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Price and income elasticity of natural gas demand in Europe and the effects of lockdowns due to Covid-19

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ABSTRACT

We analyse a panel of 25 European-countries to provide novel estimates of monthly own-price, cross-price, and income elasticities of natural-gas-demand from 2005 to 2020. We find that: *first*, there is an European Standard Behaviour (ESB) with a strong-seasonal component. *Second*, we identify three different patterns from the ESB: 1) France, Denmark and Estonia present slightly positive elasticities in the short-run and a lack of sensitivity to own-price variations in the long-run –we argue this phenomenon is due to a higher weight of heating demand-. 2) Latvia presents a lower sensitivity to own-price variations than the ESB -we argue due to the role of natural gas as a unique backup technology in the power sector-. 3) In Portugal, natural gas showed the highest own-price elasticities – we argue that natural gas is used mainly in the power sector with substitutive technologies-. *Finally*, we find that Covid-19-lockdowns highly impacted natural-gas-demand, confirming the "*double-heating-effect*".

1. Introduction

Natural gas represented 24% of total primary energy demand in 2020 [1], a role that is set to remain constant out to 2040 in the IEA's central scenario (Stated Policies Scenario) [2]. Even in the IEA's Sustainable Development Scenario, natural gas is expected to account for 23% of total primary energy demand. The unique characteristics of natural gas reinforce its important role in the world's energy mix – particularly in the context of energy transition. Despite the electrification mega-trend that is core to energy transition, natural gas is crucial to many sectors, such as power (by switching from more polluting fossil fuels and acting as a back-up for renewable generation) and industry (by minimizing the emissions in hard-to-decarbonize subsectors due to either economic reasons or high temperature process requirements). However, this buoyant outlook, as a global level, faces regional challenges based on the different regional climate ambitions and competing national strategies.

Europe is at the forefront of the fight against climate change. The European Union has recently increased its 2030 target of cutting greenhouse gas emissions to at least 55% compared with 1990 levels. This new pledge is consistent with achieving a carbon neutral economy by 2050 [3]. A fully decarbonized economy implies a major transformation in the energy system. To make this target a reality, governments will be required to implement a full battery of policy measures, ranging from new environmental taxes to establishing renewable quotas. This new paradigm is forcing the natural gas sector to enter in a different phase in Europe: demand growth will decelerate and eventually decline in the region. But the sector is already adapting to a net-zero future, as is poised to play a key role on the long-term energy system. All policies currently considered to tackle climate change could threaten natural gas demand growth. This impact is mostly manifested in the form of higher prices reducing the competitiveness of the fuel versus renewable energy sources. The ramifications of this shift will bring monumental changes to consumers behaviours, industry competitiveness, and social welfare.

Understanding demand behaviour is crucial to tailoring future measures to reach climate goals while minimizing economy distortions [4]. This paper analyses the effects of price changes on European monthly gas demand as well as other drivers of growth. Quantifying meaningful estimated own-price, cross-price and income elasticities of natural gas demand has already been shown to be a very useful tool for policy purposes [5–7].

Over the last five decades, many studies have estimated the own-price and income elasticities of natural gas demand in different

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Table 1
Selected previous studies on price and income elasticities of natural gas demand.

