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Understanding the Dynamics of the Prices of Natural Gas as an Important Step in Energy Transition

Abstract

Objectives: The natural gas seems to be an attractive supplement to the renewable energy sources in energy transition towards low carbon emissions. Given its flexibility to transmit and store, the natural gas offers a diversity of the renewables. Understanding the formation of natural gas prices is crucial for evaluating the costs of energy transition, in particular the return to investment into natural gas infrastructure.

Research Design & Methods: In order to study the natural gas prices dynamics in Poland, I developed a Vector Error Correction model (VECM) for a joint determination with prices in the USA and in Europe. The VECM setup made it possible to analyse the interactions among non-stationary prices as well as investigate how disturbances specific to the discussed markets pass on within the system.

Findings: By exploring impulse response functions and forecast error variance decompositions, I demonstrate that the European natural gas prices are not affected by shocks in the American gas market, as they are determined solely by the shocks specific to the European natural gas market. Additionally, the natural gas prices in Poland are highly correlated with, and responsive to, other European countries' prices. The results go in line with the hypothesis of the existence of a common, integrated European natural gas market.

Implications / Recommendations: In the context of energy transition, the return to investment within natural gas infrastructure can only be forecast given the predicted prices. The appropriate proportion of alternative energy sources in the energy mix can be achieved only after examining this dynamics and the differences in prices of alternative energy commodities. Hence, the feasibility of predicting natural gas prices should always be considered at the early stages of any energy transition policy.

Contribution / Value Added: The results add to the discussion on the role of natural gas in energy transition. They reveal how gas prices on the main markets have fluctuated over the recent years as well as they link the prices in Poland to natural gas prices abroad. The findings fill the gap in the literature, which so far has been focused mainly in the American market.

Keywords: natural gas market; natural gas prices; energy transition; VECM

Article classification: research article

JEL classification: C32, Q31

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Introduction

The world is going green. The new Climate Law agreed in the EU Parliament sets the target to reduce carbon emissions by at least 55% by 2030 when compared with the 1990 levels. It also commits Europe to become the first climate neutral continent by 2050. The American President Joe Biden also recommends to reach net zero carbon emissions by 2050. Such ambitious climate protection plans require the core energy transition in the form of moving away from coal to ‚greener' energy sources. This is especially encouraged in countries where carbon pricing is either implemented or scheduled for implementation, including emissions trading systems and carbon taxes.

An important question in energy transition is how to complement unstable supply of energy from renewables in a flexible way by the use of energy supplies from traditional sources. The natural gas, which provides energy for all kinds of purposes (residential, commercial, industrial, power generation uses, vehicle fuel) seems to be an attractive choice, as natural gas electric plants are very flexible and at the same time the CO2 emissions from natural gas are lower than from other fossil fuels. The huge advantage is also the ease of storing and transmitting natural gas between powerplants and countries, provided that the appropriate infrastructure is in place. Hence, natural gas offers the possibility to balance the variability of the renewable energy sources. Natural gas is also the cleanest of fossil fuels. It has been proven that switching from coal to natural gas reduces carbon dioxide and methane emissions by 30%–50%, depending on the production purpose (heat vs. electricity) (IEA, 2020). In terms of pricing, the combination of the recently low natural gas prices has given it an additional economic advantage. An interesting fact is that even though switching away from coal has become a hot topic recently, switching to natural gas has got a much longer history in Europe, especially in the residential sector. As the IEA (2020) report shows, residential gas usage in the UK overtook the coal use already in the mid-1970s. Hence, the role of gas in energy transition is irreplaceable.

Searching for the alternative to coal energy sources is particularly important, especially in view of recent events in the EU. The Polish brown coal mine (Turów) near the border with the Czech Republic has been ordered to cease activity by the European Court of Justice. The Turów mine delivers coal to the near power plant, which on average provides 7% of the total country electricity production. As the mine was forced to immediately stop extracting coal due to environmental issues, it has raised the concern about whether the other energy sources are sufficient to cover the loss. It is suggested that because of favourable weather conditions, the gap should be filled by solar and wind plants. However, the question with regard to the best long-term solution remains open. Perhaps switching to natural gas to a larger extent might provide a quick win not only for the environment, but also for the neighbourly relations. One can imagine that similar cases of suing the worst polluters might occur in the future, which is why securing the appropriate energy source is crucial.

This article discusses the role of natural gas in the energy transition and provides an overview of the European gas market. It reveals how the gas prices on the main markets have fluctuated over the recent years and tries to link the prices in Poland to natural gas prices abroad. The contribution of this paper is twofold. First, I show that the natural gas prices in Europe are not affected by shocks in the American gas market. Second, I confirm that there is a strong integration of the natural gas prices in Europe.

Similarly to coal market, the global natural gas market is geographically segmented into several localised markets, which is due to transportation costs and heterogeneous institutions (Papież & Śmiech, 2015). The role of natural gas in energy transition has recently been widely discussed in the literature, for instance by Najm and Matsumoto (2020), who deliberate on the substitution of natural gas with renewable energy sources in the global energy mix. Gillessen et al. (2019) emphasise the role of natural gas infrastructure, while Blazquez et al. (2020) highlight the role of technology and consumer preferences towards zero carbon emissions.

