in October-February when residential demand is prominent, and gas prices have limited impact. Price-based tools limiting demand according this research are more effective in modifying consumer behavior from March to August. They warn that higher elasticity of natural gas during the months from May to September can send the wrong signal to the market and contribute to the use of more polluting alternative fuels in tax policies do not respect this attribute of gas demand. Fuel switching could jeopardize potential environmental benefits of lower gas consumption. Their paper find that the lockdowns due to COVID-19 highly impacted on natural gas demand in all 15 countries confirming due the "double heating effect" heating was occurring both at households and offices. The existence of a "double heating effect" may have long-term policy implications if new consumption patterns due to teleworking get consolidated, introducing an additional factor to be considered when natural gas peak demand needs are evaluated.

The paper by IMF (2022) that examined the potential implications of disruptions in Russian gas for Europe's balances and economic output, expected alternative sources could replace up to 70% of Russian gas, allowing Europe to avoid shortages during a temporary disruption. A longer, full shut-off could interact with infrastructure bottlenecks and was expected to lead to high prices and significant shortages, especially in Central and Eastern Europe. In the short term, vulnerable countries like Hungary, Slovak Republic, and Czechia faced a risk of shortages up to 40% of gas consumption, with GDP shrinking by up to 6%. Austria, Germany, and Italy were also expected to be affected. The paper expected limited demand compression in the household sector, due to regulated prices and measures to protect consumers of some 4 bcm. The main area of demand reductions was expected to be power sector where RES, nuclear and fuel substitution was suppose so save some 42 bcm of gas demand. Industrial sector, particularly in industries exposed to global competition were expected to save another 13 bcm of gas in 2022. Similar expectations about areas of demand reductions were made by both EC (2022) and IEA (2022).

In summary, forward-looking projections often chronically overestimate natural gas demand. Typically, these projections examine natural gas consumption within the context of the neoclassical growth model. Traditional research has identified a relationship between economic development and natural gas consumption, although the causality running from natural gas consumption to economic growth is less clear. Despite this, many researchers and institutions have predicted severe economic impacts from gas shortages, as the cut-off of Russian supplies was expected to be difficult to replace in the short run. Additionally, it was incorrectly assumed that natural gas consumption in power generation would bear the brunt of replacement efforts, while industry and households were expected to only play a complementary role in savings. However, these expectations have proven to be incorrect according to the IEA (2023).

Our article aims to contribute to this body of literature by elucidating the primary factors influencing gas consumption and their implications for the EU's natural gas market. We employ a microeconomic approach grounded in sector-specific knowledge, recognizing the pivotal role of demand as a driver of natural gas prices and its direct impact on inflation levels in EU in recent years.

3. DATA AND METHODOLOGY

Our analysis utilizes monthly data spanning from January 2016 to December 2024. The variables considered include natural gas consumption (GASCONS), coal-fired power generation (COAL), the purchasing manager index, temperatures measured in heating degree days (HDD), nuclear power generation (Nuclear), power sourced from renewable energy sources (RES), power consumption (EE), and the price of natural gas (P).

Eurostat provides monthly data on natural gas consumption in European Union. Since full-year 2024 data were not available at the time of our analysis, we obtained data on natural gas consumption in daily granularity from ENTSOG. Subsequently, we conducted a regression analysis using the collected daily data to estimate the monthly consumption of natural gas in the last quarter of 2024. The average yearly consumption for the period 2016-2024 was 385 billion cubic meters. Specifically, the average consumption in the pre-crisis period of 2016-2020 was 397 bcm. Consumption peaked in 2021 at 413 bcm, coinciding with a strong rebound in industrial production in EU following the pandemic shock of 2020. However, only 2 years later, consumption reached its lowest levels of the century, dropping to approximately 331 bcm in the aftermath of the energy crisis that began in 2021 (Figure 1).