Reference	Location	Period	Results
Berkhout et al. [9]	Netherlands	1996	OPE: −0.2
Asche et al. [10]	12 European countries	1978–2002	S-OPE: −0.24 to 0.02 L-OPE: −1.84 to −1.15 S-IE: 0.03 to 0.33 L-IE: 2.09 to 2.25
Serletis et al. [15]	USA	1960–2007	OPE: −0.5 to −0.14
Yoo et al. [31]	South Korea	2005	OPE: −0.243 to −0.226 IE: 0.335 and 0.496
Andersen et al. [21]	13 OECD countries	1978–2003	S-OPE: −0.15 to −0.06 L-OPE: −0.84 to −0.16
Bernstein and Madlener [22]	12 OECD countries	1980–2008	S-OPE: −0.24 L-OPE: −0.51 S-IE: 0.45 L-IE: 0.94
Serletis et al. [23]	15 countries (both non-OECD and OECD)	1980–2006	S-OPE: −0.73 to −0.32 L-OPE: −0.65 to 2.17
Wadud et al. [32]	Bangladesh	1981–2008	OPE: −0.25 to 0.15 IE: 0.28 to 0.76
Alberini et al. [7]	USA	1999–2007	S-OPE: −0.566 L-OPE: −0.693
Payne et al. [17]	Illinois	1970–2007	S-OPE: −0.185
Steinbuks [11]	UK	1990–2007	S-OPE: −0.20 L-OPE: −0.28
Bilgili [24]	8 OECD countries	1979–2006	OPE: 0.90 to 3.76
Dilaver et al. [12]	OECD Europe	1978–2011	L-OPE: −0.16 L-IE: 1.19
Yu et al. [27]	China	2006–2009	OPE: −0.779 IE: 1.235
Burke and Yang [26]	44 countries	1978–2011	S-OPE: −0.68 to −0.5 S-IE: 0.7 to 1.13
Sun et al. [28]	China	2013	OPE: −1.431 IE: 0.207
Zhang et al. [29]	China	1992–2011	S-OPE: −1.00 to 3.10 L-OPE: −0.22 to 5.73 IE: 2.05 to 2.31
Filippini and Kumar [13]	Switzerland	2010–2014	OPE: −0.73
Malzi et al. [25]	19 OECD countries	1980–2016	S-OPE: −0.0002 L-OPE: −0.0015
Alberini et al. [7]	Ukraine	2013–2017	OPE: 0.16
Burns [20]	USA	1970–2016	OPE: −0.19 IE: −0.49

Note: OPE: Own-price elasticity, IE: Income elasticity, S: Short-run; L: Long-run.

countries and regions. These have spanned different time periods and employed different econometric approaches. As [8] highlighted, the existing literature on the topic has been characterized by several conflicting findings. Table 1 summarizes some of the major studies published in the recent years.

Focusing on the literature that analyses Europe [9], reported own-price elasticities of demand for natural gas of −0.2 for the Netherlands. This result was used to assess the impact on households' energy demand of the energy tax reform implemented in 1996 [10]. obtained, for 12 European countries[1] using yearly data from 1978 to 2002, the estimated short-run own price elasticity for natural gas was from −0.24 to 0.02 while the long-run own-price elasticity was ranging from −1.15 to 1.84. The short-run and long run income elasticities were estimated with results that range from 0.03 to 0.33 and from 2.09 to 2.25, respectively [11]. studied the case of UK from 1990 to 2007 obtaining an estimated own-price elasticity of −0.20 (short-run) and −0.28 (long-run) [12]. analysed several European countries from 1978 to 2011, finding an estimated own-price elasticity of −0.16 and an estimated income elasticity of 1.19; and using these results to predict natural gas consumption by 2020 [13]. used household-level panel data from 2010 to 2014 for 958 Swiss households and showed that the estimated own price elasticity of gas demand is around −0.73. Since Swiss households originate primarily demand for natural gas for space and water heating purposes, an inelastic demand is expected [7]. considered the case of the residential sector in Ukraine, focusing on the effects coming from major implemented tariff reforms. The evidence provided of an inelastic natural gas demand, especially for wealthier households, could be relevant if an energy tax scheme – where wealthier households subsidize the consumption of the poorer ones – was introduced. Despite the conflicting aspects of some of the results, the literature tends to concur that natural gas demand is inelastic with estimated short-run own price elasticity closer to zero and estimated long-run own price elasticity higher in absolute terms.

Natural gas demand in United States has been extensively studied [14]. obtained results, with data for ten regions in the USA between 2000 and 2006, for natural gas own-price elasticity and income elasticity in residential sector [15–17]. focused on the USA obtaining results for periods that go from 1999 to 2007 and from 1970 to 2007, respectively [18]. considered the case of Colorado highlighting the mismatch between the time frame in which price fluctuations are perceived and the one key to modify the stock of equipment [19]. examined the demand for natural gas in the residential, commercial, and industrial sectors of the North-eastern United States, comprising nine states and using annual state-level panel data over the period between 1997 and 2016 [20]. provided estimates of own price and income elasticity of natural gas consumption by residential users in the U.S. from 1970 to 2016, highlighting the time-varying nature of own-price and income elasticity.

