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Natural Gas Prices in the Framework of European Union's Energy Transition: Assessing Evolution and Drivers

Vitor Miguel Ribeiro [1], Gustavo Soutinho [2] and Isabel Soares [1,*]

[1] Department of Economics, School of Economics and Management of the University of Porto (FEP) and Center of Economics and Finance of the University of Porto (CEF.UP), 4200-464 Porto, Portugal
[2] Faculty of Economics, University of Porto, 4200-464 Porto, Portugal
* Correspondence: isoares@fep.up.pt; Tel.: +351-225-571-100

Abstract: This study analyzes European natural gas (NG) prices since the eve of the 2008 financial crisis. Spearman's rank correlation coefficients associate prices with and without taxation, whereas a hierarchical clustering analysis clarifies similarities in NG pricing behavior. After performing econometric tests to ensure the satisfaction of classical hypotheses and identify a system of endogenous variables, structured unrestricted and restricted vector autoregressive models are applied to panel data composed of 34 spatial units and 31 units of time drawn from 2007–2022 to confirm the presence of short-term and long-term causal dependencies. The nonparametric analysis identifies three groups of countries that exhibit a differentiated pricing behavior. The parametric analysis reveals a significant and asymmetric short run relation, which is imposed by liquefied natural gas (LNG) imports from Nigeria on the logarithm of NG prices. However, the sign of coefficients associated with lagged LNG imports varies across spatial units belonging to the sample. The error correction term is negative and significant, which implies evidence of cointegration. Since the main result identifies ambiguous short-term effects emerging from the diversification in favor of LNG imports from Nigeria, a straightforward policy recommendation is that this strategic option may be ill advised for Europe and, indirectly, it legitimizes the suggestion that alternative decarbonization options can play a prominent role in European NG markets in the near future.

Keywords: natural gas; liquefied natural gas; vector autoregressive model; vector error correction model; panel data

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1. Introduction

Over the last few decades, natural gas (NG) has been critical to guaranteeing a fully decarbonized economy in agreement with the recent decision by the European Union (EU) about cutting greenhouse gas (GHG) emissions by at least 55% relative to 1990 levels by 2030 [1]. Power, industry and transports are the main sectors that contribute to understanding the importance of NG in terms of an ongoing energy transition since NG can be considered a bridge fuel [2]. After a drastic economic downturn during the COVID-19 pandemic, the market is currently in a state of turmoil that has affected the entire European economy, with a strong impact felt in the cost of living and inflation [3]. The consumption of NG began to rise in the beginning of 2021, accompanied by unprecedented price increases. Along with demand side issues, other factors, such as instability in the European NG markets and uncertainty regarding Russian political actions culminated in the observation of a peak price in the first semester of 2022 [4]. Consequently, EU policy decisions regarding NG infrastructures, supply diversification and renewable energies are currently more necessary than in any other historical period. This study uses information retrieved from the Eurostat database that covers the period 2007–2022 [5] and restricts its focus to the household segment to address four research questions:

- How is the evolution of European NG prices during the period 2007–2022 characterized?
- Considering NG pricing behavior, is any clustering formation identifiable?
- If there is some prevailing reasonable doubt regarding the persistence of endogeneity problems between explanatory variables and European NG prices, which kind of causality and cointegration relationships are identified?
- Which general policy recommendations can be retrieved in light of the present study?

The conceptual idea behind the development of this study is to describe the evolution of NG prices in Europe, identify associations (if existing) and find a system of endogenous variables to explore causality and cointegration relationships (if existing). As confirmed in the literature review, econometric regression models are not often used to explain the behavior of NG prices and demand, probably due to the lack of available data and the recent development of statistical techniques to deal with causality and cointegration in the context of panel data. Considering this, the present study provides a technical contribution to the existing literature by applying a parametric analysis in the form of a structural and unrestricted vector autoregressive (VAR) model in addition to a structural and restricted vector autoregressive or, equivalently, a vector error correction model (VECM)—henceforth VAR-VECM model—and then applies it to panel data composed of 34 spatial units and 31 units of time. The current study has two research goals.

Firstly, a nonparametric approach is applied to obtain a complete outlook regarding:

- The general evolution of European NG prices since 2007;
- Organization of European NG prices in clusters according to years and countries;
- The confrontation between country-level household and spot market prices;
- The evolution of potential determinants of NG prices, namely:
    - The share of energy emerging from renewable sources;
    - The role of international trade, which includes imports and exports of NG, the share of total energy dependence, and the share of energy dependence with respect to the NG and liquefied natural gas (LNG);
    - Supply chain elements, namely stock levels, network costs, and energy and supply costs;
    - Components of NG prices, including direct and indirect taxation.

The exploratory data analysis confirms that:

- In general, NG prices have remained relatively stable and without distortions caused by taxes;
- Three distinct periods of evolution of NG prices can be identified (i.e., 2007–2011 corresponds to a period of price increases, 2012–2021 corresponds to a period of price reductions and 2022 is an outlier year characterized by galloping prices);
- Three distinct groups of countries are identified (i.e., the group formed by Serbia and Luxembourg exhibits the highest level of NG prices, the group formed by Bulgaria, Czechia, Denmark, Italy, Portugal, Georgia, Ireland, Estonia, Slovakia, Lithuania, Netherlands, United Kingdom, Sweden, Moldova, Austria and Germany displays intermediate NG prices and the group formed by Belgium, Slovenia, Latvia, Liechtenstein, Poland, Spain, North Macedonia, Ukraine, Bosnia and Herzegovina, Romania, Hungary, Turkey and France displays the lowest level of NG prices);
- Country-level household prices are perfectly aligned with spot market title transfer facility (TTF) prices (i.e., the parallel trends assumption holds) until the second half of 2021. From that moment on, TTF prices have increased exponentially;
- Transversely across all spatial units of the sample, the share of energy emerging from renewable sources has increased notably from 2007 to 2021;
- NG imports have remained relatively stable, eventually showing a rudimentary reduction since 2020; meanwhile, NG exports have decreased since the end of 2019. Therefore, coverage rate of imports by exports has decreased, which reflects Europe's greater dependence on foreign countries with regard to NG;

- Within the set of European countries holding the largest stock of NG, NG prices increased from 2007 to 2021; and
- NG prices are explained by energy costs at around 35%, network costs at approximately 24% and taxation in an order of magnitude around 21%.

Secondly, empirical work is carried out to identify potential endogenous drivers of European NG prices. In this study, the parametric approach consists of applying:

- Preliminary econometric tests to ensure that all classical hypotheses are satisfied, with the exception of the exogeneity of regressors in order to define a system of endogenous variables;
- A VAR-VECM model is applied to a panel data covering 34 European countries over 31 units of time corresponding to the period between 2007 and 2022 to identify if there is cointegration, causality in the sense of Granger and the direction of existing relations (e.g., unidirectional, bidirectional).

Regarding the first parametric task, from a vast initial set of variables taken from the Eurostat database, empirical results confirm that, if there is a system of endogenous variables, then it is necessarily composed by two variables: the logarithm of NG prices and LNG imports from Nigeria. As this African country is neither the only nor the main exporter of LNG to Europe, some energy experts may be surprised by this outcome. However, it is important to note that this study strictly follows the scientific method, so all options are derived exclusively from econometric results. Table A5 in Appendix A confirms that, even when strictly relying on factual data, Nigeria is the third most relevant importer of LNG in Europe, with a share of almost 16% during the period 2020–2022 in a market that exhibits oligopolistic characteristics. Regarding the second parametric task, cointegration outcomes are summarized as follows:

- The trend coefficient is positive but lacks statistical significance, which implies that it cannot be corroborated evidence of increasing NG prices;
- On average, the error correction term (ECT) is negative and significant, which implies evidence of cointegration between the logarithm of NG prices and LNG imports from Nigeria. Moreover, the deviation from the long run equilibrium is corrected for within the current year at a mean convergence speed of 38.304%, ceteris paribus;
- Considering a critical *p*-value of 1%, there is a long-run relationship between the logarithm of NG prices and LNG imports from Nigeria for approximately 30% of the 34 spatial units belonging to the sample.

In turn, Granger causality results clarify that:

- There is no bidirectional short run relationship between the variables;
- There is only a significant and unidirectional short run relation, which is imposed by LNG imports from Nigeria on the logarithm of NG prices;
- At the country level, it should be emphasized that increasing LNG imports from Nigeria has an ambiguous effect on the logarithm of NG prices; for example, NG prices are likely to increase (decrease) in Italy and Poland (the Netherlands), respectively.

The study is finalized with a normative discussion on the need to impose diversification strategies aimed at maximizing social welfare.

The remainder of the study is organized as follows. Section 2 provides a brief literature review, describes data and the methodology (i.e., nonparametric and parametric models). Section 3 presents results. A discussion is proposed in Section 4. Conclusions are shown in Section 5. Appendices A and B contains additional information that was not presented in the main text for the sake of brevity.

2. Materials and Methods

2.1. Literature Review

This brief review covers NG in four dimensions:

- Infrastructure;

- Demand;
- Production;
- Modelling approaches.

In turn, LNG is analyzed in three domains:

- Liquefaction;
- Regasification;
- Shipping.

Initially, let us describe the geographical and political context currently existing in Europe.

2.1.1. European Geographical and Political Context

It is convenient to identify the geographical and political scope related to this study, which embraces 34 spatial units belonging to Europe, namely: Austria (AT), Bosnia and Herzegovina (BA), Belgium (BE), Bulgaria (BG), Czechia (CZ), Germany (DE), Denmark (DK), Estonia (EE), Greece (EL), Spain (ES), France (FR), Georgia (GE), Croatia (HR), Hungary (HU), Ireland (IE), Italy (IT), Liechtenstein (LI), Lithuania (LT), Luxembourg (LU), Latvia (LV), Moldova (MD), North Macedonia (MK), The Netherlands (NL), Poland (PL), Portugal (PT), Romania (RO), Serbia (RS), Sweden (SE), Slovenia (SI), Slovakia (SK), Turkey (TR), Ukraine (UA), United Kingdom (UK) and Floating Country Composition (EA). In the floating country composition, data from a specific year always refer to the euro area. In the fixed country composition, the value of all years refers to the same list of countries. Hence, this spatial unit corresponds to the Eurozone. There are two justifications for the final list. First, political actions to tackle NG challenges are negotiated not only by EU institutions, such as the European Commission (EC) and the European Parliament and the Council (EPC), but also by alternative supranational entities such as the North Atlantic Treaty Organization (NATO). Second, both availability and transparency of data hold for all 34 spatial units through the Eurostat database [5]. These jurisdictions depend on natural gas imports from input sources outside their territorial scope and:

- In some countries (e.g., The Netherlands), domestic gas reserves are decreasing significantly;
- In other countries (e.g., East Europe), new pipeline projects (e.g., the Nord Stream 2) have increased the dependence on Russia.

A discussion focused on Russia's dominant position in the NG supply is provided in [6,7], where the authors clarify that such a strategic interaction is useful to abruptly manipulate Russia's magistracy of influence in Europe. Notwithstanding, authors in [8] confirm that political activities are also problematic in the European context. In the short run, the EC is predominantly concerned with the security of NG supply and, consequently, the imposition of stress tests and winter outlooks is exacerbated in order to assess the resilience of European NG markets [9]. In the long run, EC's objective is to increase the security of NG supply through the imposition of a policy mix of energy resources and diversification strategies. The institutional background that supports this integrated vision is influenced by the 2009 Third Energy Package (TEP), which accommodates supranational directives for European NG markets and regulations explicitly focused on NG transmission networks [10]. Nevertheless, initiatives taken by the EPC demonstrate that the European NG policy overlaps several political arenas. Because of this, authors in [11] highlight the need to distinguish between NG security and geopolitical spectrum. In general, the authors conclude that:

- Since the 2009 TEP, Europe faces strong limitations to becoming independent from Russia's NG supply due to the establishment of long-term contract obligations;
- A long run relationship between Europe and Russia is likely to persist;
- From a medium-term perspective, the role that Russia's NG supply will play on the European transition for a low-carbon economy must be defined;

- In the short run, solutions to transition Ukraine to the EU must be negotiated, and the scope of the regulation applied to the Turk stream must be determined.

From a conceptual point of view, as confirmed by the nonparametric analysis performed in this study, the final list of European spatial units can be segmented into two groups:

- Eastern countries, which have a high dependence on Russia's NG supply (>50%);
- Western countries, which have a low dependence on Russia's NG supply (<50%).

In the first group, the strategic position consists of creating reliable alternatives to Russia's NG supply. Diversification concerns are less rigid for the second group, as its members already have the opportunity to obtain NG through LNG shipping from different regions of the world and have access to alternative pipelines.

2.1.2. NG Infrastructure

Infrastructure refers to all technological facilities belonging to the NG's value chain:

- Exploration and production (E&P);
- Transport and storage (T&S);
- Distribution;
- Consumption.

Clearly, T&S plays a crucial role on the security of NG supply. Transportation connects non-European NG producers with the old continent and is organized according to high-pressure pipelines [12] and LNG shipping [13]. Since the European NG demand is characterized by a seasonal trend, storage is required to balance peak (i.e., winter) and off-peak (i.e., summer) periods, and should enable an efficient use of existing infrastructures. Although it canonically emerged from the field of regulatory economics, an alternative terminology can be used to divide the organization of NG's value chain into three categories:

- Upstream;
- Midstream;
- Downstream.

Corridors. There are four main corridors:

- Southern gas corridor (SGC) in the Caspian region, which comprises non-Russian NG pipelines predominantly located in Azerbaijan and Turkmenistan [14];
- New Russian pipelines, namely Turk Stream and Nord Stream 2 [15,16];
- North African pipelines, including Trans-Mediterranean, Medgaz and Maghreb–Europe [17]; Emphasis should be given to Algeria's strategic position as a gate to European NG market as long as its NG pipeline system is linked to the largest African NG source in the future, which is located in Nigeria. The Trans-Saharan NG pipeline is a 4400 km pipeline project that pretends to interconnect Nigerian NG fields with European NG markets through the Iberian Peninsula [18];
- East Mediterranean gas corridor (EMGC), including the Leviathan NG field in Israel and others in Jordan [19,20].

Capital and operating expenditure. The option to invest in network infrastructures requires data assumptions on capital expenditure (CAPEX), transportation costs and operational expenditure (OPEX). There is a limited amount of available data to satisfy this purpose and the accurate prediction of costs is frequently case-specific according to explanatory factors such as terrain slope, number of compressors and pressure of the pipeline, which has assisted some authors to develop approaches to estimate them [21–23].

Ownership. European NG is totally liberalized, and there is the possibility of unbundling in upstream, midstream and downstream markets [24]. In such a context, investment behavior and the strategic decision of stakeholders are likely to have a decisive role on the security of NG supply [25]. Additional sources of concern in relation to ownership include underperforming expected returns [26]. In the European contemporaneous context, which is imminently characterized by energy transition and decarbonization goals, the authors in [27] analyze stranded assets to conclude that NG demand is likely to decrease, namely in the power sector, which will lead to the risk of stranded assets in NG power plants. Notwithstanding, the authors clarify that NG power plants can provide flexibility in the future energy system, and that switching from NG to either biogas or hydrogen may provide reliable option for the energy transition. Indeed, McKinsey in [28] confirms the competitive situation of renewable energies to NG power plants in Europe.

Storage. According to [10], the essence behind storage is to ensure a greater level of security in the NG supply, thus acting as an immaterial asset with insurance value since it helps mitigate price effects that are caused by supply shocks in the short run. In general, technological characteristics of storage differ according to the type of existing geological features, as these characteristics have influential power over the maximum NG volume that can be stored, injected and withdrawn [29]. For instance:

- The reservoir rock of depleted NG fields is porously and drives the need for a higher volume of cushion gas;
- Salt caverns are located underground, but they are characterized by impermeable rocks;
- Aquifers transport groundwater through porous rocks and can store NG.

2.1.3. NG Demand

In two elegant reflections about the future of NG demand, authors in [12,30] confirm that several sources of uncertainty exist. Interestingly, both studies confirm that Norwegian NG exports are likely to decline to nearly 90 billion cubic meters (bcm) per annum between 2030 and 2035. Regarding the set of environmental and sustainability targets defined in the 2015 Paris Agreement, the Ten-Year Network Development Plan (TYNDP) of the European Network of Transmission System Operators for Gas (ENTSO-G) appeals for the imposition of Slow Progression [31]. According to [32], a Slow Progression paradigm assumes that the energy policy perspective for 2050 is not realistically achievable, so that less ambitious green targets should be pursued by policymakers. In this study, projections indicate a decrease in domestic European gas production of 12% of the EU's gas demand by 2030. Intuitively, it is claimed in [31] that establishing a less intensive adoption of renewable energy targets is necessary to ensure that these are effectively met. In fact, authors in [33] provide a meta-regression analysis of 36 studies to identify drivers of NG demand. The authors conclude that studies with predefined targets tend to predict a strong decline in NG demand, while studies without predefined targets tend to reveal that NG demand is stable. In this sense, NG demand is likely to be dependent on the ongoing energy transition combined with the objective of reducing carbon dioxide (CO_2) emissions. In a study focused on the UK, it is claimed in [34] that the technological option of capture carbon and storage (CCS) may cause a delay in the NG phase-out in UK energy systems by concluding that NG demand decreases:

- 50–60% compared to the 2010 demand with CCS; and
- 10% compared to the 2010 demand without CCS.

These results are clearly more pessimistic once confronted with the Slow Progression scenario exposed in [31], which identifies a reduction of 8% between 2015 and 2045.

2.1.4. NG Production

Conventional reserves. According to [35], it is realistic to observe a decline in the European NG production due to the exhaustion of NG resources and announced political decisions (e.g., initial statements of the Dutch government regarding the reduction of NG production were conducted in 2018 after a series of earthquakes in Groningen). Indeed, Reuters in [36] mentions that NG production in the Netherlands will be completely stopped in 2030, while Reuters in [37] confirms that the NG production's end will occur in October 2023, not only to eliminate the risk of earthquakes, but also because of the technological progress in converting high calorific NG imports into low calorific NG. Additionally, the authors in [38] argue that European consumers should not be worried about this event given the presence of several diversification options that ensure NG supply. As suggested in [39], a country-specific analysis of potential NG suppliers for Europe identifies that, with the extension of LNG infrastructure, several countries became NG exporters to Europe, namely the United States of America (USA), Qatar, Trinidad and Tobago, Nigeria and Peru. In addition to the total production capacity, the security of NG supply depends on the reaction to demand and supply shocks. Unsurprisingly, the daily production capacity is a key indicator that, nevertheless, is likely to be heterogenous. As expressed in [39], some NG suppliers produce a fixed daily production ratio, while others are more flexible in market incentives being, thus frequently denoted as swing suppliers (e.g., Norway). Moreover, NG production can be influenced by geopolitical conflicts and economic interests [40].