My main interest has been to understand how natural gas prices on distinct markets are interrelated. Obviously, the literature on the dynamics of natural gas prices is relatively rich, but the focus is in the US market, where prices are entirely determined by market forces from the mid-1990s (Joskow, 2013), providing the longest time-series to analyse. Research shows that demand shocks seem more important in explaining the dynamics of natural gas prices than supply shocks do (Arora & Lieskovsky, 2014; Hou & Nguyen, 2018; Hailemariam & Smyth, 2019). The dynamics of the European natural gas market is relatively unexplored when compared to the US market. The main question posed in the literature is whether natural gas prices in the European market are driven by changes in crude oil or US natural gas prices, or maybe by the fundamentals specific to the European natural gas market. One conclusion is that the co-movement of European and North American natural gas prices is driven by crude oil prices rather than gas-to-gas arbitrage (Bastianin et al., 2018; Brown & Yucel, 2009). The other part of the literature focuses more on natural gas prices determinants on individual markets. For instance, Erdos (2012) applies the Vector Error Correction Model (VECM) in order to show that natural gas prices traded in the UK remain in a long-term equilibrium with crude oil prices, but also react to deviations from a cointegrating relationship between the US natural gas prices and WTI prices. Hulshof et al. (2016) find out that daily spot prices at the Dutch gas hub are over the short-term horizon only mildly affected by changes in oil prices, but that they react to the level of natural gas inventories, temperature, and the production of wind electricity. Nick and Thoenes (2014) use a structural Vector Autoagression (VAR) approach in order to examine how gas prices in Germany are impacted by gas supply disruptions, weather conditions, storage activity, and LNG imports.

Typically, the commodity prices (including natural gas) are non-stationary and cointegrated on different markets. Therefore, one of flexible ways of dealing with such time-series is the aforementioned Vector Error Correction Model (VECM). Certainly, such an approach is not new in the natural-gas-related literature and has been applied, for instance, by Schultz and Swieringa (2013), or Ramberg and Parsons (2012), among others. I apply the VECM specification in order to determine the relationship between the European and the American natural gas prices, as well as their impact on the Polish prices.

The paper is structured as follows. In the subsequent section, I summarise the structure and provide some main statistics with regard to the European natural gas market. The third section describes in detail the data utilised in this study. In the fourth section, I present the model and the findings. The methodological and policy implications conclude the study.

The European gas market

In the recent years, the growing popularity of renewable energy sources such as solar, wind, or geothermal power has been observable globally. Over the past decade, renewable energy consumption has grown globally at the average annual rate of 13.7%. However, the energy supply from these green sources depends heavily on the geographical location and different weather conditions. Not all of the countries have access to the seacoast – which would allow for the production of tidal energy – as well as not all of them are able to invest in geothermal plants. Additionally, the power produced by the renewables is difficult to store. For instance, during the summer time, Norway produces the energy in the hydropower plants in amounts far beyond the country's consumption needs, and sells the surplus abroad. In winter, when rivers are frozen, the country is forced to buy energy from abroad, often at a higher price. With all these drawbacks of renewables, another source of energy is needed to replace coal and provide ‚quick wins' for lowering emissions and decreasing the levels of air pollution. Even recently, with the COVID-19 crisis – which resulted in global energy demand drop of approximately 30% at one point (the first estimates by the International Renewable Energy Agency) – the interest of investors in sustainable and resilient energy sources did not decrease.

Since 2010, natural gas prices have been on a downward trend. As a consequence, the global gas consumption has been continuously growing at the rate of 1.8% per year (IGU, 2018), reaching a record of growth of 2.3% in 2019 (IGU, 2020). However, the recent post-COVID-19 figures show a drastically different picture. According to the International Energy Agency, gas demand in 2020 fell by 2.5% and it was the largest ever recorded drop in gas consumption since the development of the gas industry in the second half of the 20th century. In comparison, gas demand fell only by 2% in 2009 because of the global financial crisis. Clearly, gas demand is impacted by lockdowns (lower electricity use) and the uncertainty of pandemic persistence (IGU, 2020). Nevertheless, the full recovery of demand to pre-COVID-19 levels is predicted within the next two years. Obviously, the natural gas infrastructure investment is critical for obtaining such growth levels. On the other hand, the pandemic's impact on the natural gas supply was rather limited, and preliminary estimates show that natural gas production was relatively stable (IGU, 2020). For the future, the IEA predicts the average natural gas demand growth of 1.5% per annum from 2019 to 2025. The earlier (pre-COVID-19) forecast for the same period mentioned 1.8% of average annual growth. Additionally, the experts suggest that the share of natural gas will reach 25% of global energy demand in 2040, overtaking oil (IGU, 2020).

The European natural gas market went through a series of regulatory and technological reforms in the last thirty years. From state-owned monopolies with bilateral long-term contracts, it moved towards a competitive and integrated market. The reforms have regulated all parts of the gas market: up-stream (production), mid-stream (transport), and down-stream (local distribution) (Chyong, 2019).

The European natural gas consumption has constantly been growing since 2014, driven by the economic growth and the need of energy transition by means of switching away from coal. We have observed a stable, constant natural gas consumption growth at the rate of around 2% per year till 2019. The leaders in 2018 included the Netherlands (growth of 10% y/y), Italy (6% y/y), and Germany (6% y/y). All these countries plan to eliminate coal from their energy production by the 2030s. With the COVID-19 crisis, gas demand in Europe suddenly declined by 7% y/y over the first five months of 2020 (IGU, 2020). After the stagnation at the beginning of 2020, the latest data from the fourth quarter of 2020 shows a consumption increase of 1.3% (European Commission, 2020).

The European gas production grew by 1.9% in 2018, mainly because of Norway on the North Sea (IGU, 2018). However, the production across the rest of Europe declined. For example, the Dutch government decided to limit gas production on its territory due to the earthquake risk. The figures of 2019 reveal the decline of the European gas production by 6.9% (IGU, 2020). The latest figures show the decrease of 15% in the fourth quarter of 2020, compared to the fourth quarter of 2019 (European Commission, 2020). The European gas reserves in the Netherlands, the UK, Germany, France, and Italy are in decline. Apart from Norway, there is no potential for supply expansion within the EU (Correljé, 2016).

A critical aspect of the European gas market is its heavy dependence on imports, either via pipelines or by means of LNG. The growing European consumption is mainly supplied by the Russian gas production growth via the Nord Stream pipeline. Other large exporters of gas to Europe include Norway and Algeria. Pre-COVID-19 figures have shown 11% growth in trade via pipelines from Russia and Norway. Generally, in 2019, the net imports increased by 6% (IGU, 2020). However, the latest data from the fourth quarter of 2020 reveals the 9% year-to-year decrease in net imports. Additionally, the recent LNG imports fell by 27% year-to-year (European Commission, 2020).