[21] analysed 13 countries of the Organization for Economic Cooperation and Development (OECD) from 1978 to 2003 obtaining own-price elasticities ranging from −0.15 to − 0.06 (short run) and from −0.89 to − 0.16 (long run) [22]. analysed 12 OECD countries from 1980 to 2008 obtaining estimated own-price elasticities of −0.24 (short-run) and −0.51 (long-run) and income elasticities of 0.45 (short-run) and 0.94 (long-run) [23]. focused on 15 OECD and non-OECD countries from 1980 to 2006, finding an estimated short-run own-price elasticity for natural gas from −0.32 to 0.73 while the long-run own price elasticity was ranging from −0.65 to 2.17 [24]. considered 8 OECD countries from 1979 to 2006 obtaining own-price elasticities ranging from 0.90 to 3.76. More recently, and using data of 19 OECD countries from 1980 to 2016, it was found that income elasticity toward natural gas use in the long run is positive while price elasticity is negative [25]. Elasticities are used to evaluate the effectiveness of environmental policies on residential natural gas use and incorporate the role of economic, demographic, and environmental factors in the context of OECD countries [26]. analysed 44 countries over the period 1978–2011 and found that own-price elasticity ranges from −0.68 to − 0.50 while income elasticity from 0.70 to 1.13 [6]. showed a literature review of various estimates for

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[1] Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Spain, Switzerland, and the UK.

energy demand responses focusing specially upon lower-income industrializing economies and covering different products including natural gas.

[27,28] have focused on China, achieving results both for own-price elasticity and income elasticity [29]. constructed an autoregressive distribution lag model to study the elasticity of natural gas demand in China's various subsectors with yearly data from 1992 to 2015. Using annual data from 1971 to 2009 [30], studied the case of Iran [31]. analysed the case of South Korea with cross-sectional data for the year 2005, obtaining an estimated own-price elasticity that goes from −0.243 to −0.226 and an estimated income elasticity that ranges between 0.335 and 0.496 [32]. focused on the case of Bangladesh from 1981 to 2008, achieving an estimated own price elasticity that ranges from −0.25 to 0.15 and an estimated income elasticity that ranges from 0.28 to 0.76.

Unlike previous work [33], focused on 15 European countries using daily data for the first-time from 2016 to 2020. They found seasonal patterns in the estimated own-price elasticities in the European Union that vary by month, and differences depending on the countries. Fig. 1 shows a very clear seasonal component in European gas consumption (see also how [34] also documents seasonal demand swings in the European gas natural market – although their objective is not the estimation of elasticities). The main two drawbacks of the work of [33] were: (1) the short time period analysed (only covering from 2016 to 2020), and that (2) only 15 European countries were examined. These drawbacks were unavoidable, as daily data was only available under those two restrictions. In this paper, we extend the results in Ref. [33] to a longer time span -from 2005 to 2020- and also covering all European Union countries that have available data (25 countries). Increasing the time period range and the number of countries examined forced us to use a monthly dataset. This is the highest frequency of available data.