Unconventional reserves. The extraction of unconventional NG (i.e., shale gas) has gained a key relevance in the last couple of decades, particularly after the USA shale gas boom in the beginning of the 21st century [41], as this allowed the USA to move from NG importer to LNG exporter [42]. Afterwards, several studies tried to assess whether a similar event could occur in Europe [43,44]. Despite the high amount of unconventional NG resources in France and Poland, the E&P of European shale gas is unable to compete with conventional NG resources [45,46].

Alternatives to conventional and unconventional reserves. The current discussion regarding decarbonizing the energy system brings new technologies into the spotlight, namely:

- Synthetic NG, which stems from the use of hydrogen (H_2), CO_2 and biomass gasification [47];
- Green gas, which is based on renewable energy sources by considering electrolysis;
- Blue gas, which is based on NG steam methane reforming (SMR), while including CCS in the production process [48];
- Biogas, which is biomethane produced from plants and injected in NG network infrastructures [49];
- Other colored gases, such as turquoise gas (i.e., pyrolysis), pink or red (i.e., nuclear), grey (i.e., steam-methane reforming including CO_2 emissions), black (i.e., hard coal), brown (i.e., lignite), orange (i.e., biogas), yellow (i.e., electricity mix) and white (i.e., H_2).

2.1.5. NG Modeling Approaches

Two modeling approaches are normally used to explain NG price and demand:

- Linear programming (LP) and mixed integer programming (MIP) models, which include PERSEUS-EEM [50], GAMAMOD-EU [39] and multiple other approaches to analyze congestion and decarbonization, among other topics [51,52];
- Nonlinear optimization, simulation and heuristic (NLSH) models, which include RAMONA [53], discounted objective functions to optimize investment realization [54] and pricing [55], GASMOD [56], GASTALE [57–59], spatial partial equilibrium in a Hotelling city [60,61] and conjectural variation [62], GaMMES [63], EGMM [64], GGM [65], WGM [66,67], COLUMBUS [68], INGM [69], BIWGT [70], FRISBEE [71], MultiMOD through a mix complementarity problem [72], MIT EPPA [73], DYNAAMO [74], complex network theory in the form of minimum spanning tree [75] and DISCOMP [76], GEMFLOW [77,78] and a panoply of nonlinear approaches reviewed in [79], including [80–88].

Interestingly, econometric regression models seem to be rarely used to explain the behavior of NG price and demand, probably due to the lack of available data and the recent development of statistical techniques to deal with causality and cointegration in the context of panel data. With that being said, the main formal contribution of this study is to provide an analysis of influencing factors on European NG prices via a parametric analysis in the form of a VAR-VECM model in the context of panel data. To the best of our knowledge, such an empirical application to European NG markets is performed for the first time in this study, constituting thus a valuable technical improvement to the existing literature.

2.1.6. LNG

Liquefaction, shipping and regasification. Due to the increased share of NG in the energy mix, LNG infrastructure has increased over the last several decades. Around one-third of global NG trade is LNG, in large part because of new LNG exports from the USA and Australia [89]. In 2018, LNG exports were available in 20 countries, while LNG imports occurred in 42 countries [90]. Consequently, NG systems in Europe may have the incentive to consider the improvement of liquefaction, shipping and regasification capacities in the near future to ensure a diversification of NG supply.

Liquefaction requires that NG be cooled up to a temperature of around −161 °C, which implies that its volume is compressed down to 1/600 of the NG volume under regular conditions [39]. Shipping embraces technological components with direct effects on the economic efficiency. LNG shipping exhibits differentiated characteristics at the level of:

- The containment system (e.g., membrane; moss type);
- The propulsion type (e.g., steam turbine; dual fuel − diesel electric),

which are likely to affect transportation costs [91].

With the increasing spot market trading volume, flexible LNG shipping is acquiring a considerable notoriety to avoid arbitrage opportunities between USA, European and Asian NG markets. Most LNG trading activities depend on long-term contracts, while the number of short-term contracts with flexible destinations remains low [39]. Nevertheless, the author in [92] confirms that two stylized facts are observed in shipping:

- An increase of flexible destination contracts;
- An ongoing structural change in favor (detriment) of short-term (long-term) contracts, respectively.

Regasification is the process through which LNG is unloaded from the vessel and reinjected either into storage or directly to the pipeline system [93]. Terminals are either located onshore or near shore, in floating storage and regasification units (FSRUs). While onshore terminals provide a permanent solution and additional security, FSRUs allow for fuel switching and greater flexibility in regions with space constraints and low level of CAPEX realization [39]. Notwithstanding, terminals have the advantage of decreasing the dominant position of Russia's NG supply [94].

From a practical point of view, LNG trading activities enable flexibility compared to high long-term investments and connect global gas hubs in the USA, Europe and Asia to balance NG prices globally [39]. In Europe, a large amount of CAPEX realization is needed to build LNG terminals, which also requires high OPEX realization due to the intensive process of liquefaction and regasification. This energy option is potentially advantageous because it can participate in the LNG market [95]. An assessment of cost components for LNG facilities and operations is provided in [96], which indicates that the most relevant OPEX components are fuel gas (58%) and maintenance (24%), as well as consumables, staff for vessels and insurance (18%).

2.2. Data

We start by analyzing all information available in the Eurostat database related to NG. Each dataset comprises several dimensions (i.e., indicators), whose description is detailed in Table 1. Additionally, Table A1 in Appendix A shows the periodicity of retrieved data. NG prices can have many indicators due to the large number of possible combinations. A possible indicator could result from combining the type of unity given in gigajoules 'GJ_GCV' with the type of consumption (e.g., band 1, which is below 20 GJ), and incorporate taxes [5]. Unlike NG prices, most of the remaining indicators are annual. Hence, this study deals with a strongly balanced dataset, whose dependent and independent variables exhibit different periodicities.

Table 1. Selected variables from the Eurostat database.

Variables	Description
Prices.TAX	Gas price for households for type of consumption D1, type of unit gigajoule ('GJ_GCV') and with taxes
Prices.VAT	Gas price for households for type of consumption D1, type of unit gigajoule ('GJ_GCV') and without taxes
Prices.TTF	Gas price obtained from virtual trading TTF
SEM	Type of semester: 0:1st and 1:2nd semester
YEAR	Specific year since 2007 with values collected
GEO	European country entered in the study
REN	Share of energy from renewable sources by country
IMP_GAS	Import of gas in million cubic meters (mcm)
EXP_GAS	Export of gas in mcm
TOT_DEP	Total energy imports dependency
GAS_DEP	NG imports dependency
LNG_DEP	Liquefied NG imports dependency
IMP.GAS.Rus	Import of NG from Russia
IMP.GAS.No	Import of NG from Norway
IMP.LNG.QA	Import of LNG from Qatar
IMP.LNG.DZ	Import of LNG from Algeria.
IMP.LNG.NG	Import of LNG from Nigeria.
EXP.GAS.DE	Export of NG by Germany.
IMP.GAS.Rus.Perc	Import of NG from Russia in percentage.
IMP.GAS.No.Perc	Import of NG from Norway in percentage.
STK	Opening stock–national territory
NETC	Network costs
NRG_SUP	Energy and supply
TAX_ENV	Environmental taxes
TAX_FEE_LEV_CHRG	Taxes, fees, levies and charges
TAX_RNW	Renewable taxes

This study restricts the focus on NG prices belonging to the segment of households, which comprises biannual data from 2007 onwards. Reference periods are from January to June for the first semester and from July to December for the second semester. The analysis is predominantly focused on NG prices, while considering that NG consumption values are measured in gigajoules–gross calorific value (GJ). Hence, the unit of measure applied to NG prices is €/GJ.

We also collect information regarding NG prices in the spot market. The virtual trading TTF located in the Netherlands clearly stands out, as it is the European market that exhibits the highest liquidity. Other examples of spot prices in Europe are Zeebrugge Hub (ZEE) in Belgium and Punto di Scambio Virtuale (PSV) in Italy [97].

2.3. Nonparametric Analysis

Let us provide the mathematical background behind the nonparametric analysis applied to the relevant set of indicators exposed in Table 1. The exploratory data analysis follows a four-step procedure, which is described as follows:

- Firstly, we compare NG prices by the type of consumption, while considering or not the inclusion of taxes;
- Secondly, we identify similarities between NG prices between the 34 European countries (i.e., between variation), time effects in their progression (i.e., within variation) and briefly inspect the presence of seasonality effects;
- Thirdly, we confront country-level prices and TTF prices;
- Finally, we assess how the share of renewables has evolved since 2007, as well as the evolution of imports and exports of NG and LNG, energy dependence according to the type of partner, analyze stock levels and components of NG prices.

Regarding the first and third steps, we use Spearman's rank correlation coefficient, which allows us to measure the dependence between the ranking of two variables by quantifying the strength and direction (i.e., whether it is linear or not) of their monotonic relationship. While Spearman's rank correlation coefficient measures the strength of association between two ranked variables, Pearson's correlation coefficient gives the intensity between two variables [98].

Spearman's correlation coefficients have similar properties to Pearson's correlation coefficients. However, unlike Pearson's correlation coefficients, Spearman's correlation coefficients do not impose a requirement on normality. Naturally, there are some weaknesses that can be pointed out, such as:

- Spearman's correlation coefficients only describe a linear relationship between two variables rather than contemplating nonlinear relationships;
- Spearman's correlation coefficients cannot be used to measure the association between two variables, whose distribution is given through grouped frequency tables; and
- Computations times are lengthy when the number of variable pairs is above 30.

Spearman's rank correlation coefficient (r) formula is given by

$$r = 1 - \frac{6\sum_{i=1}^{n} d_i}{n(n^2 - 1)}$$

where d_i correspond to the difference of ranks between two variables. Correlation can have values from -1 to +1, where -1 means negative (inverse) correlation and +1 means positive correlation. Values close to 0 represent independency between variables [98].

Regarding the second step, we consider hierarchical clustering analysis using Ward's method as linkage criteria under the Euclidean distance metric. Hierarchical clustering methods put elements into clusters based on similarity patterns [99]. This method can be either agglomerative or divisive [100]. Ward's method is agglomerative since it collects elements into groups (i.e., clusters) in order to classify observations and create new groups. The optimization procedure is executed, while ensuring that the variance within clusters is minimized [101]. Formally, the Euclidean distance between two clusters (k and l) using normalized values for the total number of observations is given by

$$d(k,l) = \sum_{j=1}^{q} \left(m_{kj} - m_{lj} \right)^2$$

Observations of minimal distance to each other will be unified into a new cluster $(k + l)$. If the new cluster exists, the distance must be redefined toward all other observations (a). Different clustering methods use different algorithms for calculating new distances. The optimal minimum distance for a given number of observations in the cluster is calculated as follows [100]

$$d(a, k + l) = \frac{(N_a + N_k) \times d(a,\ k) + (N_a + N_l) \times d(a,\ l) - N_a \times d(k,l)}{N_a + N_k + N_l}$$

where N_a corresponds to the number of observations (a) in the cluster, N_k is the number of observations (k) in the cluster and N_l is the number of observations (l) in the cluster. From the corresponding dendrogram, it is possible to identify similarities among countries and time periods. Finally, the fourth step results from simple descriptive statistics.

2.4. Parametric Analysis

2.4.1. Preliminary Econometric Tests

Before moving to the VAR-VECM analysis in the context of panel data, preliminary econometric tests are applied to guarantee the satisfaction of classical hypotheses. In particular, we check:

- Specification through the Ramsey regression equation specification error test (RESET) test;
- Multicollinearity through variance inflation factor (VIF) statistics;
- Homoscedasticity through the Breusch–Pagan test;
- Absence of autocorrelation through the Breusch–Godfrey test;
- Exogeneity of regressors through the endogeneity procedure provided in [102];
- Stationary of each time component in the panel data by considering Harris–Tzavalis (HT) [103] and Im–Pesaran–Shin (IPS) [104] panel unit root tests.

2.4.2. VAR-VECM Panel Data Model Analysis

The analysis of cointegration and causality between the variables of interest follows a standard two-step procedure:

- Firstly, we analyze the cointegration between variables of interest by employing the Westerlund Error Correction Model (WECM) panel cointegration regression and respective statistical tests [105];
- Secondly, we analyze the Granger causality between the variables of interest by applying the Dumitrescu-Hurlin (DH) panel Granger causality regression and respective statistical tests [106].

A VAR panel equation serving as the basis to perform these panel unit root tests is formally given by

$$\Delta y_{it} = \beta y_{i,t-1} + \alpha_{mi} d_{mt} + \mu_{it,}\ i = 1, \ldots, N; t = 1,\ \ldots,\ T; m = 1,2,3 \quad (1)$$

where d_{mt} allows different specifications (e.g., time-fixed effects, unit-specific effects) to be implemented, with $d_{1t} = \{\}$ representing the empty set in which no fixed effects are imposed, and thus, corresponding to the case of a homogeneous panel, $d_{2t} = \{1\}$ includes individual fixed effects. This allows for heterogeneity across units, and $d_{3t} = \{1, t\}$ includes both individual and time fixed effects.

Panel cointegration is a statistical method to investigate the long run relationship between variables in a given system of endogenous variables. In this study, WECM panel cointegration tests are used to satisfy this purpose. Following [107], we assume the data generating process

$$\Delta y_{i,t} = \delta_i' d_t + \alpha_i \left(y_{i,t-1} - \beta_i' x_{i,t-1} \right) + \sum_{j=1}^{p_i} \alpha_{i,j} \Delta y_{i,t-j} + \sum_{j=-q_i}^{p_i} \gamma_{i,j} \Delta x_{i,t-j} + \epsilon_{i,t} \quad (2)$$

where $t = 1, \ldots, T$ and $i = 1, \ldots, N$ index the time series and cross-sectional units, respectively. In turn, d_t contains a deterministic component that can accommodate three cases:

- $d_t = 0$ such that Equation (2) has no deterministic terms;
- $d_t = 1$ such that $\Delta y_{i,t}$ is generated with a constant;
- $d_t = (1, t)'$ such that $\Delta y_{i,t}$ is generated both with constant and trend.

The K-dimensional vector $x_{i,t}$ is modeled as a random walk for the sake of simplicity, so that $\Delta x_{i,t}$ is independent of $\epsilon_{i,t}$. It is assumed that these errors are independent across i and t. Any dependence across i is handled by applying bootstrapping. Equation (2) can be rewritten as follows

$$\Delta y_{i,t} = \delta_i' d_t + \alpha_i y_{i,t-1} + \lambda_i' x_{i,t-1} + \sum_{j=1}^{p_i} \alpha_{i,j} \Delta y_{i,t-j} + \sum_{j=-q_i}^{p_i} \gamma_{i,j} \Delta x_{i,t-j} + \epsilon_{i,t} \quad (3)$$

where $\lambda_i' = -\alpha_i \beta_i'$. The parameter α_i determines the speed at which the system corrects to the long run equilibrium relationship $y_{i,t-1} - \beta_i'\, x_{i,t-1}$ after a sudden exogenous shock. If $\alpha_i < 0$, then there is error correction, which implies that $y_{i,t}$ and $x_{i,t}$ are cointegrated; if $\alpha_i = 0$, then there is no error correction and, thus, no cointegration. Hence, the null hypothesis of no cointegration is $H_0 : \alpha_i = 0$ for all i. The alternative hypothesis depends on what is being assumed about the homogeneity of α_i. Group-mean tests G_t and G_a do not require α_i to be equal across units, which means that H_0 is tested against $H_1^G : \alpha_i < 0$ for at least one i. Panel tests P_t and P_a assume that α_i is equal for all i, which means that H_0 is tested against H_1^P for all units of the panel.

Regarding the Granger causality analysis, we consider the DH test developed in [106], which is a modified version of the seminal model presented in [108]. Under the presence of stationary series, it is formally given by

$$y_{i,t} = \delta_i^{'} d_t + \alpha_i \sum_{k=1}^{K} \gamma_i^k y_{i,t-k} + \sum_{k=1}^{K} \beta_i^k x_{i,t-k} + \epsilon_{i,t} \tag{4}$$

with $K \in N^*$ and $\beta_i = \left(\beta_i^1, \ldots, \beta_i^k\right)'$. The lag order K or, similarly, the number of K lags is identical for all units of the panel. The optimal number of lags to include in the panel autoregressive model is not discussed in [106], but authors in [107] highlight that this topic should not be neglected by econometricians. Autoregressive parameters γ_i^k and coefficients β_i^k can differ across units despite being constant in time. As such, their Stata routine allows to select the optimal number of lags in order to minimize either the Akaike Information Criterion (AIC), the Bayesian Information Criterion (BIC), Hannan–Quinn information criterion (HQIC) or any other. The null hypothesis of the DH model assumes noncausality in all panels: $\beta_i = 0, \forall i = 1, \ldots, N$. The alternative hypothesis of the DH model assumes causality in some panels:

$$\begin{cases} \beta_i = 0, \ \forall i = 1, \ldots, N_1 \\ \beta_i \neq 0, \ \forall i = N_1 + 1, \ldots, N \end{cases}$$

where N_1 is unknown but satisfies the condition $0 \leq N_1/N < 1$. Indeed, authors in [107] propose to associate the Wald statistics averaged across units to the test of the noncausality hypothesis for units $i = 1, \ldots, N$ such that the average Wald statistic of the panel is given by

$$W_{N,T} = \frac{1}{N} \sum_{i=1}^{N} W_{i,T}$$

where $W_{i,T}$ is the standard adjusted Wald statistic for unit i calculated over T periods. Although individual Wald statistics converge to a χ^2-distribution with K degrees of freedom, the authors show that the distribution of the average Wald statistic when $T \to \infty$ and $N \to \infty$ can be deduced from the Lindberg–Levy central limit theorem as long as the convergence of T and N is sequential, thereby implying that $W_{N,T}$ converges to a limit value $Z_{N,T}$ given by

$$Z_{N,T} = \sqrt{\frac{N}{2K}} (W_{N,T} - K)$$

that asymptotically follows a distribution $N(0,1)$. Moreover, authors in [107] propose a $\widetilde{Z}$-statistic that allows for a fixed T dimension under the assumption that $T > 5 + 2K$, whose standardized average value is given by

$$\widetilde{Z}_{N,T} = \sqrt{\frac{N(T - 2K - 5)}{2K(T - 2K - 3)}} \left[\frac{N(T - 2K - 3)}{2K(T - 2K - 1)} W_{N,T} - K \right]$$

and asymptotically follows a distribution $N(0,1)$ when $N \to \infty$. This statistic was closely examined by running Monte Carlo simulations. Their conclusion is that it has very good properties even for small T and N. They also reveal that their standardized panel statistics have good small sample properties even in the presence of cross-sectional dependence.