Other variables were chosen to characterize the underlying factors influencing natural gas demand across key consumption sectors. Specifically, natural gas demand for heating is primarily influenced by weather conditions, particularly temperatures, quantified using the heating degree day (HDD) metric. The HDD index serves as a weather-based technical indicator designed to assess the heating energy needs of buildings. We utilize Eurostat's published data on HDD, which are calculated as follows:

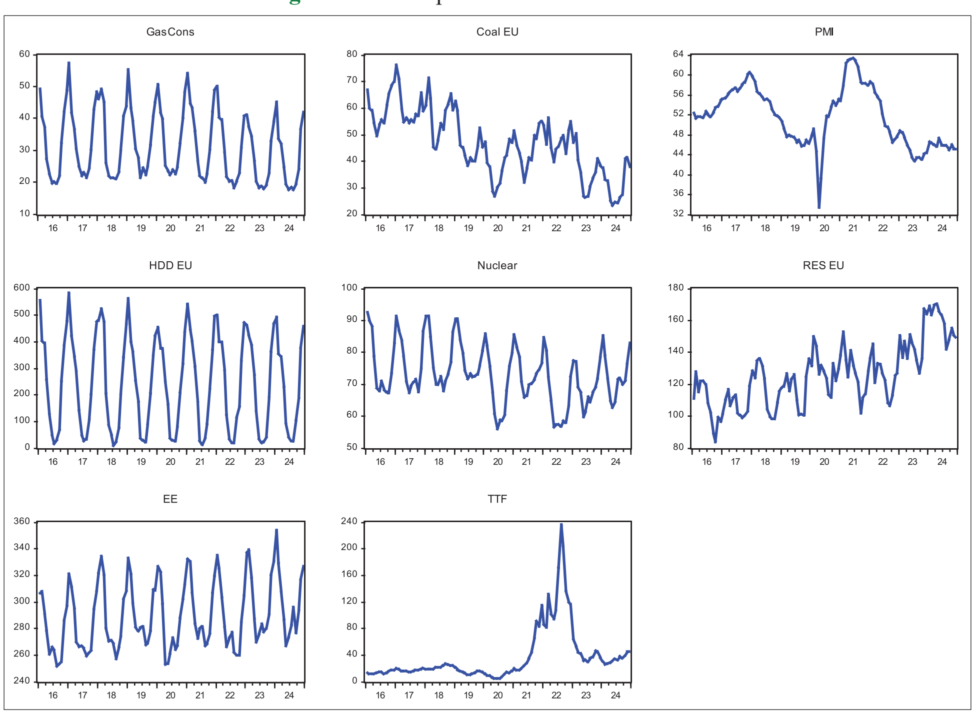
$$\text{If } T_m \leq 15°C \text{ Then } (HDD = \sum_i [18°C - T_{im}]) \text{ Else } (HDD = 0) \quad (1)$$

Where T_{im} is the mean air temperature of day i. Eurostat provides data only up to 2023. Similarly, as in case of GASCONS variable, we calculated proxy variable (HDD for Germany and France) and use regression analysis to estimate HDD for the whole EU in monthly granularity for 2024. Descriptive statistics of variables are presented in Table 1.

Power generation ranks as the second largest sector in terms of natural gas consumption. Several variables influence natural gas usage in this domain, including coal generation, renewable energy sources (RES) generation, nuclear generation, and power consumption. Each of these variables interacts with natural gas consumption in slightly different ways.

Traditionally, the narrative of complementarity is used to describe the relationship between RES and natural gas. The intermittency of solar and wind generation necessitates available capacity that can be readily deployed or put on hold for various time frames,

Figure 1: Development of observed variables



Source: Authors' calculations

Table 1: Descriptive statistics of variables

STAT	GASCONS	COAL	PMI	HDD	NUCLEAR	RES	EE	P
Mean	32.14	48.93	52.25	244.40	73.26	121.86	286.92	35.35
Median	30.28	48.51	52.20	236.52	72.31	122.74	280.30	18.29
Maximum	57.61	76.37	63.40	583.31	92.58	167.21	335.25	213.6
Minimum	17.97	26.43	33.40	8.18	55.99	83.92	251.85	12.16
Standard Deviation	10.83	11.26	5.83	177.11	9.29	16.53	23.57	37.29

Source: Authors' calculations

ranging from hours to weeks. Natural gas power plants offer this flexibility.

Coal power plants impact natural gas consumption through a different channel. Redundancy exists in the power generation market, as not all power plants are typically needed to meet power demand. The type of generation with the most favorable economics covers the marginal demand. Under ceteris-paribus conditions, the relative costs of natural gas generation versus coal generation determine the type of fuel used to generate electricity.