The Polish gas consumption has reached 20.4 billion cubic meters in 2019 and has constantly been growing since 2005. Around 30% of this amount is produced locally, with the remaining volume imported mainly from Russia and Norway. Interestingly, the biggest supplier of imported LNG to Poland is Qatar (European Commission, 2020). As for the energy transition, the main problem is that Poland is still heavily dependent on coal, which accounts for 48% of local energy production. The Polish energy plan states that the last black coal mine will be closed no later than in 2049, but international critics have called for the energy transition much sooner.

Bearing in mind the need for the reduction of carbon and greenhouse gases emissions, a well-planned gas infrastructure must be provided. As these assets require time to be developed, the industry and policymakers in newly developing natural gas markets should pay attention to network infrastructure developments. The largest recent gas-related investments in Europe include: Europe's Nord Stream pipeline (completed in 2012), which increased the transmission capacity from Russia to Europe via Germany; the Trans-Anatolian pipeline (TANAP; completed in 2018), which connects Azerbaijan with Europe via Turkey; and the Trans-Adriatic pipeline (completed in 2020) providing the supply to Italy via Greece. On the other hand, the growing number of LNG terminals around Europe ensures the diversification of energy supply (Correljé, 2016). Generally, the existing gas infrastructure is capable of meeting the EU's decarbonisation goals.

Gas prices

Over the recent decades, the natural gas prices increased globally due to a bigger than expected demand and an increase in oil prices, as a large number of long-term gas contracts are indexed in oil prices (Chyong, 2019). Worldwide, a similar increase of oil and coal prices was also observed. It is worth noting that natural gas is still much more expensive than coal; the premium of gas to coal is around 40% globally, and even higher in Europe. Recently, gas prices have started to decrease, reaching in Europe the negative growth rate of -38% in 2019 (IGU, 2020).

Theoretically, the perfect competition in the European gas market ensures that natural gas prices in different European countries only vary only by transaction costs, such as the cost of transporting gas from one place to another, or non-trade barriers (Chyong, 2019). My aim is to examine the relationship between the European and the American natural gas prices. I am particularly interested in evaluating the impact of prices abroad on the natural gas prices in Poland. Understanding the formation of natural gas prices is important especially in the process of energy sector transformation. In order to evaluate the costs of energy transition in Poland, the ability to forecast future natural gas prices is crucial, even in the planning phase, when a typical cost-benefit analysis is employed. Investing in the natural gas infrastructure, e.g. building gas power plants and pipelines, must take into account the dynamics of natural gas prices, especially in comparison with the renewable energy, which, after initial investment, is practically costless. Another important aspect is that if policymakers are aware of the response of the natural gas prices in the Polish market to shocks in other gas markets (especially within the EU), they can react relatively quickly and, if possible, adjust the energy mix towards cheaper sources if natural gas prices are predicted to increase.

To understand the natural gas price dynamics, we use the time-series of daily observations on the natural gas prices (closing prices) in the main European (the United Kingdom, the Netherlands, Denmark, and Italy), American, and Polish gas markets. All series are with different time horizons. When necessary, I limit observations to a common time frame, which is from April 13th, 2015, to April 12th, 2021 (the shortest series is from

Poland, while the longest one is from the USA). For presentation purposes, the weekly and monthly averages of prices have been calculated, and I have constructed the appropriate growth rates. The data comes from the Thomson Reuters Eikon. All data has been transformed to a common unit of measurement, i.e. EUR/MWh.

Figure 1 shows the average monthly values of the natural gas prices on the main markets from April 2015. Clearly, the natural gas prices are strongly correlated, which is particularly visible in the European market. While the European prices are similar in magnitude, the US prices are the lowest.

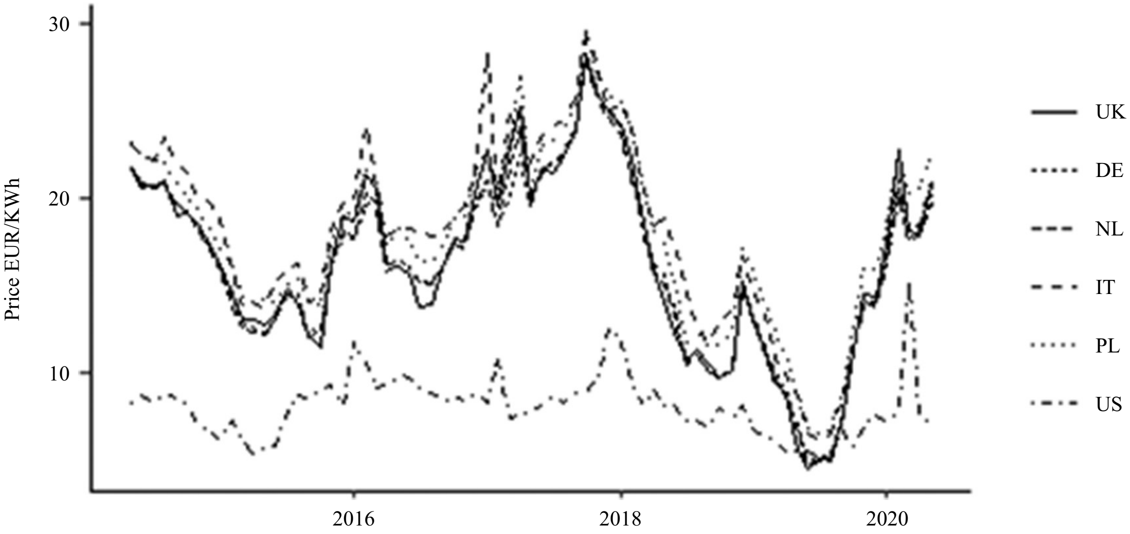


Figure 1. Natural gas prices (monthly average values)

Source: own elaboration.