3. Results

3.1. Nonparametric Analysis

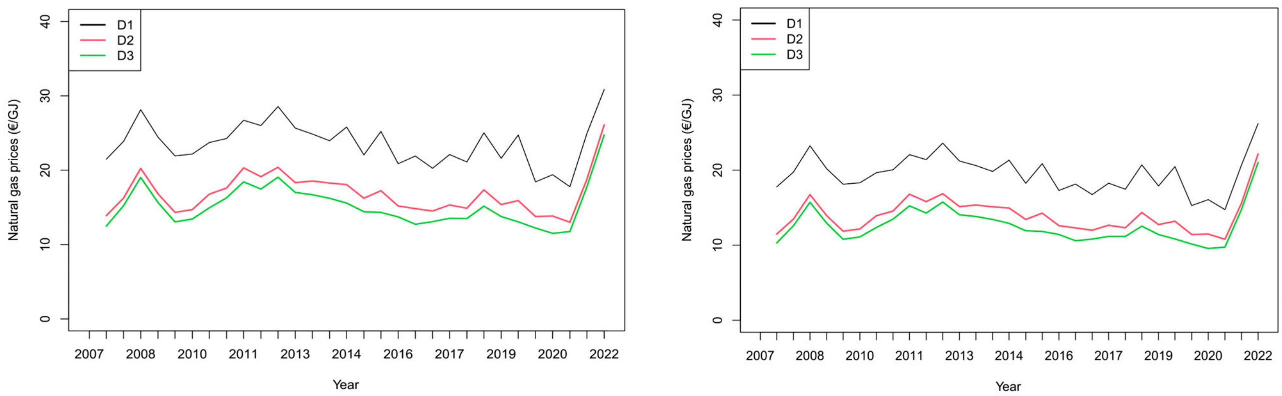
3.1.1. NG Prices in the Segment of Households

General evolution. There are three types of consumption (i.e., bands). In terms of market shares:

- Band D1 represents nearly 75% of the market;
- Bands D2 and D3 have similar shares, with proportions around 12.5%.

These have remained unchanged since 2017. Knowing that taxation is a dimension of NG prices, we analyze the evolution of NG prices when taxes and levies are included ('I_TAX') and when taxes and levies are excluded ('X_TAX').

NG prices for D1, D2 and D3 bands are presented in Figure 1a,b, and allow us to conclude that NG prices are always higher for the D1 band. Moreover, NG prices have changed in the same proportion for all bands when comparing prices with and without taxation. This conclusion is confirmed by the Spearman's rank correlation coefficients shown in Table 2. Indeed, there are high association rates for all possible combinations, with values above 0.80.



(**a**) (**b**)

Figure 1. Evolution of NG mean price for D1, D2 and D3 bands (2007–2022): (**a**) with taxation; (**b**) without taxation.

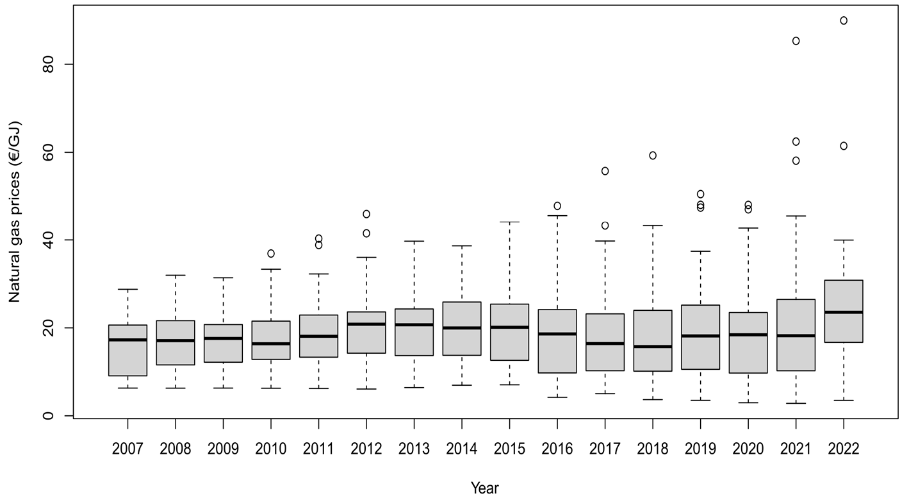
Table 2. Spearman's rank correlation coefficients.

	Prices.TAX_D1	**Prices.TAX_D2**	**Prices.TAX_D3**	**Prices.VAT_D1**	**Prices.VAT_D2**	**Prices.VAT_D3**
Prices.TAX_D1	1					
Prices.TAX_D2	0.867 ***	1	0.961			
Prices.TAX_D3	0.812 ***	0.961 ***	1			
Prices.VAT_D1	0.994 ***	0.843 ***	0.788 ***	1		
Prices.VAT_D2	0.871***	0.991 ***	0.952 ***	0.861 ***	1	
Prices.VAT_D3	0.812 ***	0.948 ***	0.990 ***	0.803 ***	0.958 ***	1

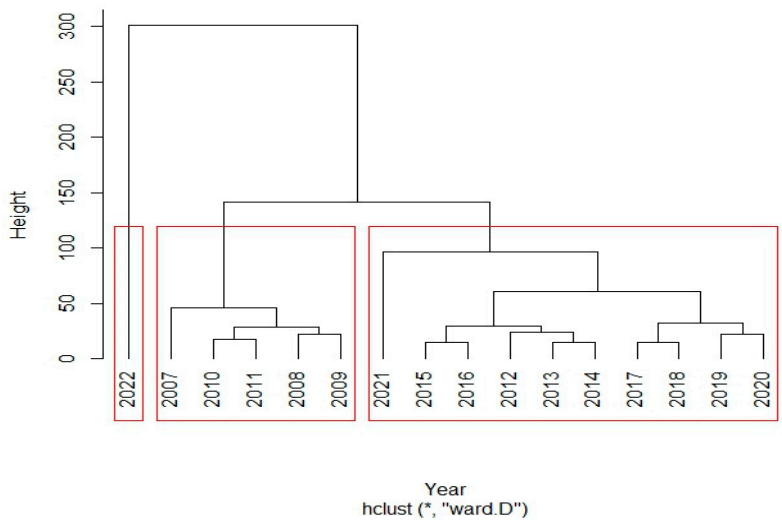
Notes: NG prices for D1, D2 and D3 bands with taxation ('TAX') and without taxation ('VAT'). Symbol *** stands for significance at the 1% level.

Within variation. Hereinafter, the focus relies on NG mean prices for the D1 band since it is the most representative type of consumption for the segment of households. When analyzing the within variation clarified in Figure 2a, the existence of three moments in terms of pricing trends become evident:

- The first corresponds to a progressive increase of prices until 2013;
- From that moment on, prices slightly decreased until 2020;
- After 2021, prices increased exponentially.



(**a**)



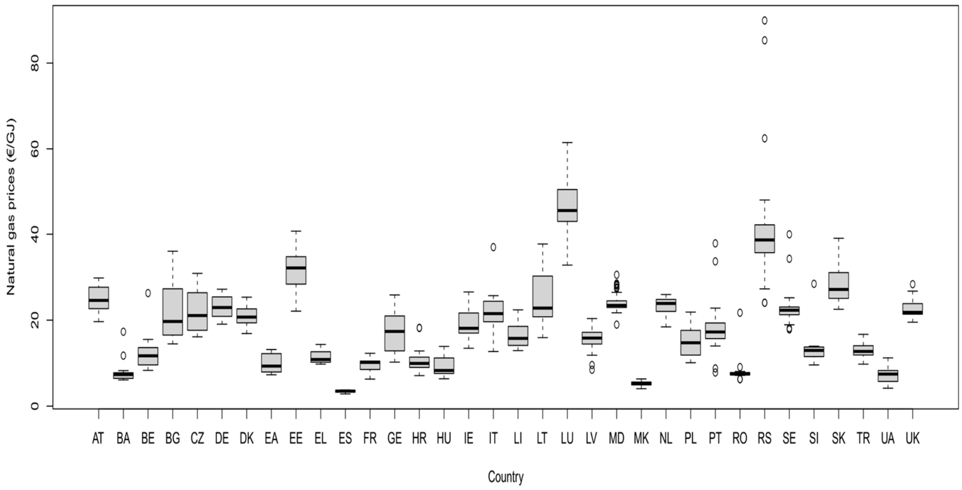
(**b**)

Figure 2. Natural gas mean price for the D1 band (2007–2022): (**a**) within variation captured by boxplots; (**b**) within variation captured by a dendrogram.

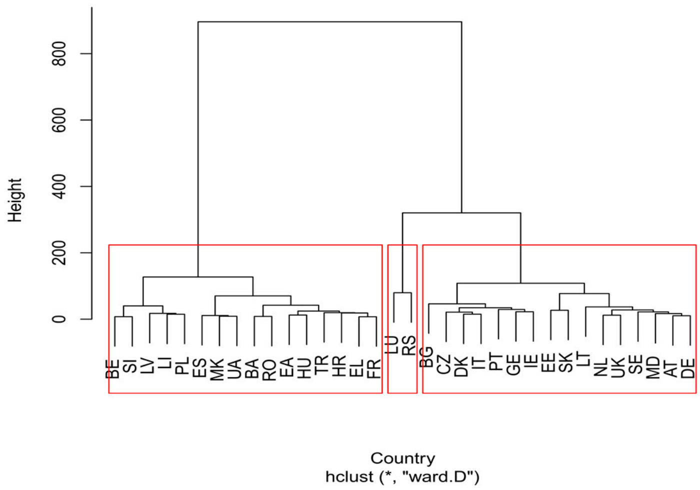
The existence of three distinct pricing periods is confirmed by applying a hierarchical cluster analysis. Figure 2b reveals that NG prices are clearly differentiated in 2022, which corresponds to an outlier year characterized by galloping prices. Moreover, 2007–2011 corresponds to a period of price increases, whereas 2012–2021 is a period characterized by price reductions.

Between variation. Between variation is observable in Figure 3a, which reveals a high variability of NG prices among the 34 spatial units. Figures 3b and 4b allow three distinct clusters to be recognized:

- A first group is composed by Luxembourg and Serbia, which exhibit the highest prices;
- Countries belonging to the second group correspond to those with intermediate NG prices; this second group is composed by Bulgaria, Czechia, Denmark, Italy, Portugal, Georgia, Ireland, Estonia, Slovakia, Lithuania, Netherlands, United Kingdom, Sweden, Moldova, Austria and Germany;
- A third group comprises countries with the lowest prices, namely Belgium, Slovenia, Latvia, Liechtenstein, Poland, Spain, North Macedonia, Ukraine, Bosnia and Herzegovina, Romania, Hungary, Turkey and France.

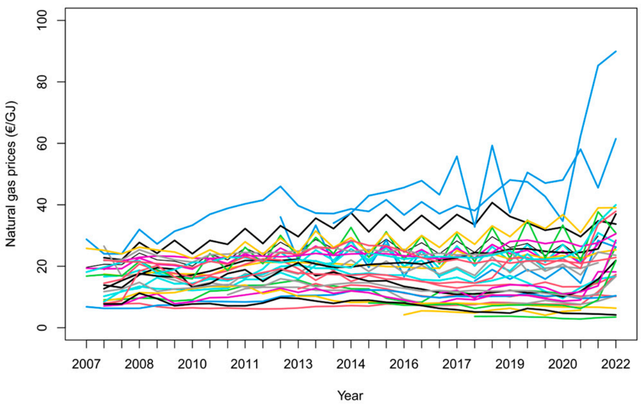


(**a**)

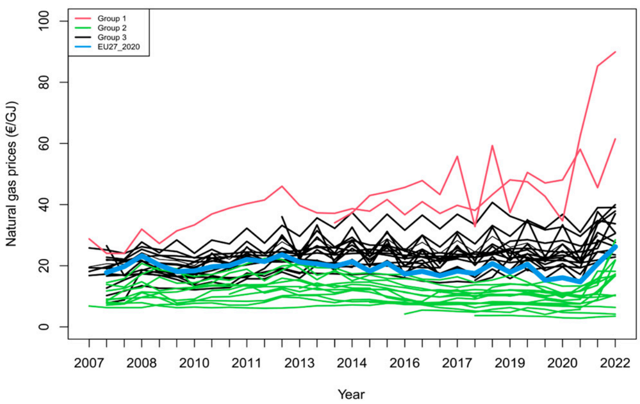


(**b**)

Figure 3. Natural gas mean price for the D1 band (2007–2022): (**a**) between variation captured by boxplots; (**b**) between variation captured by a dendrogram.



(**a**)



(**b**)

Figure 4. Natural gas mean price for the D1 band (2007–2022): (**a**) without clustering; (**b**) with clustering.

At this point, it is important to emphasize that the objective of any HCA is to identify groups instead of presenting causes for the set of clusters that are endogenously formed. Otherwise, the formation of clusters would not belong to the nonparametric analysis part of the study, but rather to the parametric analysis section. In this way, the only validation that needs to be performed is the Kruskal–Wallis test, which checks for the independence—or lack thereof—of NG prices related to the three groups of spatial units endogenously determined. It follows that the Kruskal–Wallis test (H = 623.780, $p < 0.001$) clearly rejects the null hypothesis by claiming the inexistence of mean differences in NG prices among the three groups of countries. Therefore, these groups are independent from each other at the NG pricing behavior level. Although it is unnecessary, we also provide the results of the Mann–Whitney test, which is used to assess 2 × 2 comparisons. Once again, the existence of significant mean differences between groups is confirmed ($U_{G3,G2}$ = 18,667, $p < 0.001$; $U_{G3,G1}$ = 21,696, $p < 0.001$ and $U_{G2,G1}$ = 6355, $p < 0.001$).

Figure 4a displays pricing trends for each European country. As confirmed by the hierarchical cluster analysis displayed in Figure 3b, Luxemburg and Serbia stand out from the remaining spatial units. NG prices increased exponentially around the second semester of 2021 and remained high during the first semester of 2022. Figure 4a,b highlight that, despite the high variability of NG prices between 2012 and 2020, which are mostly due to clusters 1 and 2, these remained similar across the spatial units belonging to the sample. Table A2 in Appendix A provides additional details for the period after 2018. These patterns changed after 2020 because Europe faced two unprecedented events:

- The COVID-19 pandemic;
- The invasion of Ukraine by Russia in February 2022.

Moreover, clustering results obtained in this study for European NG prices can be explained from a normative point of view. In order to clarify the evolution and potential drivers of household prices in the sample under scrutiny, we must be aware that NG markets differ sharply among European countries both during the examined period and currently. Globally, the market composition is very different, with each of the main consumption sectors playing a very different role as climatic, economic, and social conditions differ. Storage capacity, suppliers' mix, interconnections, market structure and downstream price regulation are crucial elements to explain the formation of three independent groups of NG prices. In our sample, which includes countries outside the EU, market organization varies from pure monopoly to perfect competition and even full competitive markets show diverse organization profiles.

Until 2022, market liberalization in EU countries have led to a reduction of interest for NG price regulation, at least for the wholesale market. Although the principle of free supplier choice for final consumers has been introduced by the 1998 Gas Directive, only in July 2007 it was fully opened for households. Even so, national markets' maturity, competition and political intervention have created different outcomes. According to the European Agency for the Cooperation of Energy Regulators (ACER) and the Council of European Energy Regulators (CEER), the share of European households subject to price controls was 49% in 2008 and 25% in 2015 [109]. Assuming the markup to be a reliable indicator of the theoretical gross profitability of suppliers, as well as an indicator of the level of responsiveness of retail energy prices to changes in upstream prices, the abovementioned organizations recognize that NG markets for households still exhibit huge differences in the EU, despite the average markup has decreased 157% compared to the 2014–2020 average [110]. It should be noted that the markup differs from profit because suppliers have additional operating costs (e.g., marketing, consumer services, overheads) in bringing a service or bundle to the retail market. Concentration level is also an important driver of household prices. In 2021, eleven countries registered a reduction in their concentration levels. Greece and France reduced their Herfindahl–Hirschman Index (HHI) the most (−551 and −400 points, respectively). From 2017 to 2021, the strongest reductions can be found in Greece, France and Spain (−19,712, −1600, −791 points, respectively). In 2021, seventeen member states had some form of price intervention for NG household customers, while seven of them (i.e., Belgium, UK, Romania, Slovakia, Portugal, Hungary, Estonia) had a regulatory intervention in price setting for vulnerable customers. These currently represent a market share ranging between 4% and 42%, depending on the European country. From 2007 to 2016, household price controls in Europe were still common:

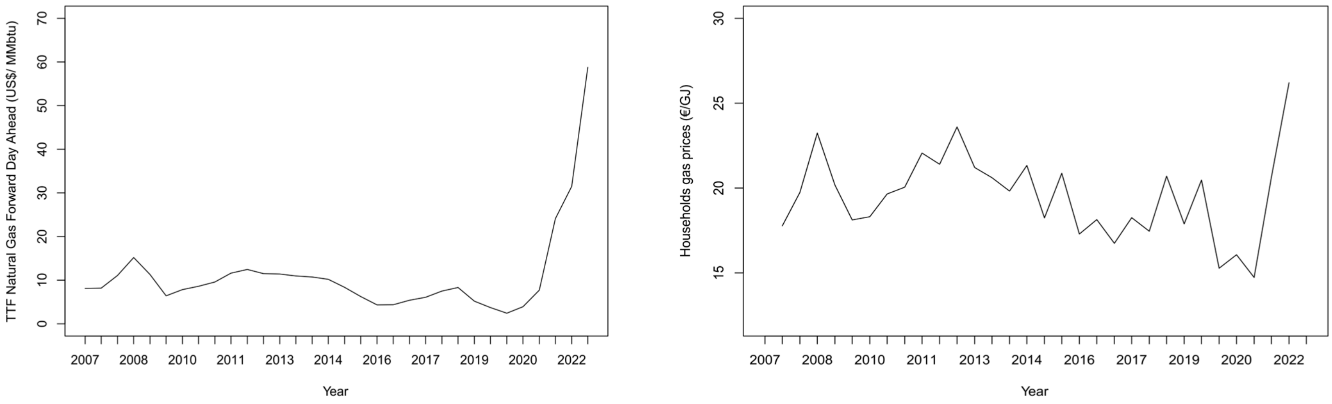
- Regulated prices for the whole retail market in Bulgaria, France, Denmark, Greece, Hungary, Latvia, Poland and Slovakia;
- Regulated prices for the household segment in Croatia, Lithuania, Northern Ireland, Portugal, Romania and Spain;
- Two other countries (i.e., Belgium and Italy) had nonregulated prices, although with (potential) ex ante intervention in price setting. Indeed, nonregulated prices were in place only in Austria, Czech Republic, Estonia, Finland, Germany, Netherlands, Slovenia, Sweden, Republic of Ireland and UK.