Nuclear power generation presents slightly different dynamics regarding natural gas demand. The marginal cost explanation is not applicable here, as the variable costs of nuclear power plants are minimal compared to those of natural gas plants. Therefore, the impact of nuclear power generation on natural gas demand stems purely from the availability of nuclear power plants. During the period analyzed, outages of the French nuclear power fleet and the decommissioning of nuclear reactors in Germany increased natural gas consumption.

The last power-related variable in our dataset is power consumption. A positive correlation between natural gas consumption and power consumption is theoretically expected. This is primarily due to policies aimed at phasing out coal and nuclear power, leaving natural gas power plants as the primary option for providing stability to power generation.

These policies, altering power generation fleet, during the observed period, caused that coal generation decreased by 40%, RES production increased by 34%, nuclear generation decreased by 9%, and power consumption rose by 5%.

The last major area of gas consumption lies within the industrial sector. We utilize the Eurozone manufacturing Purchasing Managers' Index (PMI) as a proxy variable for gas consumption in industry. PMI values above 50 indicate expansion in economic activity, while values below 50 indicate contraction, with a reading at 50 suggesting no change. PMI is widely regarded as a leading economic indicator, offering insights into overall economic conditions. A positive relationship between PMI and natural gas consumption is expected. Natural gas consumption across all aforementioned sectors is influenced by the price of natural gas. To capture price sensitivity in our model, we utilize the wholesale price of the front month contract on the most traded TTF hub. We slightly transformed this variable in our model by using the yearly moving average of the front month index to better account for the effect of various hedging structures by industrial consumers, as well as regulations determining retail prices for consumption in the residential sector.

Figure 2 illustrates the dynamic relationship between wholesale prices and retail prices for households and non-household consumers, as reported by Eurostat. The leading position of wholesale prices and their impact on retail prices is clearly evident. This helps explain why natural gas consumption remained high in 2021 despite significant price increases. While wholesale prices rose by 146% compared to 2020, consumption still managed to increase by 4%. This trend is less surprising when considering retail prices, which actually decreased by 3% in 2021. In the same manner, the slump in wholesale prices that was observed since fourth quarter of 2022 is yet to be transferred to retail prices and therefore, we suppose, current environment of subdued demand can still be to a certain extent attributed to high prices of 2022.

The ordinary least squares (OLS) regression model serves as the primary analytical tool for examining the linear association between the dependent and independent variables in this study.

This methodology allows us to identify the existence and strength of a relationship between the gas demand and the selected market fundamentals. The explanatory variables for natural gas demand are heating degree days (HDD), purchasing managers' index (PMI), wholesale price of natural gas (P), power generation from renewable energy sources (RES), generation from coal (OAL), generation from nuclear (NUCLEAR) and power consumption (EE). We utilize separate data from these complementary energy sources, as differing factors determine their usage and various policies affect their availability. This approach allows policymakers to gain clearer visibility of the potential impacts of their actions.

To ensure the robustness of our findings, we conduct an Augmented Dickey–Fuller test (ADF) test of stationarity on the time-series data involved in our analysis. The ADF test is essential for determining whether the variables exhibit a unit root, which could indicate non-stationarity (Table 2).

Since the variables are integrated in different orders I(0) and I(1) in our entire selected period and sub-sample periods, we utilize log transformation of the data to stabilize the variance of time series in our models. Results of models are discussed in the next part of our paper.

In our paper, we present results from three regression models. The first model (2) covers the entire observed period (108 observations), while the second (3) (60 observations) and third