Moreover, Figure 2 shows the monthly growth rates for each market separately. Here, I focus on the common time horizon from April 2015. The US prices seem to fluctuate much more than the European prices do, especially towards the end of the sample. This reflects different structures of the American and the European natural gas markets. The growth rates in European countries look very similar to one another. This is a clear sign of the existence of a common, integrated European gas market.

Table 1 shows the average weekly growth rates of natural gas prices on the main markets. I focus on the common horizon from April 2015. The average values are additionally split into pre- and post-COVID-19 periods with the aim of better understanding the recent dynamics and taking into account the global crisis and its impact on energy markets. It will be interesting to investigate whether the behaviour of natural gas prices will reverse soon and follow the pre-COVID-19 pattern, or whether the crisis will have the long-lasting impact on the energy market.

I observe the negative dynamics of natural gas prices in the recent years. Even though I recognise negative growth rates from 2015 to 2020, an interesting feature is observed during the COVID-19 crisis. The natural gas prices increased at the weekly average of around 0.85% in the UK and 0.7% in continental Europe, and 0.2% in the USA. This is rather unexpected, as the global demand for energy in general decreased over that period.

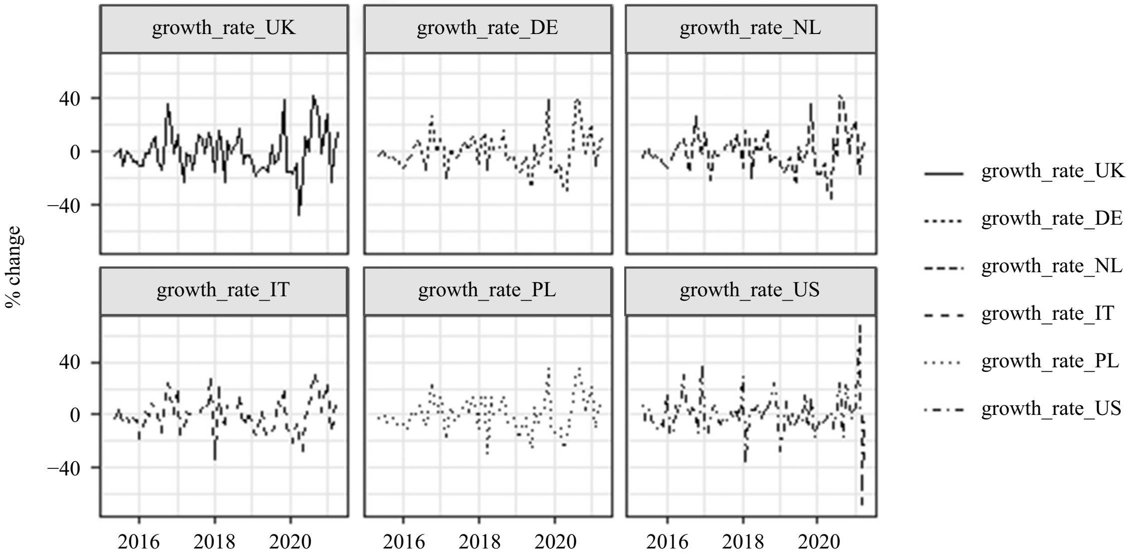


Figure 2. Monthly growth rates of natural gas prices

Source: own elaboration.

Table 1. Average weekly growth rates of natural gas prices

	the United Kingdom	**Denmark**	**the Netherlands**	**Italy**	**Poland**	**the USA**
Full sample	−0.031	−0.032	−0.041	−0.037	−0.026	−0.049
Pre-COVID-19	−0.287	−0.226	−0.262	−0.242	−0.266	−0.107
Post-COVID-19	0.904	0.676	0.768	0.712	0.849	0.162

Note: The Table presents the mean for weekly log changes (x100). The pre-COVID-19 period is from April 2015 to December 2019, while the post-COVID-19 period is from January 2020 to April 2021.

Source: own elaboration.

Table 2. Descriptive statistics for weekly natural gas prices

	Mean	**SD**	**Min.**	**Max.**	**Skew.**	**Kurt.**	**JB**	**ADF**		**ADF-GLS**	
								lev.	**diff.**	**lev.**	**diff.**
UK	16.323	5.529	3.499	44.924	0.230	4.453	30.79	−0.833	−15.873	−1.226	−3.163
DE	16.157	5.051	−3.930	30.360	−0.110	2.816	1.094	−0.646	−12.411	−1.231	−3.710
NL	16.071	5.260	3.630	41.880	0.173	4.169	19.694	−0.800	−15.865	−1.133	−3.414
IT	18.004	5.391	5.216	41.380	0.138	3.764	8.753	−0.917	−17.292	−1.009	−3.179
PL	17.758	5.221	5.663	46.535	0.329	5.150	66.962	−0.772	−16.537	−1.155	−3.097
US	8.046	2.265	4.678	35.222	5.673	66.956	55.903	−1.575	−18.337	−2.581	−7.262

Note: JB and ADF refer to the values of the Jarque-Bera normality and the Augmented Dickey Fuller tests. ADF-GLS stands for Elliott, Rothenberg, and Stock's (1996) test for a unit root. The critical values for these tests for the 1%, 5%, and 10% significance levels are –3.44, –2.87, and –2.57 (ADF); 4.61, 5.99, and 9.21 (JB), and –2.57, –1.94, and –1.62 (ADF-GLS).

Source: own elaboration.