According to Ref. [35], European natural gas demand fell by 2.8% year-over-year in 2020 due to the economic shock caused by Covid-19. This demand shock had a heterogeneous impact on the different consumer sectors based on the nature of the consumption [36]. showed that natural gas demand in the residential sector remained very stable in the European Union from 2000 to 2016. This was the case even under the Covid-19 crisis. Residential sector has proven more resilient than other sectors – such as power or industry – despite a warmer-than-usual weather pattern in the second half of the year across Europe that impacted residential heating needs. One of the factors that could have played a role in this is the so called "*double heating effect*". During the lockdowns in Europe in 2020, the residential gas consumption driver was expected to increase as millions of people in Europe were forced to spend more time at home. Despite teleworking protocols, many offices and working centres were forced to remain open, and commercial use should remain steady. This "double consumption" generates a "*double-heating effect*" that could lead to a potential increase in use of natural gas. Although many sources in the sector pointed to the possibility of the existence of this effect [37] and the impacts of widespread practice of teleworking in Europe [33,38] were the first in finding evidence of this phenomenon. Apart from reanalysing the existence of the "*double heating effect*" during a longer period (2005–2020) and with a monthly dataset, we have also examined if this effect is stronger in countries where natural gas consumption represents the primary component of residential energy demand. Table 2 shows the share of each fuel in final energy consumption in the residential sector in 2017 for the 25 European countries analysed in this paper.[2] Therefore, we expect that countries such as Italy, Netherlands, Slovakia, United Kingdom and Turkey (those with more than 50% of natural gas used in their residential sector) are the ones where the "*double heating effect*" during the covid-19-lockdowns may have been stronger than in those countries with a lower percentage of use of natural gas in the residential sector. We test this hypothesis in our paper.

The plan of the paper is as follows. In Section 2 we present the model. Section 3 provides a description of the dataset. Section 4 analyses the results and Section 5 concludes.

2. Model

Following [26],[3] and [20], we construct an autoregressive distributed lag (ARDL) model and, following [42] – where they allowed for province and/or time specific elasticities-, we also introduce iteration effects to allow for possible elasticities that may be country and/or time varying. The model has the following shape with a double logarithmic specification in a panel data context [43,44].

$$\begin{aligned} lnQ^{g}_{i,t} = {} & \alpha_0 + \sum_{j_1=1}^{u_1}\alpha_{1,j_1} lnQ^{g}_{i,t-j_1} + \sum_{j_2=0}^{u_2}\alpha_{2,j_2} lnP^{g}_{i,t-j_2} + \sum_{j_3=0}^{u_3}\alpha_{3,j_3} lnIPI_{i,t-j_3} \\ & + \sum_{j_4=1}^{11}\alpha_{4,j_4} dumon_{j_4} {}^{*} lnP^{g}_{i,t} + \sum_{j_5=1}^{24}\alpha_{5,j_5} ducountry_{j_5} {}^{*} lnP^{g}_{i,t} \\ & + \sum_{j_5=1}^{24}\alpha_{6,j_5} ducountry_{j_5} {}^{*} lnP^{c}_{i,t} + \sum_{j_5=1}^{24}\alpha_{7,j_5} ducountry_{j_5} {}^{*} lnP^{CO_2}_{i,t} \\ & + \sum_{j_6=0}^{u_4}\pi_{1,j_6} HDD_{i,t-j_6} + \sum_{j_7=0}^{u_5}\pi_{2,j_7} HDD^{2}_{i,t-j_7} + \sum_{j_8=0}^{u_6}\pi_{3,j_8} CDD_{i,t-j_8} \\ & + \sum_{j_9=0}^{u_7}\pi_4 j_9 CDD^{2}_{i,t-j_9} + \sum_{j_{10}=0}^{u_8}\pi_{5,j_{10}} \mathrm{LOCK\_DOWN}_{i,t-j_{10}} \\ & + \sum_{j_{11}=0}^{u_9}\pi_{6,j_{11}} \mathrm{LOCK\_DOWNxPeak}_{i,t-j_{11}} \\ & + \sum_{j_5=1}^{24}\pi_{7,j_5} ducountry_{j_5} {}^{*}\mathrm{LOCK\_DOWNxPeak}_{i,t} + \sum_{j_{12}=0}^{u_{10}}\alpha_{8,j_{12}} lnP^{c}_{i,t-j_{12}} + \mu_i + \varepsilon_{i,t} \end{aligned} \qquad (1)$$