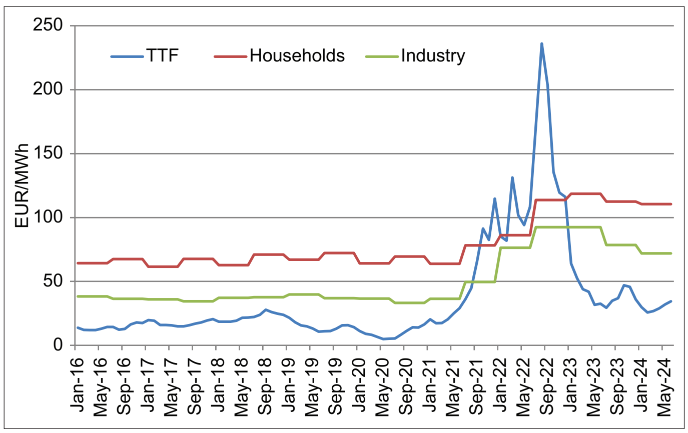
Table 2: ADF unit root test results

Period	t-Statistic					
	2016-2024		2016-2020		2021-2024	
Variable	Levels	First difference	Levels	First difference	Levels	First difference
GASCONS	−4.374***	−6.476***	−4.374***	−6.476***	−4.374***	−6.476***
COAL	−3.858**	−10.170***	−2.755**	−10.170***	−2.755*	−10.170***
PMI	−1.540	−7.532***	−1.540	−7.532***	−1.540	−7.532***
HDD	−3.229*	−5.221***	−3.229*	−5.221***	−3.229**	−5.221***
NUCLEAR	−3.502*	−4.540***	−3.502*	−4.540***	−3.502***	−4.540***
RES	−2.722***	−12.411***	−2.722***	−12.411***	−4.365***	−12.411***
EE	−2.542	−5.867***	−2.542	−5.867***	−2.542	−5.867***
P	−2.179	−8.049***	−2.1786	−8.049***	−2.179	−8.049***
TIME	−7.445***	−24.649***	−7.445***	−24.649***	−7.445***	−24.649***

***, **, * refer to 1%, 5% and 10% significance level. The null hypothesis of the ADF test is the existence of a unit root

Source: Authors calculations

Figure 2: Development of wholesale and retail price of natural gas



Source: Authors, based on data from ICE and Eurostat

(4) models (48 observations) focus on specific sub-periods: the pre-crisis period from 2016 to 2020 and the energy crisis period 2021-2024, respectively. These models differ slightly, as only statistically significant variables were included as predictors.

The following models are estimated:

$$logGascons_t = \alpha + \beta logP_t + \gamma logPMI_t + \delta logHDD_t + \omega logNuclear_t + \delta logRES_t + \mu logEE_t + \epsilon \quad (2)$$

$$logGascons_t = \alpha + \beta logP_t + \gamma logHDD_t + \omega logNuclear_t + \mu logRES_t + \theta logEE_t + \epsilon \quad (3)$$

$$logGascons_t = \alpha + \beta logPMI_t + \omega logHDD_t + \mu logRES_t + \theta logEE_t + \epsilon \quad (4)$$

We incorporated the White test into our methodology to assess the presence of heteroscedasticity in the residuals of the OLS regression model. Heteroscedasticity refers to the violation of the assumption that the variance of the error terms is constant across all levels of the independent variables. The White test results indicate that the null hypothesis of homoscedastic errors is rejected, leading us to estimate the equations with White robust standard errors to account for heteroscedasticity (Table 3). The Durbin-Watson statistic was employed to test for autocorrelation in the residuals. The test results suggest that our models exhibit favorable characteristics.

4. RESULTS

The results of the regression analysis are presented in Table 4. To account for the structural shift that the market underwent since 2021 and its implications for natural gas consumption, three models are estimated.

Model 1, covering the entire observed period, demonstrates that the selected variables account for 96.6% of the variation in monthly demand. Similarly, Models (3) and (4), describing natural gas demand in sub-sample periods, exhibit strong statistics of 96.2% and 95.8%, respectively.

An expected significant negative relationship between coal consumption and natural gas consumption is observed. This relationship is driven by fuel substitution, which serves as the primary mechanism for setting prices in the EU's gas market (Table 5).

The behavior of fuel substitution is enabled by overcapacities in power generation, particularly in Germany. During periods when coal prices are relatively cheaper compared to the price of gas, such as in 2016-2018 and 2021-2024, there is an increase in coal originated electricity generation, and vice versa. This serves as the primary balancing option for European Union's gas demand. However, the decreasing availability of coal generation, particularly in Germany, is limiting this dynamic. Currently, eight countries in the EU do not use coal in power generation, and coal phase-outs have been announced by 23 European Union's countries, including the UK by 2024, France and Italy by 2027, and Germany planning to keep some coal generation operational until 2038 (Beyond Fossil Fuels, 2023).

The implication of this trend is that the elasticity of gas demand has been decreasing, as the most flexible price-driven fuel switching option will be lost. Coal generation has proven to be a statistically significant determinant of natural gas demand in both the pre-crisis and crisis periods. This highlights the importance of fuel switching for natural gas demand and suggests expectations of increased gas consumption in the wake of continuing coal phase-outs, thereby putting pressure on natural gas availability.