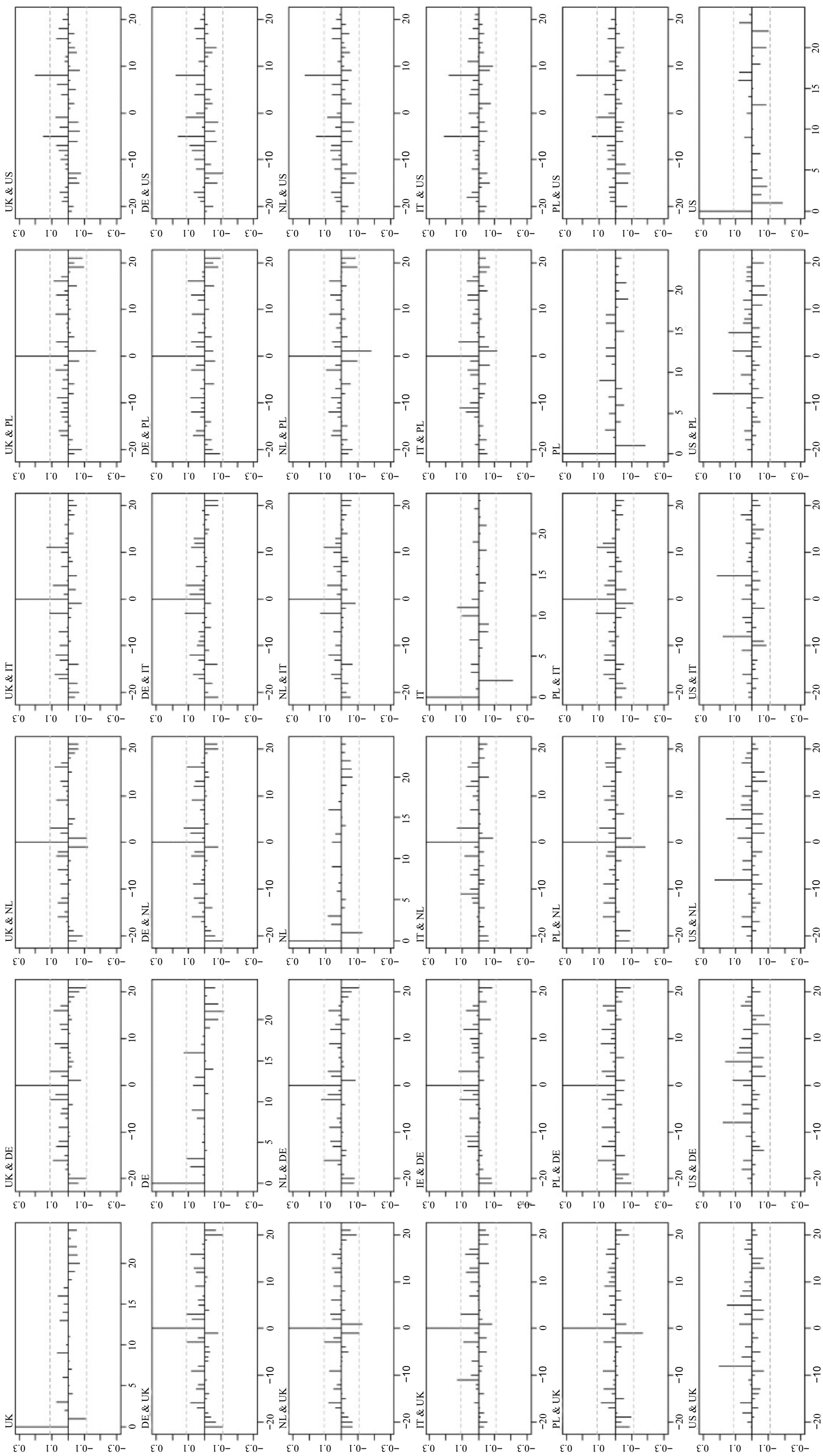


Figure 3. Cross correlations for weekly growth rates of natural gas prices

Source: own elaboration.

The descriptive statistics of the series are presented in Table 2. They confirm that the dynamics of the American natural gas prices is different from that of the European prices, which behave similarly country-by-country. In particular, the American natural gas prices are much lower than the European ones, with a smaller standard deviation, but one that is skewed and leptokurtic. Not surprisingly, the results of the ADF tests in all series indicate a unit root behaviour in levels, but not in the first differences. Hence, as is typically the case with commodity prices, natural gas prices are I(1). As the demand for natural gas tends to increase and this tendency is likely to be auxiliary, I additionally perform the ADF-GLS test for a unit root, which has higher power than the standard ADF test when dealing with a time series that is close to being integrated. The conclusions from both ADF tests are the same with the exception of the case of the USA, where the null hypothesis of non-stationarity for levels is rejected in the ADF-GLS test.

Given what is presented on graphs and in tables, the next step is to examine the dynamic relationships between the series by means of looking at cross correlograms presented in Figure 3. The panels show how natural gas prices react to their own lags (on the main diagonal) and to changes in prices on different markets. The main observation is that most of the growth rates are correlated only contemporaneously and do not react to past changes.

The model and its implications

I analyse the dynamics of prices in the natural gas market by considering the Vector Error Correction Model for a vector, denoting the natural logarithm of weekly average values of prices on these markets. As presented above, the natural gas prices in European countries have similar characteristics and dynamics. I have chosen the Netherlands as the representative country. The Netherlands has been relying on natural gas for generations and has one of the lowest share of renewables in its total energy use in Europe. As the country's largest gas field is slowly closing down, the Dutch economy is just at the beginning of the energy transition, which makes it particularly interesting to investigate in this study. I avoid fitting the model with all series, because given the sample size, the number of parameters to estimate in the system would be alarmingly large.

I start by analysing the standard VAR model with a lag length p, i.e.:

$$y_t = A_0 + A_1 y_{t-1} + \cdots + A_p y_{t-p} + \varepsilon_t, \varepsilon_t \sim N(0,\Sigma), \quad (1)$$

where y_t is the 3 × 1 vector of endogenous variables, A_0 is the 3 × 1 vector of constant terms, $A_j f$ or = 1,2,...p are 3 × 3 matrices of coefficients, and ε_t is the 3 × 1 vector of residuals.