Notwithstanding, the combination of drivers with diverse market profiles may lead to some surprising outcomes concerning end-user prices, as those presented by this research. Let us take a closer look at the cluster composed by Serbia and Luxembourg (i.e., cluster 1), where the highest level of NG prices is observed. Currently, NG represents 13% of Serbia's primary energy consumption, which is being imported from two entry points: through the Balkan stream pipeline and from Hungary. Gazprom is the only NG supplier, which means that Serbia's NG market is not open to alternative suppliers. Srbijagas dominates both wholesale and retail markets, with 90% of the market share at nonregulated prices. This indicates a serious case of market concentration, high dependence on a single supplier and political intervention. In turn, Luxembourg's NG market is dominated by a small number of vertically integrated companies. Creos Luxembourg S.A.—formerly known as SOTEG—owns and operates the transmission system, and it supplies most of the market. The majority of Creos' shares are owned by various private utilities, though the State maintains a minority ownership. On the 1 October 2015, Fluxys Belgium and Creos Luxembourg merged the Belgian and Luxembourg H-gas markets into one cross-border integrated gas market. The Belgian L-gas market remains a separated market, which is relevant for explaining the persistence of high NG price levels in Luxembourg.

Mutatis mutandis, a similar line of normative arguments that can be applied to the second cluster of European NG prices. To motivate the reader's interest, two cases can be detailed. Moldova's NG market is entirely monopolized: the majority of functions—imports, supply management, cross-border and national transmission, distribution and retail—are performed by MoldovaGaz and its subsidiaries. MoldovaGaz is owned by Gazprom (50%), the Moldovan government (36.6%) and the Transnistrian administration (13.4%). In Bulgaria, the NG market is monopolized by state players, with the state-owned Bulgargaz holding more than 90% of the market share. Moreover, strong political intervention has introduced serious bias in market development, namely through the imposition of retroactive regulated prices.

3.1.2. NG Prices in the Spot Market

Figure 5 shows all changes in country-level household prices and TTF prices, beginning in 2007. Both NG prices remained similar, with strong associations being confirmed by Spearman's correlation coefficients above 91% until the first semester of 2014. After that point, the association remained high, but dropped to 82%. Along with the evolution of both NG prices, Table 3 shows variation rates by semester and homologous variation rates. Results confirm that, in the first semester of 2020, both prices decreased in almost the same proportion. After that, TTF prices began to increase exponentially, with growth rates of 61%, 97% and 212% in the second semester of 2021.



(**a**) (**b**)

Figure 5. Natural gas prices (2007–2022): (**a**) spot market TTF; (**b**) country-level household.

Table 3. Evolution and growth rates of natural gas mean prices (2007–2022): TTF and country-level households.

Id	Time	Year	TTF Prices ($/GJ)	Household Prices (€/GJ)	TTF Price Rates (%)	Household Price Rates (%)
1	2007/01/01	2007	8.110	NA	0.000	0.000
2	2007/07/01	2007	8.175	17.770	0.801	NA
3	2008/01/01	2008	11.085	19.740	35.596	11.086
4	2008/07/01	2008	15.190	23.240	37.032	17.730
5	2009/01/01	2009	11.293	20.180	−25.655	−13.167
6	2009/07/01	2009	6.417	18.120	−43.177	−10.208
7	2010/01/01	2010	7.842	18.310	22.207	1.049
8	2010/07/01	2010	8.603	19.650	9.704	7.318
9	2011/01/01	2011	9.583	20.050	11.391	2.036
10	2011/07/01	2011	11.610	22.060	21.152	10.025
11	2012/01/01	2012	12.460	21.400	7.321	−2.992
12	2012/07/01	2012	11.502	23.600	−7.689	10.280
13	2013/01/01	2013	11.413	21.210	−0.774	−10.127
14	2013/07/01	2013	10.965	20.610	−3.925	−2.829
15	2014/01/01	2014	10.728	19.820	−2.161	−3.833
16	2014/07/01	2014	10.198	21.330	−4.940	7.619
17	2015/01/01	2015	8.357	18.240	−18.053	−14.487
18	2015/07/01	2015	6.253	20.870	−25.176	14.419
19	2016/01/01	2016	4.337	17.290	−30.641	−17.154
20	2016/07/01	2016	4.370	18.140	0.761	4.916
21	2017/01/01	2017	5.405	16.742	23.684	−7.707
22	2017/07/01	2017	6.085	18.254	12.581	9.031
23	2018/01/01	2018	7.508	17.454	23.385	−4.383
24	2018/07/01	2018	8.322	20.702	10.842	18.609
25	2019/01/01	2019	5.190	17.887	−37.635	−13.598
26	2019/07/01	2019	3.720	20.471	−28.324	14.446
27	2020/01/01	2020	2.435	15.275	−34.543	−25.382
28	2020/07/01	2020	3.920	16.070	60.986	5.205
29	2021/01/01	2021	7.713	14.732	96.760	−8.326
30	2021/07/01	2021	24.097	20.647	212.421	40.151
31	2022/01/01	2022	31.493	26.204	30.693	26.914
32	2022/07/01	2022	58.770	NA	86.613	NA

3.1.3. Share of Energy Emerging from Renewable Sources

Over the last few decades, there has been a common agreement regarding the need to increase the share of energy produced from renewable sources.

Table 4 compiles rate changes since 2004. Along with 2021 data, average values between 2004 and 2010 as well as 2011 and 2019 and growth rates from 2004 to 2021 are presented. Since 2004, an increase of approximately 88% can be observed in the energy production resulting from renewable sources, with the current share standing at 22.1%. Sweden stands out, with 60.1% of energy being produced by renewable sources. Latvia, Austria, Portugal and Denmark also exhibit a high share, namely above 30%. All countries have progressively increased, and some have succeeded in recovering from initial low values. We highlight Luxemburg, the Netherlands and Ireland, which all have growth rates above 300%.

Table 4. Share of energy from renewable sources for each spatial unit belonging to the sample.

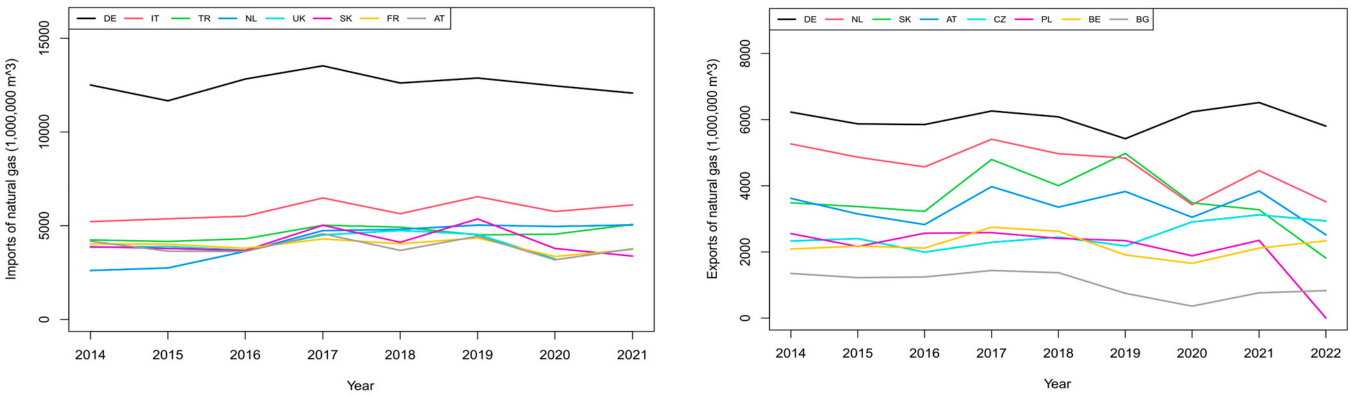
Country	2021 (%)	2011–2019 (%)	2004–2010 (%)	2007–2021 (%)
AT	36.545	33.116	27.480	32.988
BE	13	8.271	3.486	272.936
BG	23.319	18.309	10.456	123.011
CZ	17.303	14.326	8.330	107.730
DE	19.312	14.818	9.210	109.688
DK	31.681	30.454	17.893	77.057
EE	30.069	28.005	19.349	55.403
EL	21.749	15.769	8.162	166.457
ES	21.220	15.956	10.442	103.212
EU27_2020	22.090	17.536	11.874	86.030
FR	19.109	14.661	10.432	83.169
HR	31.023	27.670	23.230	33.548
HU	13.850	14.215	8.612	60.825
IE	16.160	9.043	3.821	322.910
IT	20.359	16.814	9.899	105.676
LT	26.773	23.914	17.803	50.385
LU	11.699	5.163	2.155	442.877
LV	42.132	37.721	31.474	33.863
MD	25.057	25.468	9.078	176.032
MK	19.222	18.386	16.131	19.164
NL	13.999	5.960	3.195	338.193
PL	16.102	12.111	7.593	112.052
PT	33.982	28.578	21.844	55.564
RO	24.478	23.971	19.267	27.047
RS	25.983	21.006	16.075	61.635
SE	60.124	51.805	42.916	40.097
SI	25	21.996	19.541	27.933
SK	17.345	11.979	7.613	127.834

3.1.4. International Trade

NG imports. Table 5 shows NG imports in Europe. Since most spatial units belonging to the sample have a redundant proportion, we only display those that represent more than 1% of total imports and include mean imports of countries belonging to the EU and the Euro Area (EA). Overall, there is a decrease of imports in the period 2020–2022. Germany is the biggest importer, representing around 21% of total imports. Italy and Turkey stand out, with rates around 10% of the total imports. As confirmed in Figure 6a, spatial units belonging to the sample exhibit a stable amount of NG imports when the period of analysis is enlarged to 2014–2022.

Table 5. Natural gas imports since 2014 for some spatial units belonging to the sample.

Countries	Mean	Mean. 2020–2022	Total	Total. 2020–2022	Perc. (%)	Perc. 2020–2022 (%)
EU27_2020	53,198	52,525	90,4365	262,624		
EA	43,714	43,411	74,3136	217,056		
DE	12,625	12,516	21,4629	62,580	20.53	20.9
IT	5868	6042	99,750	30,211	9.54	10.09
TR	4723	5189	80,291	25,945	7.68	8.66
NL	4217	4909	71,690	24,545	6.86	8.2
UK	4064	3224	56,895	6447	5.44	2.15
SK	4004	3275	68,069	16,373	6.51	5.47
FR	3992	3762	67,858	18,809	6.49	6.28
AT	3808	3293	64,740	16,463	6.19	5.5
BE	3795	3713	64,511	18,563	6.17	6.2
PL	3457	3047	58,775	15,235	5.62	5.09
CZ	3106	3541	52,795	17,706	5.05	5.91
ES	3022	2987	51,379	14,937	4.92	4.99
BG	1314	885	22,343	4426	2.14	1.48
HU	1034	838	17,586	4188	1.68	1.4
EL	572	954	9729	4769	0.93	1.59
PT	491	523	8348	2614	0.8	0.87



(**a**) (**b**)

Figure 6. Top-8 European countries enrolled in natural gas international trade activities (**a**) imports; (**b**) exports.

NG exports. Table 6 reveals that Germany is the biggest exporter of NG, with rates close to 21%. Other important exporters of NG are the Netherlands (16.2%), Slovakia (12.9%) and Austria (11.8%). While Germany had an increase of 2.5% since 2020, exports decreased in the remaining spatial units in the sample. As confirmed in Figure 6b, this stylized fact is more pronounced after the first semester of 2020, when NG exports sharply decreased due to the COVID-19 pandemic. We also analyze:

- Imports of NG and LNG according to the preponderance of international trade partners (Tables A3–A5 in Appendix A); and
- Exports of NG according to the preponderance of international trade partners (Tables A6 and A7 in Appendix A).

Table 6. Natural gas exports since 2014 for some spatial units belonging to the sample.

Countries	Mean	Mean. 2020–2022	Total	Total. 2020–2022	Perc. (%)	Perc. 2020–2022 (%)
EU27_2020	27,865	26,215	473,698	131,073		
EA	21,505	20,413	365,587	102,064		
DE	6045	6262	102,757	31,312	21.052	23.549
NL	4655	3859	79,132	19,294	16.212	14.510
SK	3709	3067	63,055	15,333	12.918	11.531
AT	3400	3259	57,799	16,296	11.841	12.256
CZ	2488	2999	42,291	14,995	8.664	11.277
PL	2218	1693	37,703	8467	7.724	6.368
BE	2189	1976	37,211	9881	7.624	7.431
BG	1049	616	17,836	3080	3.654	2.316
UK	961	845	13,447	1690	2.755	1.271
FR	687	885	11,681	4423	2.393	3.326

3.1.5. Energy Dependency

Total dependency. Data confirm that most European countries have an energy deficit. On average, this situation has not changed since the COVID-19 pandemic began. Countries holding the highest total energy dependency are Luxemburg, Ireland, Italy, Belgium, Portugal and Moldova, with rates above 75%. It is equally important to highlight that some countries decreased their dependency in the last years, particularly Portugal (14.12%) and Ireland (12.20%). Overall, the total energy dependency in Europe is around 57%. Estonia and Denmark are the countries with holding the lowest percentage, around 5.62% and 13.87%, respectively. Figure 7 confirms the decreasing trend of energy dependency rates in the subset of European countries that hold the highest total energy dependency.

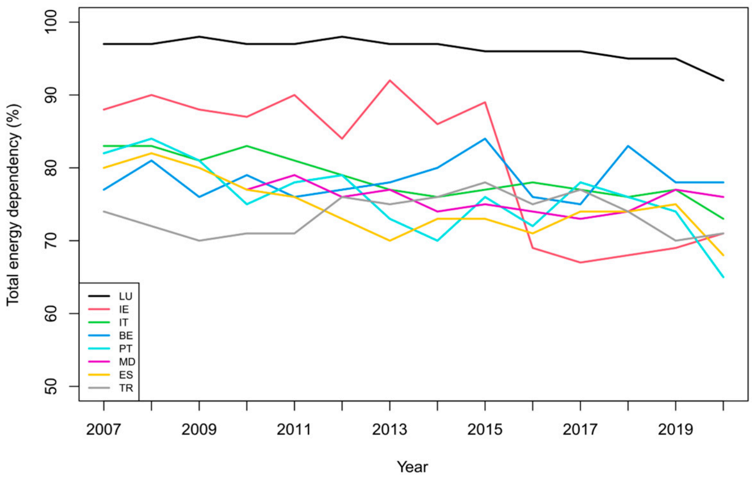


Figure 7. Evolution of the total energy dependency in the top-8 European countries with the highest rate of energy dependency.

NG and LNG dependencies. Table A8 in Appendix A reveals the dependency of NG for each European country. In the EU, deficit rates are around of 75%. Nine European countries are totally dependent on NG and sixteen have percentages above 74.7%. Only Denmark (−51.16%) and the Netherlands (−39.37%) do not have an NG deficit. In opposition, countries such as Germany (87.91%), France (99.23%) and Italy (90.70%) are a source of concern. Table A8 in Appendix A also reveals that LNG has a redundant use in most European countries. Exceptions include the Netherlands, Belgium and France (above 90% and 50%, respectively). For the sake of brevity, it is relegated to Table A9 in Appendix A the energy dependency by country of origin.

3.1.6. Supply

The largest reserves of NG and respective growth rates are presented in Table 7. Due to their strategic policy, Germany, Ukraine, Italy and France have higher stocks (i.e., above 10% of total gas in Europe). Columns '2015–2019' and '2007–2019' show mean values in these periods. From the growth rate, one can highlight that all these countries increased their stock of NG by around 100% since 2007. These outcomes remained constant in 2020.

Table 7. Natural gas stock in the top-10 European holders.

Country	2020	Share (%)	2015–2019	2007–2019	Growth.2020_2015–2019	Growth.2020_2007–2019
DE	842,558.458	18.913	615,937.940	339,140.515	36.793	148.439
UA	628,500	14.108	494,705.400	525,844.385	27.045	19.522
IT	606,968.014	13.625	560,233.511	551,333.658	8.342	10.091
FR	450,911.573	10.122	339,726.280	343,656.041	32.728	31.210
NL	392,948.871	8.821	347,982.206	318,170.008	12.922	23.503
AT	327,834.616	7.359	211,839.021	174,917.166	54.756	87.423
HU	246,415	5.531	120,985.200	126,493	103.674	94.805
SK	147,116	3.302	80,757.400	75,473.231	82.170	94.925
ES	136,591	3.066	93,620.800	99,748.385	45.898	36.936
CZ	125,863.019	2.825	81,014.036	83,365.783	55.360	50.977

3.1.7. NG Pricing Components

Table A10 in Appendix A shows the distribution of NG price components. Results present both values for 2021 and mean prices since 2017. These include:

- Energy and supply (NRG_SUP);
- Network costs (NETC);
- Taxes, fees, levies and charges (TAX_FEE_LEV_CHRG);
- Value added tax (VAT), renewable taxes (TAX_RNW);
- Capacity taxes (TAX_CAP);
- Environmental taxes (TAX_ENV);
- Other (OTH).

By analyzing EU reference values, three components stand out. Almost 35% of NG prices are due to energy and supply costs, followed by network costs (24.4%), and taxes, fees, levies and charges (20.7%). Values of each component remain relatively stable. Energy and supply rates are slightly higher, while TAX_FEE_LEV_CHRG are lower than EU reference values.