Model 1 further indicates a negative correlation between gas consumption and both nuclear and renewable energy sources (RES) power generation. These findings are consistent with theoretical expectations, considering the flexibility of gas-powered generation, which positions it as an excellent complementary power source for wind and solar farms (Bertsch et al., 2014). This characteristic contributes to natural gas being recognized as a "bridge" fuel.

The correlation with nuclear power generation is also evident, given the reduced availability of nuclear power due to technical issues in the French nuclear fleet and the phase-out of German nuclear generation. In these instances, natural gas power plants played a role in filling the gap (Aune, 2015).

The final variable in our gas demand model related to the power sector is electricity demand. The significant and positive correlation uncovered is expected, given the role of natural gas as a marginal fuel in power generation.

Weather-related demand is the primary factor driving gas consumption in the residential and commercial sectors due to heating requirements. Analysis of yearly fluctuations in temperatures reveals changes in Heating Degree Days (*HDD*) of up to 12%. Since this segment of natural gas demand is believed to be the least price-sensitive due to applied pricing mechanisms, weather variations often become the most important driver in the natural gas market. The significant positive correlation observed aligns with expectations.

Table 3: Testing for homoscedasticity

Model	White test for heteroskedasticity			
2016-2024	F-statistic	1.264	Prob. F (28,31)	0.262
	Obs*R-squared	31.989	Prob. Chi-square (28)	0.275
2016-2020	F-statistic	0.511	Prob. F (10,25)	0.866
	Obs*R-squared	6.113	Prob. Chi-square (10)	0.806
2021-2024	F-statistic	0.898	Prob. F (15,43)	0.571
	Obs*R-squared	14.077	Prob. Chi-square (15)	0.520

Comparison of Models (3) and (4) indicates higher HDD sensitivity during the period 2021-2024. This result can be attributed to a combination of price-induced demand destruction and the success of extensive campaigns aimed at natural gas savings, especially during the winter of 2022-2023. This was the first winter when the EU did not rely on Russia as its main natural gas supplier, leading to prevalent fears of physical shortages.

The positive correlation between the Purchasing Managers' Index (*PMI*) and gas demand suggests that the level of industrial activity has an effect on gas consumption. The economic forces typically drive continuous growth in energy efficiency, leading to a decoupling between energy production and gas consumption, which is evident from the results of our model.

The impact of wholesale price on natural gas demand is evident in our analysis. The negative correlation between price and gas consumption, identified at a 1% level of statistically significance, aligns with economic theory. However, the price variable did not prove to be significant in the energy crisis period 2021 to 2024. This can be attributed to the construction of our variable, calculated as a yearly rolling average of the calendar contract. While this price serves as a good proxy for retail price, it may not fully capture shorter-term volatility, which drives phenomena like coal-to-gas switching (and vice versa) in power generation. These dynamics are captured by other variables in our model.

Since our subperiods are characterized by both low and high price environments (models [3] and [4], respectively), we believe that the effect of prices is captured by the remaining variables. Retail gas consumers have adapted to operate within their given price regimes, with generally higher consumption in model (3) and lower consumption in model (4). Their consumption habits remained relatively rigid after the initial adjustment.

Table 4: Results of regression analysis

	Model for period					
Model#	2016-2024		2016-2020		2021-2024	
Variable	Coefficient	t-Statistic	Coefficient	t-Statistic	Coefficient	t-Statistic
log (HDD)	0.150***	16.344	0.140***	12.425	0.143***	10.951
log (NUCLEAR)	−0.282**	−2.247	−0.317**	−2.145		
log (RES)	−0.695***	−9.908	−0.718***	−7.728	−0.387**	−2.471
log (EE)	2.812***	13.539	3.152***	13.408	2.452***	7.082
log (PMI)	0.293***	4.057			0.599***	5.437
log (P)	−0.064***	−5.884	−0.078**	−2.314		
C	−9.669***	−13.182	−10.152**	−11.874	−11.385***	−8.429
R-squared	0.966		0.962		0.958	
Adjusted R-squared	0.962		0.962		0.952	
Durbin-Watson stat	1.358		1.787		1.4727	

***, ** refer to 1%, 5% significance level
Source: Authors calculations

Table 5: Generation capacity on German market by fuel type

Fuel	2016	2017	2018	2019	2020	2021	2022	2023	2024
Nuclear	10 793	10 793	9 516	9 516	8 114	8 114	4 056	4 056	0
Gas	32 398	32 627	31 361	31 664	31 712	31 942	30 553	31 878	36 327
Coal	47 326	48 699	46 310	46 498	43 525	43 986	37 374	35 819	36 774
RES	97 384	106 387	113 744	119 229	123 631	130 153	135 208	143 269	169 185