where $i = 1, \ldots, N$ indicates the country and $t = 1, \ldots, T$ the time period. For country i and time period t, $Q^{g}_{i,t}$ denotes the demand for natural gas; $P^{g}_{i,t}$ is the real price of natural gas; $IPI_{i,t}$ is the real Industrial Price Index; $P^{c}_{i,t}$ is the real price of coal as an alternative energy[4]; $P^{CO_2}_{i,t}$ is the real price of CO_2 emissions; μ_i is the unobservable country fixed effects and $\varepsilon_{i,t}$ the unobservable idiosyncratic error term. Dummies for month (*dumon*) and country (*ducountry*) were also included in (1) in the consideration of possible spatial and temporal effects on the consumption of natural gas and iteration effects as in Ref. [42]. Alternative ways to introduce the space-time neighbouring effect may also be considered such as with a formal spatial panel data approach [45,46], which may be considered in future research and it is an important limitation of our

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[2] Table 2 are the most recent statistics in Eurostat (2020) that are closer to the year 2020 of the Covid-19- lockdowns.

[3] As stated in [[29], page 336], "[39] *showed that the ARDL approach yields consistent estimates of the coefficients irrespective of whether the regressors are I(1) or I(0).* [40] *used the ARDL approach to estimate the energy demand function of Danish resident and compared the estimates of ARDL approach with that of cointegration technique and error correction model (ECM). It turns out that the results of ARDL approach and the cointegration/ECM approach are very similar.* [41] *pointed out that the ARDL model is the general form of the ECM and the partial adjustment model. The ECM and the partial adjustment model impose unreasonable constraints on short-run elasticity and long-run elasticity …*". All this justifies why equation (1), that is specified at price level with a double logarithmic specification, is commonly used in the literature [7,11,13,20,29,42].

[4] We opted for using coal as substitute fuel, as previously done in Refs. [26, 29] to avoid the high correlation between wholesale gas price and wholesale power price. Due to the power market design (pay-as-cleared), wholesale power price is a function of the wholesale gas price in most of the hours either through being the marginal technology or establishing the opportunity cost for technologies such as hydro.

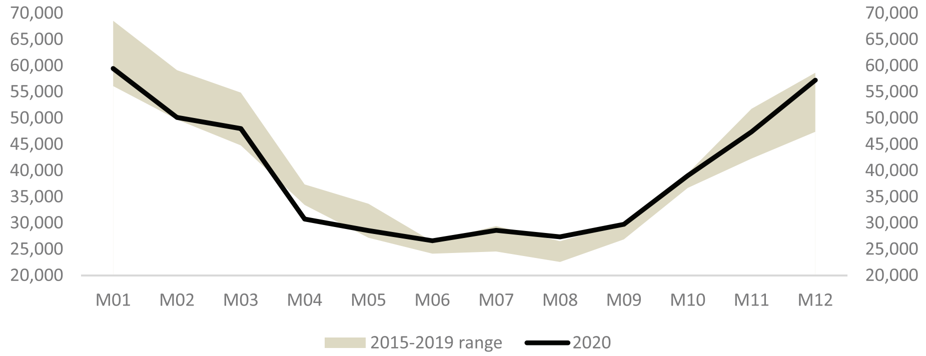

Fig. 1. Europe gas consumption (mcm). Source: Eurostat.

Table 2
Share of fuels in the final energy consumption in the residential sector in 2017 (%) Source: Eurostat (2020).