3.2. Parametric Analysis

3.2.1. Preliminary Econometric Tests

In the following section, assume that the dependent variable of the regression model is the D1 band NG price applied to the segment of households without taxes included and measured in gigajoules. Additionally, consider only explanatory variables as having a sufficiently high number of observations to ensure that the study is built on a strongly balanced panel data, with summary statistics presented in Table 8. Although the explanatory data analysis may be important to contextualize the evolution of NG prices, it is useless in the sense that neither analysis either allows the inference of significant determinants of the target or identifies cointegration and short-term relations between the target and relevant explanatory variables. This issue, however, is overcome by performing a parametric analysis.

Table 8. Summary statistics of the target and explanatory variables for the parametric analysis.

Variable	Description	Obs.	Mean	Std. Dev.	Min	Max
id	ID of country	1054	17.500	9.815	1	34
t	Time	1054	16.000	8.949	1	31
GasPriceD1	D1 band GV_GCV Household NG price without taxes	904	18.945	9.857	2.831	89.928
imp	Imports of NG in mcm	503	3555.463	8031.624	0	51,326
exp	Exports of NG in mcm	481	1774.837	4179.512	0	29,438
dep_gas	External dependency of NG	431	78.182	41.109	−120.970	136.632
dep_lng	External dependency of LNG in percentage	431	8.590	27.451	−59.682	108.108
imprus_g3000	Imports of NG from Russia in mcm	461	430.092	1177.382	0	6824.791
exprus_g3000	Exports in mcm	437	15.926	57.473	0	346
stk	Stock level of NG	488	4621.890	10,942.030	−0.600	79,014.560
IMPLNGQA	Imports of LNG from Qatar	451	122.736	299.048	0	2699
IMPLNGDZ	Imports of LNG from Algeria	446	86.873	270.533	0	3029.905
IMPLNGNG	Imports of LNG from Nigeria	448	69.924	194.080	0	1703.498

The panel data consists of 31 units of time representative of the period 2007–2022 and 34 spatial units belonging to Europe. We start by applying preliminary econometric tests to ensure that classical hypotheses are not violated. The correlation matrix and VIF statistics exposed in Table 9 are in favor of excluding the covariate imp since its VIF value is above the critical value of 5.

Table 9. Pearson's correlation matrix and variance inflation factor statistics.

	GasPriceD1	imp	exp	dep_gas	dep_lng	imprus_g3000	exprus_g3000	stk	IMPLNQA	IMPLNDZ	IMPLNNG	VIF
GasPriceD1	1.000											3.160
imp	−0.177 ***	1.000										9.460
exp	−0.124 ***	0.954 ***	1.000									4.250
dep_gas	0.014	0.104	−0.142 *	1.000								1.310
dep_lng	0.085	0.171	0.355 ***	−0.208 ***	1.000							1.470
imprus_g3000	−0.136 ***	0.831 ***	0.775 ***	0.122	−0.099	1.000						3.020
exprus_g3000	−0.063	0.568 ***	0.569 ***	0.113	0.007	0.463 ***	1.000					1.060
stk	−0.180 ***	0.930 ***	0.877 ***	−0.158 **	0.225 ***	0.737 ***	0.510 ***	1.000				2.360
IMPLNGQA	−0.188 ***	0.751 ***	0.636 ***	0.043	0.005	0.506 ***	0.427 ***	0.771 ***	1.000			2.430
IMPLNGDZ	−0.243 ***	0.603 ***	0.499 ***	0.175 **	0.131 *	0.505 ***	0.396 ***	0.529 ***	0.499 ***	1.000		3.320
IMPLNGNG	−0.279 ***	0.766 ***	0.677 ***	0.187 **	0.113	0.623 ***	0.518 ***	0.728 ***	0.692 ***	0.662 ***	1.000	2.930

Notes: *** $p < 0.01$ ** $p < 0.05$ * $p < 0.1$.

Regarding specification, the results of the Ramsey RESET test indicate that that the null hypothesis of no omitted variable bias is rejected when a log-linear functional form is imposed, $F(3,\ 141) = 0.140$, p-value = 0.935.

Another important classical hypothesis is the homoscedasticity. To detect its presence, we use the Breusch–Pagan test, whose null hypothesis is that the variance of disturbance terms is constant. The corresponding result rejects the null hypothesis, $\chi^2(1)$=7.610, p-value = 0.006. This implies that the sample is characterized by heteroscedasticity and, consequently, the Huber–White procedure must be imposed to restore the classical hypothesis of homoscedasticity.

The presence of autocorrelation Is Ir aspect that must be assessed by applying the Breusch–Godfrey test, whose result indicates the presence of autocorrelation $F(12,\ 142) = 35.300$, p-value = 0.000. Mutatis mutandis, a similar result is observed when executing a likelihood ratio test under a GLS estimation, $\chi^2(28)$=149.37, p-value = 0.000. Several methods exist to restore the classical hypothesis of the absence of autocorrelation (e.g., Cochrane–Orcutt for AR(1) processes; the Newey–West estimator; apply GLS if the matrix of variances and covariances is known or EGLS if the matrix of variances and covariances is unknown). These methods and the respective estimates are not examined in this study since the main goal is to identify a system of endogenous variables to identify the presence of cointegration, short run relations and their direction.

Regarding the classical hypothesis of the exogeneity of regressors, we adopt the procedure recommended in [102]:

- Considering insights from authors in [111,112], lagged control variables are adopted as external instruments;
- Endogeneity tests are executed to confirm whether each explanatory variable is exogenous or not, considering the POLS model with robust standard errors. A note of mention is given to the fact that, if statistical tests detect the presence of endogeneity, then researchers need to test the orthogonality of instruments, confirm the optimal number of instruments to be added by checking whether the model should be just-identified or over-identified and test the quality of external instruments. When all the previous steps are satisfied, we apply the 2SLS/IV method to estimate coefficients. Note, however, that the goal of this study is to identify a system of endogenous variables to assess the presence of cointegration, short run relations and their direction [113,114]. Following authors in [102], checking endogeneity formally requires to:
    1. Estimate the original structural equation, $y = f(\mathrm{X},\ u)$;
    2. Estimate the reduce form equation for each explanatory variable $x_i = f(\mathrm{X},\ z, v_i)$ to obtain residuals $\hat{v}_i$, which contain the endogenous information. Similar to the first step of the 2SLS/IV method, predicted values $\hat{x}_i$ only contain the exogenous information. Hence, the potential endogenous variable x_i is segmented into the exogenous part $\hat{x}_i$ and the endogenous part $\hat{v}_i$. Formally: $x_i = \hat{x}_i + \hat{v}_i$; and
    3. Estimate the unrestricted structural equation model, whose specification includes the endogenous component $\hat{v}_i$ in order to test the null hypothesis that the respective coefficient is null (i.e., the absence of endogenous information $\hat{v}_i$ and, consequently, the exogeneity of x_i) against the alternative hypothesis capturing the presence of endogenous information $\hat{v}_i$ and, thus, the endogeneity of x_i.

If the observed *p*-value is above the critical *p*-Value, we do not reject the null hypothesis. Under this circumstance, $\hat{\mathrm{v}}_{\mathrm{i}}$ is not significant such that x_{i} is exogenous and the use of instruments becomes unnecessary. If the observed *p*-Value is below the critical *p*-Value we reject the null hypothesis. Under this circumstance, $\hat{\mathrm{v}}_{\mathrm{I}}$ is significant such that x_{I} is endogenous. Results of the individual significant tests are exposed in Table 10. Although most explanatory variables are exogenous, LNG import from Nigeria is the regressor closest to be considered endogenous. In fact, F(1,118) = 2.320, *p*-Value = 0.131, which implies failure to reject the null hypothesis for a critical *p*-Value of 15%. As such, jointly with the logarithm of NG prices, LNG imports from Nigeria are considered for the subsequent application of a VAR-VECM panel data model.

Table 10. Individual significant tests to check the presence of endogeneity.

Variable	F	*p*-Value	Decision
exp	0.220	0.640	Exogenous
dep_gas	0.120	0.732	Exogenous
dep_lng	0.880	0.349	Exogenous
imprus_g3000	0.060	0.812	Exogenous
exprus_g3000	0.000	0.987	Exogenous
stk	1.140	0.288	Exogenous
IMPLNGQA	0.600	0.442	Exogenous
IMPLNGDZ	0.340	0.563	Exogenous
IMPLNGNG	2.320	0.131	Potentially endogenous #

Notes: Symbol # materializes the capture of a reasonable doubt with respect to the endogeneity of regressor IMPLNGNG. For a critical *p*-Value of 15%, the null hypothesis claiming its exogeneity is rejected. Mutatis mutandis, the opposite is applied to the remaining regressors, whose results defend the presence of exogeneity.

The last step before verifying whether there is cointegration and causality, in the sense of Granger, between both variables in the context of panel data is to check for the presence of unit roots [115]. When a time series is not stationary, spurious relations can arise. To overcome this source of concern, integration techniques (e.g., taking the first or higher order differences) are applied to impose stationary and ensure the correct identification of short and long run dependencies. Several panel unit root tests exist to satisfy this purpose. Theoretically, they differ in some particularities (e.g., method to estimate coefficients, test statistics, formulation of null and alternative hypotheses, assumptions regarding the independence of disturbance terms μ_{it}). In this study, we consider the HT test [103] and the IPS test [104] due to the characteristics exhibited by the panel data (i.e., small T and large N). Results shown in Table 11 confirm that there is stationarity in both variables without needing to take first or higher-order differences for a critical p-Value of 5%.

Table 11. Harris–Tzavalis and Im–Pesaran–Shin unit-root test results.

HT		ρ	**Z**	***p*-Value**	**Decision (α = 0.05)**
ln (GasPriceD1)		0.522	−10.062 ***	<0.001	I(0)
IMPLNGNG		0.144	−25.246 ***	<0.001	I(0)
IPS	$\bar{t}$	$\tilde{\bar{t}}$	$\tilde{\bar{Z}}$	*p*-Value	
ln (GasPriceD1)	−6.455	−3.438	−14.731 ***	<0.001	I(0)
IMPLNGNG	−4.543	−3.451	−14.828 ***	<0.001	I(0)

Notes: Hypotheses of the HT panel unit root test—H0: panels contain unit roots; H1: panels are stationary. Hypotheses of the IPS panel unit root test—H0: All panels contain unit roots; H1: Some panels are stationary. Since the panel does not have a reasonably large number of time periods and units, a lag structure for ADF regressions is disregarded. Panel unit root tests are performed with the inclusion of time trend and removing cross-sectional means. Analysis with T = 31 and N = 34. Symbol *** stands for significance at the 1% level.

3.2.2. VAR-VECM Panel Data Analysis

We start by analyzing whether there is cointegration (i.e., a long run relationship between the two variables under scrutiny). We use WECM panel cointegration tests, which implement four panel cointegration tests. According to [105], these are designed to test the null hypothesis of no cointegration by testing whether the ECT in a conditional error correction model is equal to zero. If the null hypothesis of no error correction is rejected, then the null hypothesis of no cointegration is also rejected. Each test is able to accommodate individual-specific short-run dynamics, including serially correlated error terms and non-strictly exogenous regressors, intercept and trend terms, as well as individual-specific slope parameters. A bootstrap procedure is also possible to handle applications with cross-sectionally dependent data. The rejection of null hypothesis in mean group tests G_t and G_a suggest the existence of cointegration in at least one cross-sectional unit. Panel tests of P_t and P_a statistics pool information over all cross-sectional units to test the null hypothesis of no cointegration [114].

Results in Table 12 show evidence in favor of not rejecting the null hypothesis of no cointegration between the logarithm of NG prices and LNG imports from Nigeria, thereby suggesting the absence of a long run relationship between both variables. Notwithstanding, the null hypothesis of no cointegration is rejected for the G_a test, which suggests that the long run relation prevails in some European countries. Note that, in small datasets, such as in this case study where T = 31, results may be sensitive to the specific choice of parameters, such as lag and lead lengths and the kernel width. Nevertheless, several robustness checks (i.e., bootstrap, restrict the short-run dynamics and use a shorter kernel window) imply the same qualitative results.

Despite the particularities of each cross-section unit, the mean group VECM can be displayed, which averages estimated coefficients of the error-correction equation over all cross-sectional units together with the implied long-term relationship. Considering that the postulated relationship between both variables allows for a linear time trend and using

Equation (3), the mean group VECM or, equivalently, restricted VAR regression due to the presence of a long run relation, sustains the following estimates:

$$\begin{array}{lllll} \Delta ln(\widehat{\text{GasPriceD1}})_t = & 0.720 & +0.018\,t & +0.0004\ \text{IMPLNGNG}_{t-1} & -0.383\ ln(\text{GasPriceD1})_{t-1} \\ & (0.172) & (0.011) & (0.001) & (0.049) \\ & [4.18] & [1.59] & [0.72] & [-7.83] \end{array}$$

which allows us to conclude that:

- The coefficient associated with the independent term is significant, which suggests evidence of unobserved heterogeneity affecting the nondeterministic component of the regression model;
- The trend coefficient is positive but lacks statistical significance, which implies that it cannot be corroborating evidence of increasing NG prices;
- The ECT (i.e., parameter α_i) associated with the regressor $\ln(\text{GasPriceD1})_{t-1}$ corresponds to the lagged value of the residuals that are obtained from the cointegration regression of the dependent variable on the set of regressors, which is derived from the long run cointegrated relationship. Hence, it determines the speed at which the system corrects back to the equilibrium relationship after a sudden shock. The result indicates that the ECT is both negative and significant. Considering the sample of 34 spatial units, this implies the prevalence of error correction such that, on average, there is evidence of cointegration between the logarithm of NG prices and LNG imports from Nigeria. Knowing that the adjustment term containing long run information is significant at the 1% level, its economic interpretation suggests that the previous year's error—or, similarly, the deviation from the long run equilibrium—is corrected for within the current year at a mean convergence speed of 38.304%, ceteris paribus. This means that the standard compound annual growth rate (CAGR) can be applied to evaluate the number of semesters it takes for a given country to converge to the long run equilibrium. Knowing that the mathematical formula is given by $\text{CAGR} = (\text{EB}/\text{BB})^{\frac{1}{n}} - 1$, knowing that CAGR = 38.304%, EB stands for the long-term NG price target, BB stands for the short-term NG price and n corresponds to the number of semesters, then a numerical exercise in which it is assumed $EB = 50$ and $BB = 10$ implies that 5 semesters (i.e., two and a half years) ensure convergence to the long run equilibrium: $n = ln(5)/ln(1.383) = 5$.
- Additionally, the 95% confidence interval of the centric coefficient that represents the ECT lies between -0.479 and -0.287, thereby implying the accommodation of a mean convergence speed ranging between 28.716% and 47.893%.
- Although the VECM regression associated with each country is not discussed in the main text for the sake of brevity, we report the estimated mean long run relationship and short run adjustment, which is given by

$$\begin{array}{lllll} ln(\widehat{\text{GasPriceD1}})_{t-1} = & 1.870 & +0.042\,t & +0.001\ \text{IMPLNGNG}_{t-1} & -0.383\ \Delta ln(\text{GasPriceD1})_{t-1} \\ & (0.282) & (0.014) & (0.001) & (0.049) \\ & [6.64] & [3.03] & [0.71] & [-7.83] \end{array}$$

A deeper look on individual outcomes allows us to identify, for a critical p-Value of 1%, twelve countries that exhibit a significant ECT: Bosnia and Herzegovina, Denmark, Estonia, Spain, Croatia, Hungary, Ireland, Liechtenstein, The Netherlands, Poland, Sweden and United Kingdom. If the level of significance is relaxed to $\alpha = 0.05$, we also include Bulgaria, Czechia, Estonia, France, Italy, Luxembourg, Moldova, Macedonia, Romania, Serbia and Slovakia.

Afterwards, to explore short run causality in the panel, the DH Granger noncausality test is executed, while assuming that the number of lags is set to minimize either the AIC, BIC or HQIC [106]. Results displayed in Table 13 confirm:

- No evidence in favor of a bidirectional short run relation between both variables;

- No evidence in favor of a significant and unilateral short run relation derived from the logarithm of NG prices to Nigeria's LNG imports;
- Evidence in favor of a significant and unidirectional short run relation imposed by Nigeria's LNG imports on NG prices.

Table 12. Panel cointegration test results with the Westerlund error correction model.

***ln* (GasPriceD1) and IMPLNGNG [1.880,1.410]**				
Statistic	**Value**	**Z**	***p*-Value**	**Decision (α = 0.05)**
G_t	−2.227	0.999	0.841	Absence of LR relation
G_a	−23.563	−9.905 ***	0.000	Presence of LR relation
P_t	−8.845	3.970	1.000	Absence of LR relation
P_a	−7.647	1.223	0.889	Absence of LR relation

Notes: Hypotheses of the WECM panel cointegration test—H0: No cointegration; H1: Some (G_t and G_a) or all (P_t and P_a) panels are cointegrated. Average AIC is used to select lag and lead lengths. The optimal pair [lag, lead] is exposed in the first line of the table within brackets. Analysis with T = 31, N = 34 and 1 covariate. Symbol *** stands for significance at the 1% level. Abbreviation LR stands for long run.

Table 13. Panel noncausality test results with the Dumitrescu–Hurlin model.

Lag Criterion		**Statistics**		**Optimal Number of Lags (k)**	**Decision (α = 0.05)**
	$W_{N,T}$	$Z_{N,T}$	$\tilde{Z}_{N,T}$		
Direction: ln(GasPriceD1) → IMPLNGNG					
Exogenous (1 lag)	0.656	−0.807	−0.866	1	Absence of SR relationship
AIC	1.873	−0.211	−0.429	2	Absence of SR relationship
BIC	0.656	−0.807	−0.866	1	Absence of SR relationship
HQIC	1.873	−0.211	−0.429	2	Absence of SR relationship
Direction: IMPLNGNG → ln(GasPriceD1)					
Exogenous (1 lag)	1.972	2.279 **	1.821 *	1	Presence of SR relationship
AIC	293.493	275.254 ***	161.518 ***	6	Presence of SR relationship
BIC	293.493	275.254 ***	161.518 ***	6	Presence of SR relationship
HQIC	293.493	275.254 ***	161.518 ***	6	Presence of SR relationship

Notes: Hypotheses of the DH panel noncausality test—H0: no Granger causality; H1: causality for at least one unit of the panel. Symbols *, ** and *** stand for significance at the 1%, 5% and 10% level. Abbreviation SR stands for short run. The observed p-Value is only captured in $Z_{n,t}$ and $\tilde{Z}_{N,T}$ statistics. Analysis with T = 31, N = 34.