Source: Entsoe

Finally, the comparison of models (3) and (4) reveals a slightly lower ability of the latter to explain consumption, with all coefficients showing lower elasticity. This can be explained by a general loss of flexible demand. Even though gas consumption is now predominantly driven by weather-related factors, coal-to-gas switching in power generation, and power consumption, the relationship of these variables to gas consumption is weaker as non-flexible demand now covers a larger share of overall natural gas demand.

5. CONCLUSION

The anticipated Golden Age of natural gas, as prophesied by the IEA in 2011, appears to have been prematurely curtailed. Over the span of 2 years marked by exorbitant and fluctuating prices, a staggering 20% decline in natural gas demand occurred in EU. Despite the resilience demonstrated by the market design in the liberalized EU's natural gas sector, which adeptly navigated shocks and accommodated the ebb and flow of supply and demand, certain facets of the energy security trilemma faced challenges.

While spot pricing facilitated a reduction in consumption and proved effective in resource allocation during times of uncertainty, other dimensions of the energy security trilemma were adversely affected. Affordability suffered a blow due to the elevated price levels experienced from 2021 to 2024, outweighing the benefits derived from the removal of natural gas oil price indexation following market liberalization. In terms of security, it became evident that heavy reliance on a single low-cost supplier, even with a diversified portfolio of transport routes, was insufficient and economically burdensome. This underscores the imperative for the incorporation of redundancies in a system as critical as energy supply to ensure its robustness.

Since 2021, when natural gas prices reached historically high levels, EU has witnessed a 20% decline in natural gas consumption over the subsequent two years, primarily attributed to price elasticity. It is noteworthy to remind the reader that this is not the first instance of such a scenario in the 21st century. A similar trend unfolded more gradually following the Great Recession, where elevated oil prices, coupled with Japan's sudden shift to natural gas post the Fukushima disaster, created a high-price environment. This led to a 26% reduction in EU natural gas demand between 2008 and 2015, as per BP (2023) data. Subsequently, a period of lower prices facilitated an 18% rebound in demand over the next 5 years.

It\s crucial to highlight that the prices observed in EU during the recent episode surpassed those witnessed earlier, as historical reliance on Russia's Gazprom export options had traditionally shielded EU from the volatility of global gas markets. However, this insulation from natural gas pricing dynamics is no longer applicable, marking a significant shift in the European Union's energy landscape for the foreseeable future.

The supply side of the natural gas market in EU remains constrained until 2025-2026, awaiting the commissioning of new LNG production capacities. During this period, the primary means of balancing supply and demand lies in managing the demand for natural gas, a process heavily contingent on various weather-related factors. As elucidated in this paper, EU's natural gas demand is influenced not only by prices but also by temperatures, renewable power generation, and nuclear generation. The latter, affected by weather conditions (for instance, in summer when reactors may need to reduce output due to the warming of water streams vital for their cooling systems), underscores the intricate relationship between energy production and meteorological conditions. Furthermore, short-term variations in power consumption and coal-based power generation are also significantly impacted by meteorological factors, emphasizing the complexity of the interplay between weather and EU's natural gas market dynamics.

Our modeling indicates that a portion of flexible gas demand has already been priced out from the market post-2021. However, a swift return to historically normal prices on the EU's natural gas market may see this demand resurface, echoing past trends. Particularly in the short term, until new supply capacities are introduced, this resurgence could lead to a return to a higher natural gas pricing regime during adverse weather conditions, amplifying heating or natural gas power generation requirements.

From a policymaker's standpoint, the key safeguard against such unwelcome developments lies in consistently incentivizing measures to enhance building insulation, facilitating the expansion of renewable power generation capacities, and implementing thoughtful reforms in energy market design policies. We believe that heightened price volatility in the European Union's gas market may persist, given the increased dependence of European Union's natural gas supply on global factors, not solely regional ones. Simultaneously, with the growing electrification trend, demand will be more susceptible than ever to weather developments.

Therefore, designing mechanisms that foster new market flexibilities on both the demand and supply sides will be imperative to ensure the optimal functioning of the natural gas market in the coming decades.

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