As presented in Table 3, the lag length $p = 2$ is chosen as optimal, based on the AIC and FPE criteria.

Table 3. VAR lag order selection criteria

Lag	**AIC**	**HQ**	**SC**	**FPE**
1	−15.955	−15.897	−15.810	1.177
2	−15.982	−15.880	−15.727	1.145
3	−15.972	−15.826	−15.608	1.157
4	−15.971	−15.781	−15.497	1.159
5	−15.947	−15.714	−15.365	1.186

Note: AIC: Akaike information criterion; HQ: Hannan-Quinn information criterion; SC: Schwarz information criterion; FPE: Final prediction error. The presented values of FPE are multiplied by 10^7.

Source: own elaboration.

As all series are non-stationary, instead of fitting the standard VAR model, I perform the Johansen cointegration test to verify whether there exists a cointegrating relationship between natural gas prices on different markets. As the natural gas prices are cointegrated, the VECM specification is fitted as

$$\Delta y_t = B_0 + \Pi y_{t-1} + B_q y_{t-q} + \cdots + \\ + B_q \Delta y_{t-q} + \varepsilon_t, \varepsilon_t \sim N(0,\Sigma), \qquad (2)$$

where Πy_{t-1} is the error correction term, which captures the effect of how the growth rate of a variable in y changes, if one of the variables departs from its equilibrium value. The matrix is assumed to have rank r, which indicates the number of cointegrating relationships between the variables. Note that the coefficient matrix can be expressed as $\Pi = \alpha\beta'$ where β' is referred to as the cointegration matrix and α as the loading matrix. β contains the information on the long-run relationships between variables, and – on the speed at which the dependent variable converges back to the equilibrium. Note that $q = p - 1 = 1$, as one lag is ‘lost’ for differencing.

The results of the Johansen test are shown in Table 4, including both trace and maximal eigenvalue test.

The first null hypothesis of no cointegration (H_0:$r = 0$) as well as the second one (H_0:$r \leq 1$) are rejected in both tests. There is no evidence for rejecting the final null hypothesis (H_0:$r \leq 2$), leading to the conclusion that the rank of the cointegrating matrix is 2, which means that two cointegrating relations have emerged. To ensure that the VECM is correctly specified, I have run a set of diagnostic tests. Failing to satisfy the normality of error assumption is not a problem given the sample size, and, more importantly, the specification passes the errors autocorrelation test.

Note that I have experimented with ‘larger’ specifications, i.e. with lag lengths $p = 3$ and $p = 4$, which translates into additional $(t-2)$and $(t-3)$ terms in the VECM specification. However, the results are qualitatively the same as in the more parsimonious version of the model. As a robustness analysis, I additionally present the estimates of the enlarged model, but my main focus continues to be the original specification.

Estimates. The estimated coefficients of the VECM model are presented in Table 5. The estimated cointegrating vectors are shown in Table 6.

The negative and statistically significant value of the error correction coefficient indicates the existence of a long-run causality between the natural gas prices. I observe this in equations for the Dutch and the Polish prices. In other words, the changes in natural gas prices in the Netherlands and in Poland can be explained by natural gas prices in Europe as a whole. Additionally, these parameters indicate the rate of convergence to the equilibrium. The corresponding estimates for the US market are insignificant in the smaller model, but significant when more lags are added to the specification.

The individual lag coefficients in Table 5 are interpreted as a short-term causality, i.e. short-term impact on the natural gas prices. I observe that the US natural gas prices do not depend on the European prices, but only on their own lags. For the European market, I observe the interdependence of prices, i.e. both Polish and Dutch natural gas prices depend on their past realisations.

Table 4. The results of the Johansen cointegration test

Null hypothesis	Trace statistic	5% critical value	Max-Eigen statistic	5% critical value
$r = 0$	95.19	42.44	58.47	25.54
$r \leq 1$	36.72	25.32	33.00	18.96
$r \leq 2$	3.72	12.25	3.72	12.25

Source: own elaboration.

Table 5. VECM estimates

	$\Delta \boldsymbol{ln}(\boldsymbol{NL_t})$			
	Estimate	**SD**	**Estimate**	**SD**
Error correction terms				
ECT1	0.447***	0.116	0.404***	0.128
ECT2	−0.529***	0.134	−0.488***	0.147
Deterministic				
constant	0.222***	0.068	0.185**	0.073
Lagged differences				
$\Delta ln(NL_{t-1})$	0.431***	0.146	0.445***	0.146
$\Delta ln(PL_{t-1})$	−0.673***	0.152	−0.684***	0.153
$\Delta ln(US_{t-1})$	0.019	0.040	0.015	0.040
$\Delta ln(NL_{t-2})$			0.501***	0.157
$\Delta ln(PL_{t-2})$			−0.551***	0.170
$\Delta ln(US_{t-2})$			−0.024	0.041
	$\Delta \boldsymbol{ln}(\boldsymbol{PL_t})$			
Error correction terms				
ECT1	0.688***	0.111	0.669***	0.122
ECT2	−0.805***	0.129	−0.788***	0.141
Deterministic				
constant	0.357***	0.065	0.334***	0.069
Lagged differences				
$\Delta ln(NL_{t-1})$	0.730***	0.139	0.734***	0.140
$\Delta ln(PL_{t-1})$	−0.996***	0.146	−1.003***	0.146
$\Delta ln(US_{t-1})$	0.005	0.038	0.003	0.038
$\Delta ln(NL_{t-2})$			0.708***	0.150
$\Delta ln(PL_{t-2})$			−0.830***	0.162
$\Delta ln(US_{t-2})$			−0.023	0.039
	$\Delta \boldsymbol{ln}(\boldsymbol{US_t})$			
Error correction terms				
ECT1	0.276*	0.165	0.514***	0.180
ECT2	−0.212	0.191	−0.477**	0.207
Deterministic				
constant	0.329***	0.096	0.442***	0.103
Lagged differences				
$\Delta ln(NL_{t-1})$	−0.075	0.207	−0.109	0.206
$\Delta ln(PL_{t-1})$	0.240	0.217	0.272	0.215
$\Delta ln(US_{t-1})$	−0.313***	0.056	−0.325***	0.056
$\Delta ln(NL_{t-2})$			−0.192	0.222
$\Delta ln(PL_{t-2})$			0.135	0.239
$\Delta ln(US_{t-2})$			−0.241***	0.058

Note: * denotes 10% significance; ** denotes 5% significance; *** denotes 1% significance.
Source: own elaboration.