Focusing on individual statistically significant outcomes allows us to confirm the sign exhibited by short-term effects. Considering the AIC and applying the delta method for the definition of confidence intervals, it can be concluded that:

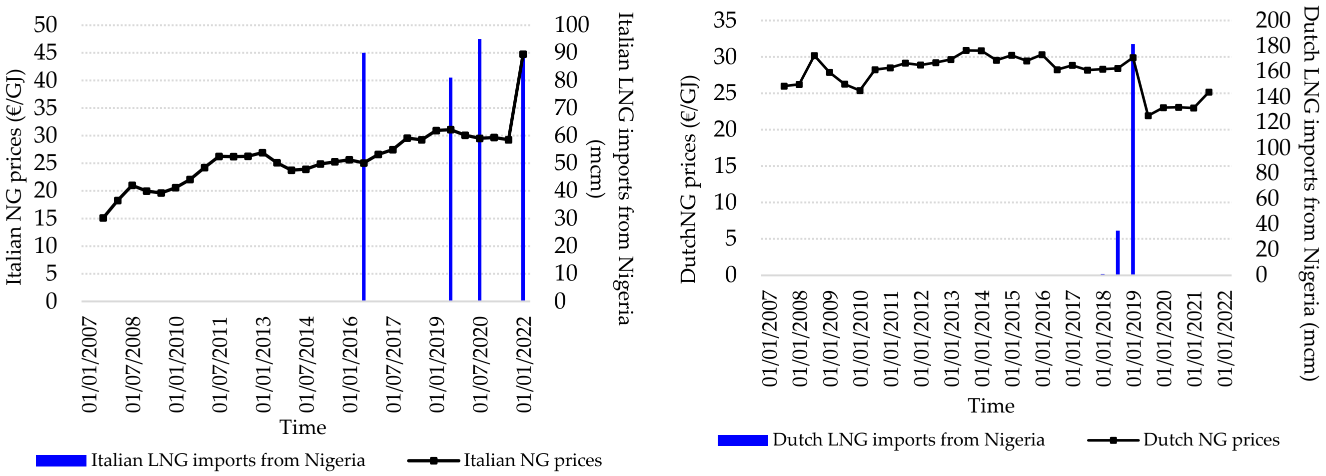
- An increase of LNG imports from Nigeria leads to a rise of NG prices in Italy and Poland;
- An increase of LNG imports from Nigeria leads to a reduction of NG prices in the Netherlands;
- An increase of LNG imports from Nigeria implies ambiguous impact on NG prices in Portugal.

Similar qualitative results are obtained once the cross-sectional dependence is accounted for by considering a bootstrap approach with 100 replications. To confirm the additional insights on autoregressive parameters and coefficients presented in Equation (4), estimates of the unrestricted VAR regression related to the abovementioned countries are clarified in Table 14. To enhance the visualization of short-term outcomes, a graphical illustration for the European countries shown in Table 14 is provided in Figure 8.

Table 14. Short run estimated coefficients with the Dumitrescu–Hurlin model.

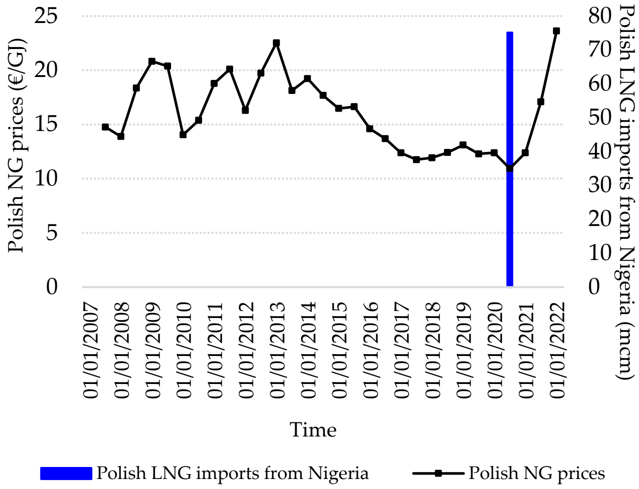
Regressor	Italy (Id: Unit 17)	Poland (Id: Unit 25)	The Netherlands (Id: Unit 24)	Portugal (Id: Unit 26)
d_t	1.175 *	−0.029	1.964 **	1.034
	(0.599)	(0.442)	(0.768)	(0.635)
$ln(\text{GasPriceD1})_{i,t-1}$	1.217 **	0.812 ***	0.404	1.070 ***
	(0.430)	(0.237)	(0.311)	(0.231)
$ln(\text{GasPriceD1})_{i,t-2}$	−0.799	−0.152	0.1874	−0.035
	(0.604)	(0.272)	(0.277)	(0.336)
$ln(\text{GasPriceD1})_{i,t-3}$	0.320	0.344	−0.283	−0.327
	(0.556)	(0.272)	(0.278)	(0.317)
$ln(\text{GasPriceD1})_{i,t-4}$	−0.388	0.074	0.271	0.184
	(0.425)	(0.266)	(0.257)	(0.218)
$ln(\text{GasPriceD1})_{i,t-5}$	0.257	−0.182	−0.216	−0.359 **
	(0.253)	(0.217)	(0.192)	(0.154)
$ln(\text{GasPriceD1})_{i,t-6}$	0.006	0.105*	0.025	0.108
	(0.001)	(0.053)	(0.019)	(0.061)
$\text{IMPLNGNG}_{i,t-1}$	4.63×10^{-4}	0.002	−0.001 ***	−0.001 ***
	(0.000)	(0.002)	(0.000)	(0.000)
$\text{IMPLNGNG}_{i,t-2}$	6.08×10^{-4}	0.004 **	−0.001	-2.48×10^{-4}
	(0.000)	(0.002)	(0.001)	(0.000)
$\text{IMPLNGNG}_{i,t-3}$	0.001 **	0.006 **	-1.10×10^{-5}	0.002 ***
	(0.000)	(0.002)	(0.000)	(0.000)
$\text{IMPLNGNG}_{i,t-4}$	2.65×10^{-4}		−0.002 ***	−0.001 *
	(0.001)		(0.000)	(0.001)
$\text{IMPLNGNG}_{i,t-5}$	0.002 ***		0.003 ***	0.002 **
	(0.001)		(0.001)	(0.001)
$\text{IMPLNGNG}_{i,t-6}$	5.30×10^{-4}		−0.017 ***	3.55×10^{-5}
	(0.001)		(0.000)	(0.001)
F-statistic	$F(12,12)$ =15.650 ***	$F(9,15)$ =7.080 ***	$F(12,12)$ =710.600 ***	$F(12,12)$ =13.330 ***
R^2	0.940	0.810	0.999	0.930
Adj. R^2	0.880	0.695	0.997	0.860
RMSE	0.051	0.124	0.034	0.090

Notes: Symbols *, ** and *** stand for significance at the 1%, 5% and 10% level. Standard errors in parenthesis. Analysis with T = 31, N = 34 and $d_t = 1$. RMSE stands for root mean squared error.

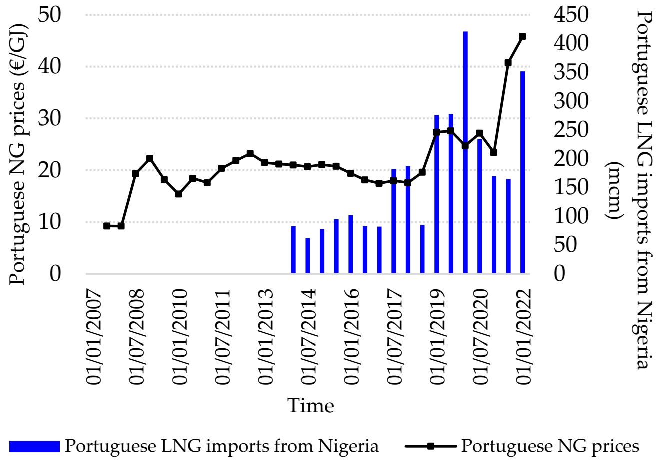


(**a**) (**b**)

Figure 8. *Cont.*



(c)



(d)

Figure 8. Short-term effects of liquefied natural gas imports from Nigeria on European natural gas prices (2007–2022): (**a**) Italy; (**b**) The Netherlands; (**c**) Poland; (**d**) Portugal.

4. Discussion

4.1. Comparing the Main Results of This Study with the Existing Literature

Regarding price stability in Europe, in a numerical model of international energy markets, authors in [71] show that trade between continents will grow considerably over the next couple of decades and prices in the main import regions will remain around current levels, despite constraints on exports from the Middle East may alter this scenario. Results of the nonparametric exercise combined with the lack of statistical significance of the coefficient representing the time trend in the VAR-VECM model are aligned with the prediction of stability in NG pricing behavior.

Regarding the evolution of NG prices in the short and long run due to the increase of LNG imports, in a simulation study, authors in [58] address interactions among demand, supply, pipeline and LNG transport, storage and investments over the period 2005–2030. Their results indicate that LNG can compete with pipelines in the near future and significant decreases in Cournot prices between 2005 and 2010 indicate that short-term investments in the European NG transport capacity are likely to diminish market power by making markets more accessible.

Moreover, authors in [69] show that, regardless of constraints on gas-to-liquids (GTLs) capacity, higher oil prices lead to higher production and consumption of NG. However, when GTL capacity is allowed to expand, higher oil prices generally lead to higher NG prices and to less gas consumption in the electric power and industrial sectors as they switch to cheaper fuels and more NG is diverted to the production of GTLs. Mutatis mutandis, a similar outcome is observed in [59]. Following an industrial organization (IO) framework, authors in [82] show that entry of LNG importers in the NG market can have a positive competitive effect even in the case LNG bears higher total costs, but only under some stringent conditions:

- New competitors must be allowed to enter the LNG market;
- Existence of a vivid spot market; and
- Reduction of LNG costs.

It is confirmed in [65] that, when NG serves as a bridge technology, short-term usage rates of LNG import capacity temporarily increase large scale pipeline expansions. Knowing that domestic gas prices in Russia are substantially lower than export netback prices, and considering that the Russian government aims to increase the domestic price level in the long term, the author in [60] analyzes long-term effects of higher NG prices in Russia on European NG markets. The author estimates that, under an inelastic demand price elasticity of −0.5, a 70% increase in the domestic NG price in Russia results, on average, in an annual consumption decline of 116 bcm in the domestic market. Regarding the impact on Europe, two propagation mechanisms are pointed out: stock effects and scarcity rents. Under the presence of demand price elasticity equal to 1, the annual average increase in the export supply to Europe may account for 33.7 bcm. However, a reduction in domestic NG consumption may reduce scarcity rents, which implies a higher potential for NG exports in the long run. Finally, it is estimated that increasing the domestic NG price is associated with an annual average increase in the export tax revenue of 38.4 billion USD, ceteris paribus. Considering that NG production is expected to decrease in the near future, two options are tested in [32]: increased imports of LNG from different global sources and increased deliveries of Russian pipeline gas via Nord Stream 2. Their simulations show that Nord Stream 2 impacts the NG transit through Poland more severely (i.e., 23% loss of transit flows compared to 2014) than the transit through Ukraine (i.e., 13% loss). Completely cutting Ukraine's transit from the NG system is found to be a detrimental strategy for Russia because only 40% of this flow can be rerouted via Nord Stream 2 in the short run. Increased imports of LNG are found to require 17% of European NG pipelines to be bidirectional, which requires significant investments into the current European network infrastructure and contests these results.

Bearing in mind the dichotomy between the rigidity associated with pipeline building and the flexibility related to LNG exporters, the author in [61] uses basic game theory to show how the commitment to serve a single market confers a strategic advantage on piped gas. The economic intuition is straightforward: by overinvesting in the domestic market, this strategic action conducted by a pipeline exporter (e.g., Russia) can induce LNG rivals to shift sales to their other markets (e.g., Qatar). Hence, the author demonstrates that Russia's dependence on Europe can be perceived as good for NG buyers, even though they can benefit from diversifying into LNG imports. Finally, the author also confirms that the HHI of imports can mismeasure supply security. With that being said, the main finding of the present study—that European NG prices are caused in the sense of Granger by LNG imports from Nigeria and this short run effect can be either positive or negative depending on the specific characteristics exhibited by each European country—is partially aligned with the set of empirical results found in the existing literature. Notwithstanding, since the VAR-VECM model confirms that the evolution of NG prices in Europe is largely dependent on country-specific characteristics, this outcome also opens some normative space to claim that existing results observed in the literature can be at least partially contested since one-size-fits-all effects do not exist.

4.2. Policy Insights and General Recommendations for Policymaking

This study contributes to the strand of literature focused on European NG markets, which is essentially concerned with:

- The decline of production and the strong dependence of NG in almost all European countries. [4];
- The increase in global temperatures has been accompanied by a growing frequency and severity of extreme weather conditions and climate disasters. In this context, the EU has already employed several measures, such as new environmental taxes to establishing renewable quotas [115]. However, although the growing of renewable energy, NG has upheld a key role in power sector [1];
- The NG demand in the near future, which is driven by incremental innovations, use of renewable energy sources and political decisions to decarbonize the energy sector. Uncertainties on these domains may deter investment realization in gas infrastructures [116].

Moreover, European NG markets have changed considerably in the last couple of decades for several reasons, and two in particular deserve to be emphasized:

- The liberalization of energy markets;
- The rise of global LNG trading.

Currently, it is crucial to define measures and actions to be taken by national jurisdictions to address policy domains such as infrastructure investments, constraints of supply diversification, and leveraging the role of alternative options to NG. Bearing this motivation in mind, a set of indicators was retrieved from Eurostat to formulate a complete characterization of the actual situation faced by 34 national jurisdictions belonging to Europe. More precisely, the framework accommodates two complementary empirical exercises:

- Initially, a nonparametric analysis provides useful information for policymakers, investors and managers on how European NG prices have changed. In particular, an exploratory data analysis assesses the evolution of NG prices and potential determinants affecting them from 2007 onwards where, among several stylized facts, it is confirmed that spatial units belonging to the sample are characterized by:
    - A low level of domestic resources;
    - A high demand for NG;
    - A large dependence of NG from Russia, Norway and Ukraine;
    - A large dependence of LNG from Qatar, Algeria, Nigeria, Russia and USA.
- Following that, a parametric analysis confirms that only LGN imports from Nigeria have influential power on NG prices, both in the short-term and long-term equilibria. Note that LNG, which is a green gas, holds the advantage of being strongly correlated with the increasing price trend for CO2, but also has the constraint of accommodating predominantly North African countries as predominant non-European suppliers. Indeed, the VAR-VECM panel data analysis confirms that:
    - Increasing LNG imports from Nigeria has a significant long run impact on NG prices in approximately 30% of the sample; and
    - Significant effects in the short run are observed in Italy, Poland and The Netherlands. Whilst the impact of increasing LNG imports from Nigeria is a price reduction in the Netherlands, a price rise holds in countries such as Italy and Poland.

Given these results, which reinforce the need to reduce the dependence of NG and legitimize the presence of causality in the sense of Granger and cointegration in the sense of Westerlund of LNG imports from Nigeria on European NG prices, at least two questions naturally arise:

- Does the one-size-fits-all logic hold when applying diversification strategies in European NG markets?
- Which costs and benefits result from applying diversification strategies in European NG markets?

Historically, European countries have tried to develop efforts to reduce NG consumption by increasing the share of renewable energy sources. In the limit, this happens as a mere matter of political lobbying or populism. The EC, International Energy Agency (IEA) and ACER also propose supply diversification to increase energy security and security of supply in Europe. However, geopolitical interests are frequently observed, including Russia's interest on the Nord Stream 2 pipeline and the USA's interest to export LNG from fracking to the EU. After the invasion of Ukraine by Russia, the EU is trying to become less dependent on Russian gas supply. Regarding the development of network infrastructures, European countries have a well-connected gas pipeline system, which ensures security of gas supply. The EU has also promoted several projects to improve NG infrastructures, enhance LNG import capacities and enable NG trading among EU Member States. However, due to the changing nature of EU's NG markets, additional investment realization may be needed.

This empirical study confirms that the urgent need to diversity NG imports by means of accommodating additional LNG imports may be at least partially contested, given that empirical results confirm the presence of ambiguous short-term impacts of LNG imports from Nigeria on European NG prices, which may inhibit the release of EU's dependence on NG. In some European countries (e.g., Italy), a greater penetration of LNG imports from Nigeria leads to higher system costs due to the need for:

- Developing new infrastructures
- Proceeding to the renewal or adaptation of existing infrastructures;
- Political adjustments for infrastructure investments and NG supply,

which implies a rise of NG prices. However, in other European countries (e.g., The Netherlands), a greater penetration of LNG imports from Nigeria leads to lower system costs due to:

- Efficiency gains;
- The dissuasion of corporate practices such as price gouging and cherry-picking,

which implies a reduction of NG prices. Given the inexistence of one-size-fits-all effects and, consequently, the persistence of a reasonable doubt raised by the empirical finding on LNG imports, this study implicitly claims that alternative decarbonization options, such as blue hydrogen, have room to occupy a significant role in European NG markets in the near future. This is not only because of the need to reduce the dependence on NG, but also the fact that the net benefit of green gas adoption can be positive, neutral or negative depending on the specific characteristics exhibited by each European country.

5. Conclusions

After providing an exploratory data analysis focused on NG prices and potential determinants, this study performs an empirical work to identify drivers of European NG prices in the framework of decarbonization. Preliminary econometric tests ensure that all classical hypotheses are satisfied, with the exception of the exogeneity of regressors in order to define a system of endogenous variables, whose statistical tests determined as being composed by the logarithm of NG prices and LNG imports from Nigeria. Afterwards, a VAR-VECM model is considered in the context of panel data that covers 34 spatial units from Europe over 31 units of time representative of the period 2007–2022 to identify cointegration, causality in the sense of Granger and the direction of the relationship (e.g., unidirectional, bidirectional) between the logarithm of NG prices and LNG imports from Nigeria. Cointegration results confirm that the trend coefficient is positive, but lacks statistical significance, so that it cannot be corroborated evidence of increasing NG prices. On average, the ECT is negative and significant, which implies evidence of cointegration. The deviation from the long run equilibrium is corrected for within the current year at a mean convergence speed of 38.304%, ceteris paribus. In turn, Granger causality results clarify that there is only a significant and unidirectional short run relation imposed by LNG imports from Nigeria on the logarithm of NG prices. At the country level, results indicate that increasing LNG imports from Nigeria has ambiguous effect on European NG prices. This finding legitimizes a normative discussion on the need to impose diversification strategies aimed at maximizing social welfare. Given the reasonable doubt relative to the penetration of green gas, alternative decarbonization options to NG and LNG imports, such as blue hydrogen, may be pursued by European countries in the future.