Countries	Electricity	Derived Heat	Gas	Solid fuels	Oil and petroleum products	Renewables and wastes
EU-27	24.7	8.7	32.1	3.4	11.6	19.5
EU-28	24.6	7.6	36.2	3.1	10.8	17.6
Belgium (BE)	19.6	0.2	41.1	0.9	30.3	8.1
Czechia (CZ)	18.4	14.2	26.7	11.2	0.7	28.9
Denmark (DK)	18.4	36.3	13.4	0.0	4.8	27.0
Germany (DE)	19.9	6.6	40.3	0.9	18.5	13.7
Estonia (EE)	17.0	34.3	5.8	0.1	0.9	41.9
Ireland (IE)	25.3	0.0	21.7	11.7	38.9	2.5
Greece (EL)	36.8	1.3	8.5	0.1	26.5	26.8
Spain (ES)	43.0	0.0	18.3	0.5	18.6	19.7
France (FR)	34.9	3.3	27.3	0.1	12.1	22.4
Italy (IT)	17.5	3.9	51.5	0.0	6.9	20.3
Latvia (LV)	11.7	30.1	9.7	0.5	4.4	43.6
Lithuania (LT)	17.2	31.6	11.0	4.0	3.8	32.3
Luxembourg (LU)	15.9	0.0	48.6	0.0	29.1	6.4
Hungary (HU)	16.8	8.0	48.6	1.6	1.3	23.6
Netherlands (NL)	20.5	3.1	70.9	0.0	0.4	5.1
Austria (AT)	23.5	11.8	20.8	0.3	14.3	29.4
Poland (PL)	13.0	19.4	18.4	31.9	3.3	13.9
Portugal (PT)	38.9	0.0	9.4	0.0	14.4	37.3
Slovenia (SI)	27.2	7.0	10.4	0.0	11.7	43.7
Slovakia (SK)	21.3	20.3	54.4	1.5	0.4	2.2
Finland (FI)	34.3	28.3	0.4	0.1	5.8	31.1
Sweden (SE)	51.7	34.4	0.5	0.0	2.5	10.9
United Kingdom (UK)	23.8	0.7	62.7	1.3	6.2	5.3
Norway (NO)	75.2	2.4	0.1	0.0	1.2	21.2
Turkey (TK)	22.8	0.0	50.9	8.4	1.1	16.8

study. The month October, and country Norway were taken as the reference to avoid de dummy variable trap. We also included other independent variables in equation (1) such as real prices of CO_2[5] as independent variables, but they were not statistically significant. Finally, variables to capture the effect of the lockdown due to the covid-19 (LOCK_DOWN); an iteration effect of the LOCK_DOWN variable multiplied by a variable capturing the peak-day in each of the countries of natural gas demand (Peak), i.e., LOCK_DOWNxPeak; Heating Degree Days (HDD) and Cold Degree Days (CDD) –including their squares-were also included –more information about these variables is given in the following Section-. LOCK_DOWNxPeak was also allowed to vary per country.

We allow for the existence in (1) of lags u_1, u_2, ….,u_{10} and following [19,40], we select them according to F-tests and t-tests to check the statistical significance of the variables as model selection criteria and the within-R^2. Following [18], we also considered up to 12 lags for the demand for natural gas, 6 lags for the different prices, 2 lags for HDD and CDD -which are expected to have a short-influence on demand- and up to 12 lags for the rest of the variables in (1). We obtain from (1) the following monthly short and long-run elasticities of natural gas:

- Short-run own-price elasticity of natural gas demand for country j_5 in a day of month j_4 as[6] $\alpha_{2,0} + \alpha_{4,j_4} + \alpha_{5,j_5}$.
- Long-run own-price elasticity of natural gas demand for country j_5 in a day of month j_4 as[7] $\left(\sum_{j_2=0}^{u_2} \alpha_{2,j_2} + \alpha_{4,j_4} + \alpha_{5,j_5}\right)/\left(1 - \sum_{j_1=1}^{u_1} \alpha_{1,j_1}\right)$.

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[5] With this variable we have tried to capture the effect of climate policy developments and its capacity to modify consumers behaviours. Although there are other policy instruments at national level, the heterogenous nature of these programmes and the different implemented mechanisms make extremely complicated not only to find a suitable proxy variable but also to establish a correct interpretation of the potential results.

[6] If the country and the month are the ones that are taken as the reference to avoid the dummy-variable trap, then it will be only $\alpha_{2,0}$.

[7] If the country and the month are the ones that are taken as the reference in order to avoid the dummy-variable trap, then it will be only $\left(\sum_{j_2=0}^{u_2} \alpha_{2,j_2}\right)/\left(1 - \sum_{j_1=1}^{u_1} \alpha_{1,j_1}\right)$.