Table 6: VECM normalised cointegrating vectors

	$ln(NL_t)$	$ln(PL_t)$	$ln(US_t)$
$r1$	1.000	0.000	−2.527
$r2$	0.000	1.000	−2.125

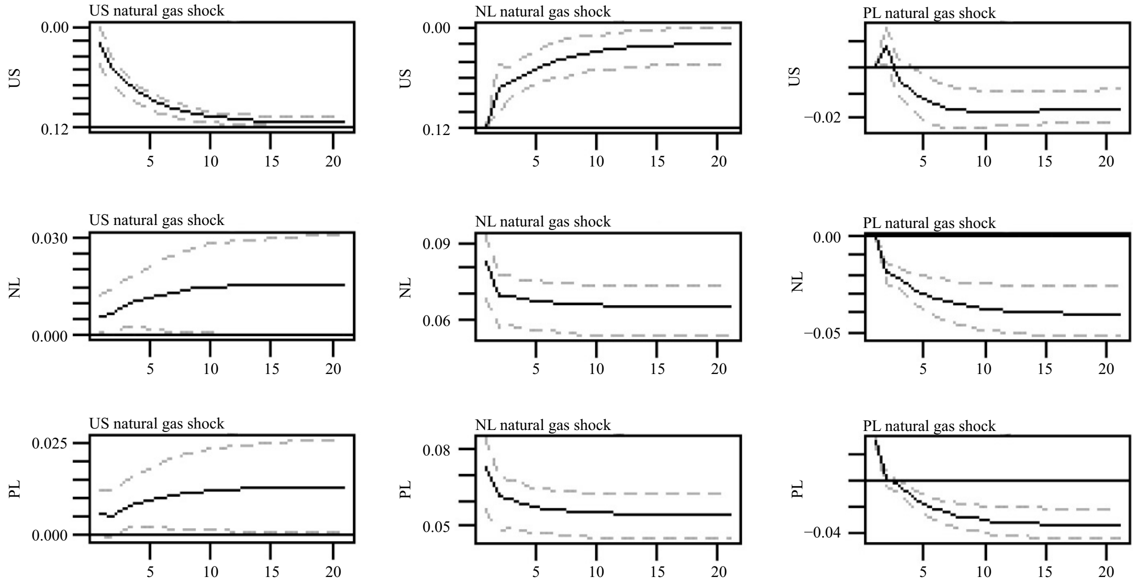
Note: The Table presents the cointegrating vectors for VECM with lag.

Source: own elaboration.

Impulse response functions. In order to investigate the effect of innovations in all variables in the system on the natural gas prices, the impulse response analysis is performed. The impulse responses to one standard deviation innovations are presented in Figure 4. Note that the situation in which the impulse responses do not necessarily approach zero is common in cointegrated models, because the variables are not stationary.

The top row illustrates the response of natural gas prices in the USA. The top left panel shows that in response to their own shock, the American prices initially jump by around 12% and then revert to the pre-shock level relatively quickly, and five months after the shock they are back in equilibrium. The middle panel illustrates that the shock in the Netherlands leads to an initial increase in the American natural gas prices by 1.5%, which accelerates to 2.5% after three months. Finally, the reaction to a shock in Poland is initially insignificant, but after a month the US natural gas prices start to decrease to approximately –1.5%.

The middle row of Figure 4 focuses on the responses of the natural gas prices in the Netherlands. Firstly, it seems that prices in the Netherlands are not significantly affected by shocks to natural gas prices in the USA. Secondly, the country's own shock leads to an immediate increase in natural gas prices of approximately 8%. After the initial jump, the prices start to drop, but even after five months they are still over 6% above the level observed before the occurrence of the shock. Thirdly, the innovation in the Polish market leads



Note: The solid lines represent the impulse response functions to three structural shocks. The dashed lines denote the upper and lower 75% bootstrapped confidence bounds.

Figure 4. Impulse responses in VECM

Source: own elaboration.

to a decrease in the Dutch natural gas prices of approximately 4% after 10 weeks, and prices do not return to their equilibrium level.

The reaction of natural gas prices in the Polish market to three structural shocks is presented in the bottom panels of Figure 4. They show that the reaction of Polish prices to a shock in the USA is insignificant. In the reaction to shocks in the European (Dutch) natural gas market, the Polish prices initially increase by around 7%, and start to fall gradually. The prices never come back to their equilibrium level and even after 20 weeks they are almost 6% higher than originally. In fact, no matter how long the horizon is considered, the prices remain well above the original level. Finally, the reaction of natural gas prices in the Polish market to the shock in Poland is an initial jump of prices by about 3%, with its relatively quick reversion to equilibrium, which lasts 2–3 weeks. Then, I observe a gradual decrease in prices, resulting in approximately 3% drop in the long run. Again, the prices do not return to their original level.

The analysis of all impulse-response functions leads to two main conclusions. First, Dutch and Polish natural gas prices exhibit similar behaviour. In the long run, they both increase after the occurrence of an innovation in the European gas market and decrease in response to the shock in the Polish market. However, they do not react to changes in the USA. Second, the US prices seem to behave differently. The reaction to shocks in Europe is significant, but smaller in magnitude. What is more, the response to a shock in the US gas market is only short-lasting, as the prices quickly come back to the original levels.