Despite the effort to provide a valid contribution, this study is not exempted from limitations. Future studies may consider a difference-in-differences analysis and/or propensity score matching models to test the effect of several LNG policies in Europe. Future work may also provide country-level policy recommendations.

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Appendix A. Additional Tables

Appendix A.1. General Outcomes

Table A1. Description of the dimension of concepts represented in the datasets.

Dataset	Dimension 1	Dimension 2	Dimension 3
Gas prices for household consumers - bi-annual data (from 2007 onwards) Code: NRG_PC_202 Semester (1 January 2017–1 January 2022)	Type of consumption [4141901] Band D1: Consumption < 20 GJ [4141902] Band D2: 20 GJ < Consumption < 200 GJ Band D3: Consumption > 200 GJ	Taxes "I_TAX" "X_TAX" "X_VAT"	Type of unit "GJ_GCV" "KWH"
Gas prices for non-household consumers—bi-annual data (from 2007 onwards) Code: NRG_PC_203 Semester (1 January 2017–1 January 2022)	Type of consumption [4142901] Band I1: Consumption < 1000 GJ [4142902] Band I2: 1000 GJ < Consumption < 10,000 GJ [4142903] Band I3: 10,000 GJ < Consumption < 100,000 GJ [4142904] Band I4: 100,000 GJ < Consumption < 1,000,000 GJ [4142905] Band I5: 1,000,000 GJ < Consumption < 4,000,000 GJ [4142906] Band I6: Consumption > 4,000,000 GJ	Taxes "I_TAX" "X_TAX" "X_VAT"	Type of unit "GJ_GCV" "KWH"
LD Code: NRG_CB_GASM Siec: G3000 Monthly 1 January 2014→1 December 2021	NRG_BAL [IMP] Imports [EXP] Exports [STATDIFF] Statistical		Type of unit [MIO_M3] Million cubic meters [TJ_GCV] Terajoule (gross calorific value - GCV)
Household consumption volumes of gas by consumption bands Code: NRG_PC_202_V Annual (1 January 2017→1 August 2022)	Type of consumption [4141901] Band D1: Consumption < 20 GJ [4141902] Band D2: 20 GJ < Consumption < 200 GJ Band D3: Consumption > 200 GJ		Type of unit [PC] Percentage
Non-household consumption volumes of gas by consumption bands Code: NRG_PC_203_V Annual (1 January 2017→1 August 2022)	Type of consumption [4142901] Band I1: Consumption < 1000 GJ [4142902] Band I2: 1000 GJ < Consumption < 10,000 GJ [4142903] Band I3: 10,000 GJ < Consumption < 100,000 GJ [4142904] Band I4: 100,000 GJ < Consumption < 1,000,000 GJ [4142905] Band I5: 1,000,000 GJ < Consumption < 4,000,000 GJ [4142906] Band I6: Consumption > 4,000,000 GJ		Type of unit [PC] Percentage

Table A1. *Cont.*

Dataset	Dimension 1	Dimension 2	Dimension 3
Share of energy from renewable sources Code: NRG_IND_REN Annual (1 January 2004→1 August 2020)	[REN] Renewable energy sources		Type of unit [PC] Percentage
Energy imports dependency Code: NRG_IND_ID] Annual (1 January 2007→1 January 2020)	Siec [TOTAL] Total [G3000] NG [O4200] NG liquids		Type of unit [PC] Percentage
Imports of NG by partner country—monthly data Code: NRG_TI_GASM Monthly (1 January 2014→1 August 2022)	Siec "G3000" "G3200"	Partner (164 countries)	Type of Unit [MIO_M3] Million cubic meters [TJ_GCV] Terajoule (gross calorific value—GCV)
Exports of NG by partner country—monthly data Code: NRG_TE_GASM Monthly (1 January 2014→1 August 2022)	Siec "G3000" "G3200"	Partner (164 countries)	Type of Unit [MIO_M3] Million cubic meters [TJ_GCV] Terajoule (gross calorific value—GCV)
NG import dependency by country of origin Code NRG_IND_IDOGAS Siec: G3000 (NG) Annual (1 January 2015→1 January 2020)	"DZ" "NG" "NO" "QA" "RU" "UK" "US"		Type of unit [PC] Percentage
Stock levels for gas products—monthly data Code NRG_STK_GASM Siec: G3000 Monthly (1 January 2008→1 August 2022)	stk_flow [STKCL_CG] Closing stock—cushion gas [STKOP_NAT] Opening stock—national territory [STKCL_NAT] Closing stock—national territory [STKOP_ABR] Opening stock—held abroad [STKCL_ABR] Closing stock—held abroad		Type of Unit [MIO_M3] Million cubic meters [TJ_GCV] Terajoule (gross calorific value—GCV)
Gas prices components for household consumers—annual data Code: NRG_PC_202_C Annual (1 January 2017→1 January 2021)	Components of energy prices (nrg_prc) [NRG_SUP] Energy and supply [NETC] Network costs [TAX_FEE_LEV_CHRG] Taxes, fees, levies and charges on energy imports [VAT] Value added tax (VAT) [TAX_RNW] Renewable taxes [TAX_CAP] Capacity taxes [TAX_ENV] Environmental taxes	Type of consumption "4141901" "4141902" "4141903" "All."	Type of unit "GJ_GCV" "KWH"

Table A2. NG mean prices (D1 band) for all semesters after 2018 and percentage point differences between specific moments (i.e., before and after the pandemic; invasion of Ukraine by Russia).

Country	MEANS	S1_2018	S2_2018	S1_2019	S2_2019	S1_2020	S2_2020	S1_2021	S2_2021	S1_2022	DIF_21S2_20	DIF_22_21S2	DIF_22_20
AT	24.971	24.482	29.640	26.082	27.439	23.503	27.216	22.678	29.811	NA	26.838	NA	NA
BA	7.661	7.540	8.262	8.129	7.877	7.698	7.607	7.496	11.744	17.297	52.560	47.288	124.702
BE	12.057	10.877	11.428	12.076	12.009	11.716	11.104	11.637	14.998	26.292	28.016	75.301	124.414
BG	22.115	15.220	18.896	15.810	18.902	15.836	19.690	14.482	28.374	26.217	79.180	−7.604	65.555
CZ	21.758	20.120	26.383	21.670	27.051	21.323	27.084	20.956	30.883	27.625	44.835	−10.548	29.558
DE	23.185	22.697	27.083	24.087	25.209	21.785	24.892	20.879	27.192	NA	24.817	NA	NA
DK	20.764	22.617	24.072	22.314	23.839	22.632	23.464	22.497	24.464	25.345	8.094	3.602	11.987
EA	10.058	7.732	7.734	7.958	7.908	8.876	8.203	7.617	8.638	10.403	−2.690	20.442	17.202
EE	31.491	33.451	40.703	36.204	34.111	31.721	32.715	29.631	34.762	33.734	9.586	−2.956	6.347
EL	11.377	10.170	10.759	10.092	11.019	9.870	10.852	10.241	10.678	10.175	8.187	−4.707	3.094
ES	3.401	3.679	3.689	3.740	3.506	3.427	2.973	2.831	3.264	3.501	−4.771	7.290	2.171
FR	9.522	10.121	10.208	10.266	11.195	10.226	10.553	9.533	9.744	10.393	−4.721	6.660	1.624
GE	17.504	16.151	20.974	18.474	23.968	19.064	NA	NA	NA	NA	NA	NA	NA
HR	10.453	9.091	10.584	10.635	10.516	9.477	8.651	9.004	18.216	18.179	92.210	−0.207	91.812
HU	9.280	7.837	7.590	7.561	7.316	6.977	6.740	6.708	6.669	6.366	−4.421	−4.539	−8.760
IE	18.926	16.989	23.034	17.892	22.283	18.427	20.673	17.188	24.583	23.547	33.408	−4.215	27.784
IT	21.568	24.445	24.169	25.568	25.696	24.864	24.397	24.522	25.647	36.990	3.149	44.226	48.767
LI	16.387	13.771	13.760	14.119	13.575	14.824	13.297	13.369	14.440	17.199	−2.592	19.105	16.017
LT	24.769	21.454	32.611	22.612	35.030	22.673	33.368	21.809	37.714	30.828	66.339	−18.256	35.971
LU	46.542	32.803	59.288	37.417	50.518	47.064	48.065	58.103	45.553	61.462	−3.211	34.924	30.592
LV	15.597	14.490	15.325	16.928	14.634	11.839	9.572	13.078	15.830	16.701	33.708	5.505	41.068
MD	24.246	22.627	24.496	28.024	28.530	27.365	28.265	26.469	27.619	30.554	0.928	10.627	11.654
MK	5.212	4.827	5.753	6.317	5.284	4.059	5.287	5.710	NA	NA	NA	NA	NA
NL	23.343	23.794	23.884	25.134	18.432	19.371	19.883	19.310	21.144	NA	9.152	NA	NA
PL	14.962	11.026	11.470	12.116	11.355	11.450	10.097	11.870	15.796	21.877	37.950	38.500	91.061
PT	18.215	14.530	16.195	22.593	22.798	20.443	22.422	19.343	33.674	37.867	64.722	12.451	85.232
RO	8.395	6.285	7.138	7.347	7.453	7.479	7.267	6.246	9.077	21.725	21.356	139.350	190.466
RS	41.389	38.105	43.257	48.076	47.451	42.696	34.698	62.445	85.298	89.928	99.777	5.428	110.621
SE	22.889	22.717	23.604	24.971	22.315	22.246	22.699	25.206	34.282	39.962	54.101	16.569	79.633
SI	13.784	9.581	12.962	13.944	13.880	13.073	10.920	11.702	13.628	28.452	4.242	108.779	117.636
SK	28.526	27.143	33.148	29.648	34.882	32.206	36.787	30.949	38.972	39.046	21.010	0.191	21.240
TR	12.938	12.206	11.898	11.997	11.977	11.186	10.601	9.759	11.168	16.694	−0.169	49.489	49.237
UA	7.178	5.139	5.016	4.760	6.260	5.747	4.718	4.596	4.448	4.168	−22.599	−6.297	−27.473
UK	22.698	20.940	22.023	21.034	21.678	21.757	21.698	20.965	21.852	22.852	0.436	4.576	5.032
MEANS	18.328	16.608	19.619	18.400	19.585	17.732	18.378	18.146	23.130	26.048	30.439	12.614	46.893

Appendix A.2. Monthly Imports by Partner

NG. Table A3 shows the monthly mean ('IMP') and amount of NG in mcm traded by the ten major partners of European countries since 2014 ('IMP.total').

Table A3. Imports of NG of all European countries across the biggest 10 partners.

Partner	IMP	IMP.Total	IMP.20-22	IMP.Total. 20–22	Perc.IMP	Perc.IMP. 20–22
Total	3395.917	10,636,010.710	3034.512	3,207,478.901	100	100
NO	543.662	1552,156.281	591.233	468,256.149	14.593	14.599
RU	426.391	1240,370.225	540.114	458,016.377	11.662	14.280
DE	344.376	982,504.994	334.328	264,787.526	9.238	8.255
UA	285.135	796,382.094	222.055	165,431.094	7.488	5.158
SK	234.642	650,427.333	239.623	173,487.333	6.115	5.409
NL	232.526	648,747.239	206.129	152,741.451	6.100	4.762
AT	211.324	592,340.143	212.660	160,558.143	5.569	5.006
CZ	180.621	502,487.484	234.987	172,480.484	4.724	5.377
PL	155.580	429,090.134	128.733	91,400.134	4.034	2.850
BE	137.993	389,552.873	155.687	118,322.188	3.663	3.689

To identify the evolution of dependency by partner, we highlight volumes of imports during the pandemic and the war in Ukraine ('IMP.20–22' and 'IMP.total.20–22'), as well as rates during all time periods since 2020. Results reveal the importance of Norway and Russia as main partners, corresponding to around 26% of total NG traded among European countries. In the last two years, the Russia's market share increased to 14.28%. Other important partners are Germany, Ukraine, Slovakia and the Netherlands, who are all above 6%. When the analysis is disaggregated by the two biggest partners, Germany is the major importer of NG from Norway and Russia with similar growth rates over the last two years (14.27% and 6.99%). It is also worthwhile to highlight that imports of Turkey from Norway declined (−76.64%) while the growth rates climbed 31.69% with Russia (Table A4a,b)).

Table A4. Imports of NG by two main partners: (**a**) Norway and (**b**) Russia.

Country	IMP	IMP.Total	IMP.20–22	IMP.Total.20–22	Perc.
(**a**)					
DE	2552.306	270,544.466	2916.749	99,169.466	14.279
UK	2426.708	198,990.061	1774.566	17,745.660	−26.874
FR	1325.82	141,862.781	1331.565	46,604.781	0.433
NL	1309.018	140,064.890	1676.087	58,663.028	28.042
BE	1246.794	133,407	1281.706	44,859.700	2.800
LT	93.016	9859.700	115.315	3920.700	23.973
ES	55.520	5496.470	23.314	629.470	−58.008
DK	22.247	2358.158	0.358	12.158	−98.391
TR	15.278	1466.660	3.569	85.660	−76.640
(**b**)					
EA	4862.142	481,352.039	6243.693	168,579.701	28.414
DE	3980.827	421,967.632	4259.342	144,817.632	6.996
TR	1344.350	143,845.400	1770.383	61,963.400	31.691
BG	952.159	100,928.895	807.556	27,456.895	−15.187
RS	198.958	14,126	194.686	6814	−2.147
BE	183.157	19,414.600	521.576	17,733.600	184.77
NL	138.545	14,685.783	313.200	10,648.783	126.064
LV	137.400	14,564.412	325.631	11,397.074	136.995
ES	132.633	14,059.118	117.886	4008.118	−11.119
UK	83.175	6487.641	232.911	1397.469	180.025

LNG. In terms of LNG imports, main partners changed once compared to NG. Main partners come from very different regions of world: Qatar, Algeria, Nigeria and USA, meaning that the dependency on Russia and Norway decreases. In this sense, LNG may be a good alternative to reduce the dependency on NG (Table A5).

Table A5. Imports of LNG of all European countries across the biggest 10 partners.

Partner	IMP	IMP.Total	IMP.20–22	IMP.Total.20–22	Perc.IMP	Perc.IMP.20–22
TOTAL	463.834	1,037,132.323	613.586	518,480.538	100	100
QA	122.426	346,465.513	129.063	100,410.635	33.406	19.366
DZ	83.827	234,714.869	123.038	92,032.631	22.631	17.750
NG	72.211	203,128.278	103.445	78,411.556	19.586	15.123
US	51.658	146,761.639	145.797	114,013.069	14.151	21.990
RU	34.347	97,168.493	96.544	74,242.645	9.369	14.319
NO	19.232	53,754.667	17.032	12,535.748	5.183	2.418
TT	14.662	40,687.110	17.721	12,847.533	3.923	2.478
NSP	9.327	25,967.505	4.790	3467.945	2.504	0.669
PE	8.377	23,027.462	2.430	1691.606	2.220	0.326
EG	4.273	11,738.384	12.786	8937.086	1.132	1.724

Appendix A.3. Monthly NG Exports by Partner

Table A6 shows that the largest amounts of exported gas come from Germany, Austria and Czechia which represent almost 50% of NG exports.

Table A7 reveals that all partners for the exports of LNG are not European countries. Among these NSP, Other Asian countries ('ASI_OTH') and China represent almost 75%. This confirms that, currently, LNG is used less frequently in Europe.

Table A6. Exports of NG of all European countries across the biggest 10 partners.

Partner	EXP	EXP.Total	EXP.20–22	EXP.Total. 20–22	Perc.EXP	P.EXP.20–22
Total	1647.659	4,961,102.011	1463.662	1,387,551.257	100	100
DE	367.125	1,034,924.642	378.516	287,293.492	20.861	20.705
AT	267.411	744,472.534	276.611	203,585.534	15.006	14.672
CZ	232.409	644,702.793	295.095	214,238.793	12.995	15.440
IT	168.841	472,249.427	172.505	127,480.835	9.519	9.187
FR	129.713	361,120.228	95.909	70,588.828	7.279	5.087
BE	127.713	358,489.892	111.192	82,949	7.226	5.978
NL	101.307	281,834.936	125.659	92,107.981	5.681	6.638
CH	69.628	195,586.259	63.946	48,279.165	3.942	3.479
UA	46.389	128,404.168	23.452	16,885.168	2.588	1.217
SK	34.884	96,906.959	57.136	41,708.959	1.953	3.006

Table A7. Exports of LNG of all European countries across the biggest 10 partners.

Partner	EXP	EXP.Total	EXP.20–22	EXP.Total. 20–22	Perc.EXP	P.EXP. 20–22
Total	25.665	55,281.390	47.924	36,614.052	100	100
ASI_OTH	14.988	11,286.200	13.702	9687.600	20.416	26.459
CN	9.438	7050.379	10.124	7035.907	12.754	19.216
NSP	8.083	22,575.737	2.471	1811.319	40.838	4.947
TW	1.939	1438.684	1.843	1278.900	2.602	3.493
SG	1.487	4073.820	2.445	1691.820	7.369	4.621
KR	1.471	1085.500	1.569	1085.500	1.964	2.965
IN	1.154	3168.990	2.885	2013.990	5.732	5.501
JP	1.104	3025.790	0.278	192.600	5.473	0.526
BR	1.058	2898.007	0.043	30.007	5.242	0.082
AME_OTH	0.944	696.948	1.007	696.948	1.261	1.903

Appendix A.4. Energy Dependency by Country of Origin

Table A8 shows European countries' dependency from the seven biggest NG providers. These seven partners comprise three distinct regions in the world: Algeria ("DZ") and Niger ("NG") located in Africa; Qatar ("QA") in the Middle East; and Russia ("RU") and Norway ("NO") in Europe. This is a very important aspect since geographical closeness seems to contribute to the choice of corresponding partners. Indeed, when looking to market shares, we can observe that most NG from south European countries (Portugal, Spain, Italy and Turkey) comes from Nigeria and Algeria. We can highlight various rates, such as 53.79% of the Portuguese gas is imported by Nigeria and 64.1% of Spain, Italy and Turkey's gas is provided by Algeria. We can also see that the dependence of Portugal on Nigeria gas increased in 2020 compared to 2015–2019, and Spain decreased the importance of Algeria by purchasing NG from Russia and USA. Russia is clearly the biggest partner of several European countries, with dependencies above 50%, more than 90% or even 100%. Norway is also another important partner, mainly to some north European countries, such as Belgium, France, Lithuania and the Netherlands (all above 35% in 2020). Qatar has also some countries with imports, most of them around 10%. Finally, there are two other major partners. The United Kingdom exports mainly gas to Ireland and the Netherlands (18.9%), while the USA has five countries with dependencies above of 10% (Greece, Lithuania, Portugal, Malta and Spain). On average, European countries imported much more gas from USA in 2020 than between 2015 and 2019. Table A9 gives an overview of dependency shares by partner for all European countries in 2020, and mean shares between 2015 and 2019.

Table A8. Energy import dependency shares by European country.

Countries	Dep.Total	Dep.Total. 20–22	P.Dep.Total	Dep.Gas	Dep.Gas. 20–22	P.Gas	Dep.LNG	Dep.LNG. 20–22	P.LNG
AT	64.738	58.324	−9.910	87.921	73.247	−16.690	23.580	0	−100
BA	29.213	25.401	−13.050	100.002	100	−0.002	0	0	–
BE	78.357	78.055	−0.390	100.002	99.132	−0.870	55.763	0	−100
BG	40.185	37.882	−5.730	94.420	96.420	2.118	0	0	–
CZ	31.119	38.898	25.000	97.282	86.038	−11.558	0	0	–
DE	62.262	63.711	2.330	87.912	89.104	1.356	0	0	–
DK	5.624	44.856	697.580	−51.160	37.417	−173.137	0	0	–
EA	–	–	–	–	–	–	–	–	–
EE	13.867	10.502	−24.270	100	100	0	0	0	–
EL	69.922	81.415	16.440	99.878	100.694	0.817	0	0	–
ES	74.552	67.890	−8.940	99.836	97.474	−2.366	0	0	–
EU27_2020	56.717	57.497	1.380	74.655	83.597	11.978	90.591	98.705	8.957
FR	48.064	44.463	−7.490	99.230	94.720	−4.545	53.266	0	−100
GE	73.537	79.653	8.320	99.636	99.671	0.035	0	0	–
HR	50.234	53.589	6.680	33.696	68.774	104.101	0	0	–
HU	57.475	56.628	−1.470	82.401	75.622	−8.227	16.201	0	−100
IE	81.215	71.302	−12.210	77.248	63.742	−17.484	0	0	–
IT	78.650	73.454	−6.610	90.704	92.848	2.364	0	0	–
LI	–	–	–	–	–	–	–	–	–
LT	71.111	74.909	5.340	100.088	98.929	−1.158	7.143	0	−100
LU	96.268	92.458	−3.960	100	100	0	0	0	–
LV	51.148	45.481	−11.080	96.293	100.099	3.953	0	0	–
MD	75.648	75.989	0.450	99.935	99.544	−0.391	0	0	–
MK	51.566	63.291	22.740	100.006	99.992	−0.014	0	0	–
NL	41.911	68.068	62.410	−39.367	45.032	−214.390	95.849	104.262	8.777
PL	33.711	42.760	26.840	74.038	78.252	5.692	0	0	–
PT	75.993	65.261	−14.120	100.206	99.280	−0.924	0	0	–
RO	23.116	28.201	22.08	16.282	16.634	2.162	−10.928	−27.806	154.447
RS	31.545	29.836	−5.420	82.196	79.643	−3.106	30.115	41.867	39.024
SE	33.271	33.511	0.720	100	100	0	0	0	–
SI	49.538	45.801	−7.540	99.420	99.371	−0.049	0	0	–
SK	63.822	56.329	−11.740	100.369	88.052	−12.272	0	0	–
TR	73.636	70.648	−4.060	99.078	98.580	−0.503	0	0	–
UA	34.094	34.057	−0.110	54.389	31.181	−42.670	2.303	0	−100
UK	35.150	–	–	42.073	–	–	−9.536	–	–

Table A9. Natural gas import dependency shares by partner.

Country	DZ	NG	NO	QA	RU	UK	US	DZ. 15–19	NG. 15–19	NO. 15–19	QA. 15–19	RU. 15–19	UK. 15–19	US. 15–19
AL	–	–	–	–	–	–	–	–	–	–	–	–	–	–
AT	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BA	0	0	0	0	100	0	0	0	0	0	0	100	0	0
BE	0.040	0.210	50.180	11.960	14.450	6.640	3.960	0.112	0.104	47.116	12.286	9.260	6.852	0.422
BG	0.980	1.050	0.310	2.510	83.770	0	5.430	0.430	0.342	0.422	0.388	97.130	0	0.174
CY	NA	NA	NA	NA	NA	NA	NA	–	–	–	–	–	–	–
CZ	0	0	0	0	100	0	0	0	0	0.360	0	99.640	0	0
DE	0	0.060	23.790	0.040	68.660	1.560	0.400	0.008	0.014	11.070	0	52.470	0.398	0
DK	0	0	19.580	0	62.320	0	0	–	–	–	–	–	–	–
EE	0	0	1.290	0	98	0	0.710	0	0	0.124	0.006	99.838	0	0.006
EL	5.730	5.320	2.440	12.260	42.220	0.210	25.700	18.374	2.842	3.994	3.562	63.120	0.032	1.442
ES	29.610	12.830	7.290	8.950	11.520	0	15.890	50.164	12.754	10.618	9.822	2.940	0.008	2.932
FI	0	0	0.810	0	82.230	0	0.290	0	0	0.808	0	99.058	0.018	0.006
FR	8.130	7.590	38.910	1.770	19.040	1.040	2.880	8.568	5.506	45.182	3.164	20.354	1.062	0.784

Table A9. *Cont.*

Country	DZ	NG	NO	QA	RU	UK	US	DZ. 15–19	NG. 15–19	NO. 15–19	QA. 15–19	RU. 15–19	UK. 15–19	US. 15–19
GE	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HR	0	0	0	0	64.110	0	0	0	0	0.072	0	51.288	0.020	0
HU	0	0	0	0	95	0	0	0	0	0	0	95	0	0
IE	0	0	0	0	0	100	0	0.486	0.148	35.622	9.090	1.086	46.876	0.974
IS	–	–	–	–	–	–	–	–	–	–	–	–	–	–
IT	22.840	0.350	11.880	10.490	43.720	0.190	2.720	23.078	0.168	5.698	9.286	46.940	0.306	0.706
LI	3	0	23.990	0	47	0	0	0.010	0.015	29.815	0.005	53.260	0.885	0.005
LT	0	0	37.510	0	41.790	0	20.690	0	0.752	42.288	0	54.914	0	2.046
LU	0.090	0	32.900	0	27.230	0	0	0.098	0	45.294	0	26.422	0	0
LV	0	0	0	0	100	0	0	0	0	0	0	100	0	0
MD	0	0	0	0	100	0	0	0	0	0	0	99.964	0	0
ME	–	–	–	–	–	–	–	–	–	–	–	–	–	–
MK	0	0	0	0	100	0	0	0	0	0	0	100	0	0
MT	0	0	0	0	0	0	18.820	0	4.730	1.580	0	0.107	0.077	8.770
NL	0	0.680	37.310	0.460	33.180	18.880	4.840	0.450	0.550	48.830	1	34.680	5.700	2.750
NO	–	–	–	–	–	–	–	–	–	–	–	–	–	–
PL	0	0.460	6.040	13.370	69.560	0	5.800	0	0	2.980	9.286	77.212	0.004	1.328
PT	9.340	53.790	1.370	2.300	9.700	0	18.870	33.912	33.090	0.718	9	0.380	0.026	8.068
RO	0	0	0	0	90.960	0	0	0	0	0	0	97.434	0	0
RS	0	0	0	0	100	0	0	0	0	0	0	100	0	0
SE	0	0.040	12.100	0.030	27.650	1.050	0.270	0.006	0.008	17.642	0.496	1.730	0.414	0.052
SI	0.070	0	0.030	0.030	8.820	0	0.010	0.076	0	0.028	0.054	26.268	0	0
SK	0	0	0	0	85.450	0	0	0	0	0	0	96.682	0	0
TR	11.650	3.950	0.290	6.770	33.680	0	6.220	9.504	3.884	0.598	3.998	48.206	0.032	1.100
UA	0.020	0.040	2.270	0.680	53.360	1.200	9.320	0.950	0.286	9.702	1.176	34.466	2.148	0.132
UK	–	–	–	–	–	–	–	0.918	0.282	69.732	17.440	2.870	0.586	1.838
Mean	2.691	2.540	9.126	2.106	53.336	3.846	4.201	4.328	1.926	12.656	2.649	52.727	1.925	0.986

Appendix A.5. NG Pricing Components

Table A10. Distribution of shares of gas prices components for household consumers.

Country	NETC	NRG_SUP	OTH	TAX_CAP	TAX_ENV	TAX_FEE_ LEV_CHRG	TAX_RNW	VAT
AT	27.998	31.527	2.375	0	4.569	20.238	0	13.294
BA	9.992	64.636	0	0	0	12.686	0	12.686
BE	23.909	43.222	0.552	0.601	0.891	16.434	0.039	14.351
BG	22.617	54.689	−4.114	0	0	11.347	0	15.461
CZ	14.976	58.984	0.078	0	0	13.020	0	12.942
DE	22.348	32.469	1.229	0	8.989	22.591	0	12.373
DK	14.026	24.522	0	0	16.871	30.726	0	13.855
EA	24.914	33.150	−0.680	0.762	8.544	20.968	0.904	11.439
EE	10.181	52.036	0	0	5.373	18.891	0	13.518
EL	22.047	63.702	0.614	0.383	1.550	7.125	0	4.578
ES	32.666	30.740	1.053	1.017	1.849	18.297	0.200	14.180
EU27_2020	24.376	34.323	−0.623	0.697	8.019	20.650	0.846	11.712
FR	31.090	32.407	0	3.605	5.356	18.251	0	9.291
GE	37.372	36.159	0	0	0	13.235	0	13.235
HR	28.425	38.242	0	0	0	16.667	0	16.667
HU	20.716	44.211	0.005	0	0	17.536	0	17.532
IE	24.644	44.410	0	0	5.895	15.473	0	9.578
IT	26.242	41.333	−4.804	0	9.259	16.212	1.127	10.630

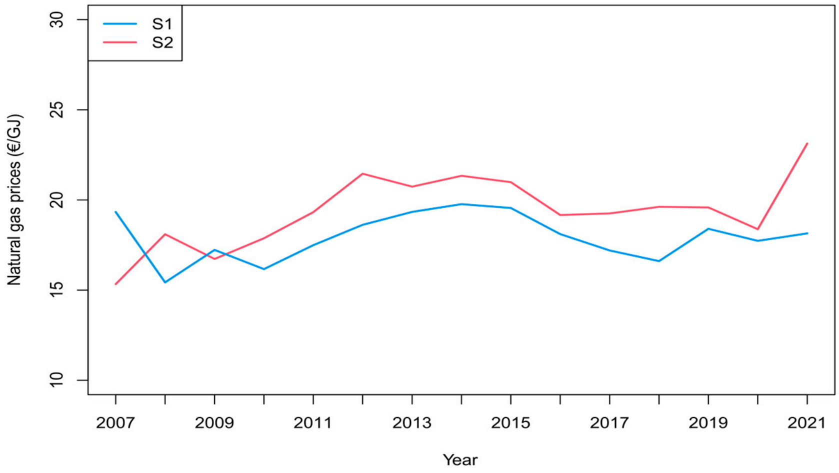
Table A10. *Cont.*

Country	NETC	NRG_SUP	OTH	TAX_CAP	TAX_ENV	TAX_FEE_ LEV_CHRG	TAX_RNW	VAT
LI	60.103	13.577	0	0	6.951	13.160	0	6.209
LT	37.632	29.526	0	1.686	0	16.421	0	14.735
LU	28.121	42.734	1.683	0	6.456	14.573	0	6.434
LV	46.556	21.623	0	0.050	1.267	15.911	0	14.594
MD	28.486	57.717	0	0	0	6.898	0	6.898
MK	7.771	65.758	0	0	0	13.235	0	13.235
NL	14.895	20.992	0	0	16.288	32.056	3.977	11.792
PL	22.492	44.552	0.001	0.002	0.003	16.478	0.854	15.618
PT	26.731	30.598	2.259	0	5.165	21.336	0	13.912
RO	17.283	55.182	0	0	0	13.768	0	13.768
RS	10.661	72.114	0.305	0	0	8.613	0	8.308
SE	38.937	17.141	NA	NA	6.353	21.961	NA	15.608
SI	19.716	35.366	0	0	6.194	22.459	2.281	13.983
SK	42.785	28.645	0	0	0	14.285	0	14.285
TR	14.305	57.582	0.946	0	0	14.056	0	13.110
2021.Mean	25.303	41.026	0.027	0.275	3.813	16.835	0.320	12.419
2020.Mean	25.454	40.387	0.309	0.376	3.725	17.078	0.379	12.474
2019.Mean	24.943	41.584	0.344	0.346	3.413	16.737	0.282	12.351
2018.Mean	27.092	42.340	0.581	0.275	2.955	17.460	0.145	13.636
2017.Mean	27.632	41.557	0.674	0.267	2.904	17.741	0.211	13.830

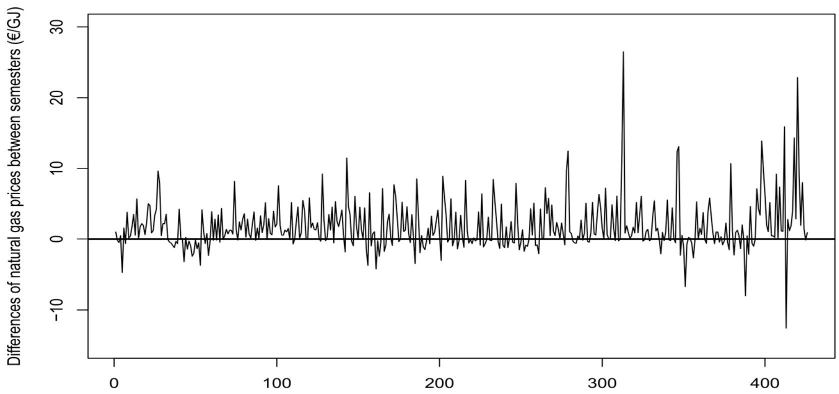
Appendix B. Additional Figures

Seasonality Effects

Figure A1 confirms the seasonality of NG prices. Since 2009 onwards, mean NG prices for all European countries in the second semester are unambiguously higher than those in the first semester. This conclusion is confirmed when confronting time differences of NG prices between first and second semesters by country. Many governmental measures were established regarding society, economics or financial politics. Among these measures, the lockdowns were some of most important with significant direct effects on lifestyles. Table A1 in Appendix A shows mean prices considering the total time period ('Means') and gas prices over the last semesters from 2018 to the first semester of 2022 (the last time point with data). In this way, we intend to represent possible seasonality associated to gas price. The last columns correspond to the differences (in percentage) between pre- versus post-pandemic ('Dif.21S2-20'); post-pandemic versus the effect of war in Ukraine ('Dif.22-21S2'); and the current situation versus prepandemic ('Dif.22-20'). Therefore, we aim to recognize the importance of these two crucial moments on the gas prices. From these results, we may conclude that, during the first year of the pandemic crisis (2020), gas prices did not change much when comparing with the pre-COVID-19 period. Indeed, for all European countries, behaviors are quite similar and changes were mostly due to seasonality. However, prices, on average, were slightly lower in 2020 (17.73€) than in 2019 (18.40€), but higher than 2018 (16.61€). During the first semester of 2021, the average price fell again, following the usual trends of seasonality (18.15€). However, this situation started changing in the second semester, with a difference of 30.4% between prices after the end of the post-COVID-19 pandemic (second semester of 2021) and the beginning of 2020. Serbia, Croatia, Bulgaria, Lithuania, Portugal, Sweden and Bosnia and Herzegovina had the highest growth of gas prices, all with rates above 50%. Among the countries with declining prices, we can highlight Ukraine, Spain, France and Hungary.



(**a**)



(**b**)

Figure A1. NG mean prices in the D1 band (2007–2022): (**a**) first versus second semester (unordered); (**b**) first versus second semester (ordered by year and country).

On average, across the European countries, prices increased 33.7% after the pandemic period. The advent of the war in Ukraine coincided with other rises in gas prices. During this period, prices between the last semester of 2021 and the first semester of 2022 increased 12.6%. Romania, Slovenia and Belgium were the countries with the highest rates (above 50%). Lithuania and Czechia were some of those with the lowest differences (below −10%). Unfortunately, there are not yet values for Germany and the Netherlands in 2022, and, consequently, it is not possible to assess the progression in these two countries for this period. Finally, on average, prices from the pandemic crisis to the current situation increased about 46.9%, which has represented a major crisis faced by almost European countries. Only two countries had a decrease in prices (Ukraine and Hungary, with −27.3% and −8.8%, respectively). There were yet other countries, such as France, Spain, Greece, United Kingdom and Estonia, with small increases in prices (below 10%). However, in general, the majority of prices increased. Prices in Romania, Bosnia and Herzegovina, Belgium, Slovenia and Serbia climbed more than 100%. Poland, Portugal, Sweden, Bulgaria, Turkey and Italy were others with percentages above the mean of European countries. Figure A1 presents these differences ordered by year from 2007 to 2022 along with the name of European countries. As we can observe, almost all differences are positives, meaning that prices in the second group are, in general, higher than the first one. After the explanatory analysis regarding NG prices for type of consumption < 20 GJ (Band D1), in next sections, we investigate possible factors that have contributed to the evolution of gas prices and, in particular, since the beginning of the COVID-19 pandemic in 2020. To this end, we begin to analyze how the spot market gas prices have changed since 2007 and compare them with prices for households.

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