Forecast error variance decomposition. In order rto compare the contribution of the variables to the change in natural gas prices, the forecast error variance decomposition is shown in Figure 5.

In the short run, the American natural gas prices are almost entirely determined by idiosyncratic

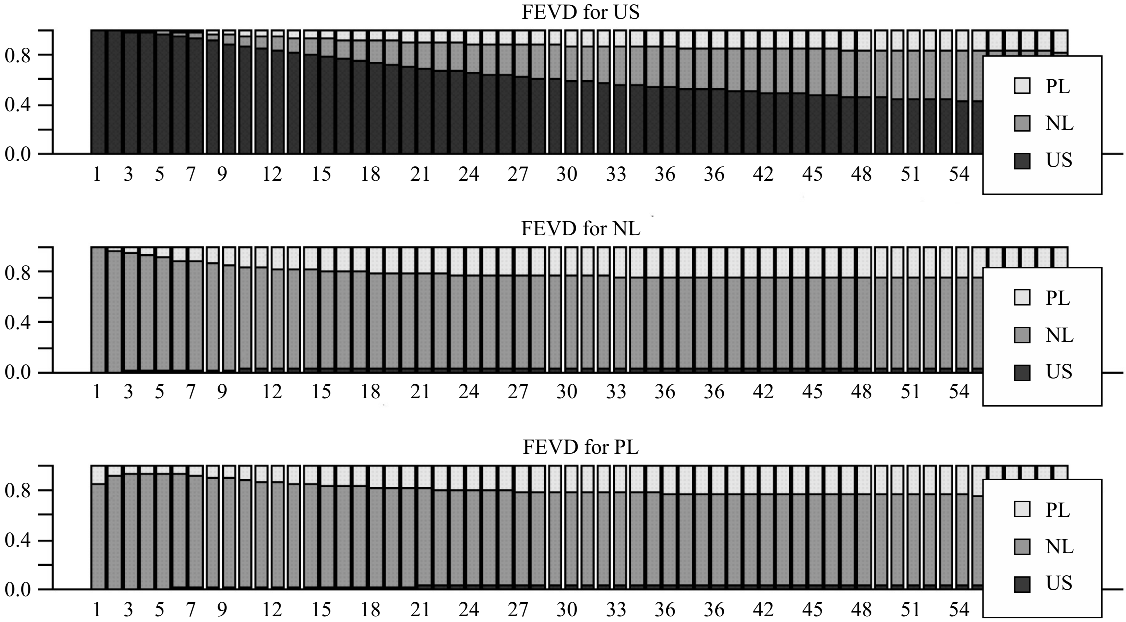


Figure 5. Forecast error variance decomposition

Source: own elaboration.

shocks. However, for further horizons, there is a visible increase of the European shocks' contribution, which rises to about 60% (40% due to the Netherlands and 20% because of the Polish shocks).

The figures for the Dutch and the Polish prices look very similarly. The natural gas prices in both markets are predominantly (around 80%) driven by shocks specific to the Dutch natural gas market. The contribution of shocks in the Polish market increases with horizon in order to stabilise at around 20% after three months. The impact of the US prices is negligible.

In general, the FEVD analysis leads to two conclusions. First, it confirms that developments in the US gas market do not affect European natural gas prices. Second, it shows that natural gas prices in the USA are linked to natural gas prices in Europe on medium and long horizons. These conclusions are consistent with the observations from the impulse-response functions.

Concluding remarks and policy implications

In this study, I have investigated the dynamics of the natural gas prices in Europe (the Netherlands and Poland) and in the USA over the period of 2015–2020. I have applied the Vector Error Correction Model, which is appropriate for investigating the dynamic interactions among non-stationary variables such as commodity prices, including natural gas are non-stationary. As my main interest is to understand the formation of the natural gas prices in Poland, the key results are twofold. First, the natural gas prices in Europe are not affected by shocks in the American gas market, but they are determined by shocks specific to the European natural gas market. Second, the natural gas prices in Poland are highly correlated and responsive to the Dutch prices. Having experimented with the remaining European countries in the sample (the United Kingdom, Denmark, and Italy), one can draw similar conclusions, which are in line with the assumption of the single, integrated European gas market.

This work matches other studies which discuss the single market hypothesis for natural gas, e.g. the recent research by Chiappini et al. (2019). With longer time-series, studies are able to show that there exists a very strong integration among most of the European gas markets and that this integration has increased in recent years. Moreover, parallel to the findings herein, research states that there is no perfect integration between the European market and the American one.

In a broader context, understanding the dynamics of natural gas prices is essential in energy transition. The return to investment in natural gas infrastructure can only be forecast based on the predicted prices. When the investment is planned, several factors should be considered. With regard to the costs, there is, for example, the initial investment into a gas plant or a pipeline, as well as future operating costs, including the expenditure on the natural gas. With regard to the benefits, apart from the reduction of emissions, there is, for example, a monetary gain from reducing the carbon taxes burden. Without the knowledge on the dynamics of natural gas prices, these two aspects cannot be compared. Therefore, only after examining the dynamics and the differences in the prices of alternative energy commodities, can the appropriate proportion of alternative energy sources in the energy mix be achieved.

Clearly, this work's approach to studying the integration of natural gas prices is not without limitations. One of the possible directions for future research in the field is to improve the quality of the estimates by employing a longer time series of natural gas prices. Also, it might be interesting to conduct the analysis similar to that of Chiappini et al. (2019), allowing for structural breaks, especially if one is interested in the impact of the COVID-19 pandemic. Additionally, the specification of the model could (and perhaps should) be enriched in such a way as to control for other important determinants of the natural gas prices, such as the price of renewable energy sources or some indicators of the infrastructure developments, such as LNG terminals. I shall leave it all for future research.

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