- Short-run cross-price elasticity of natural gas demand for country j_5 with regard to coal as[8] $\alpha_{6,j_5} + \alpha_{8,0}$.
- Long-run cross-price elasticity of natural gas demand for country j_5 with regard to coal as[9] $(\sum_{j_{12}=0}^{u_{10}} \alpha_{8,j_{12}} + \alpha_{6,j_5})/(1 - \sum_{j_1=1}^{u_1} \alpha_{1,j_1})$.
- Short-run cross-price elasticity of natural gas demand for country i regarding CO_2 emissions[10] as α_{7,j_5}.
- Long-run cross-price elasticity of natural gas demand for country j_5 with regard to CO_2 emissions[11].
- Short-run income elasticity of natural gas demand for any country is $\alpha_{3,0}$.
- Long-run income elasticity of natural gas demand for country i regarding CO_2 emissions is $\sum_{j_3=0}^{u_3} \alpha_{3,j_3}/(1 - \sum_{j_1=1}^{u_1} \alpha_{1,j_1})$.

We can also obtain from (1) the short and long run impact of the "double heating effect" due to the lockdown[12] –see Section 4 for more details-as follows:

- Short-run effect in any month (it does not include the cumulative effect of the peak month of demand of natural gas and the lockdown) is $\pi_{5,0}$.
- Long-run effect in any month (it does not include the cumulative effect of the peak month of demand of natural gas and the lockdown) is $\sum_{j_{10}=0}^{u_8} \pi_{5,j_{10}}/(1 - \sum_{j_1=1}^{u_1} \alpha_{1,j_1})$.
- The short-run effect in any month (including the cumulative effect of the peak month of demand of natural gas and the lockdown) for country j_5 is $\pi_{5,0} + \pi_{6,0} + \pi_{7,j_5}$.
- Long-run effect in any month (including the cumulative effect of the peak month of demand of natural gas and the lockdown) is $(\sum_{j_{10}=0}^{u_8} \pi_{5,j_{10}} + \sum_{j_{11}=0}^{u_9} \pi_{6,j_{11}} + \pi_{7,j_5})/(1 - \sum_{j_1=1}^{u_1} \alpha_{1,j_1})$.

3. Data

This study has been developed using monthly data for the period that goes from January 2005 to December 2020 for 25 European countries,[13] generating $N = 25$ and $T = 186$ observations, and utilizing the entire available sample size. Despite not considering all European countries due to restrictions on the access to the data, the country group represents a consistent sample over the period of analysis that comprises more than 95% of European natural gas consumption. Gas consumption dataset was gathered from public sources such as Eurostat, IEA, natural gas Transport System Operators (TSOs) and the different European energy ministries.

Regarding the natural gas price reference, this paper has used the TTF daily closing spot price as a proxy, retrieved from Ref. [47] in € per MWh. We contend that TTF is a good proxy, since it has become not only the supreme traded gas hub in Europe but also a global price reference, as described by Ref. [48]. This price reference has been transformed into real terms on a country basis using a harmonised index of consumer prices (HICP) published by Eurostat.

As the proxy for the coal price in Europe, we have used the monthly average daily closing price of the CIF ARA, retrieved from Ref. [47] and converted into real terms with the Eurostat's HICP for each country of study.

The impact of the economic activity is covered by the Production in Industry Index[14] variable, generated using a "Production in Industry - Percentage change on previous period" dataset, seasonally- and calendar-adjusted, and published by Eurostat.

The monthly Heating Degrees Days (HDD) and Cooling Degrees Days (CDD) variables were calculated from daily average temperature retrieved from National Oceanic and Atmospheric Administration's (NOAA) National Centres For Environmental Information (NCEI).[15] We have defined the range of 18–22° Celsius as the ideal temperature interval in which there are not energy needs to air condition residences, offices, and public buildings. These values were selected based on [49], choosing the most commonly used values in the literature for Europe to calculate the HDD and CDD.

As described in Ref. [33], we included a variable named LOCK_DOWN in order to analyse the impact of Covid-19 measures. This variable is defined based on the *Oxford Covid-19 Government Response Tracker* project database, developed by the Blavatnik School of Government, to evaluate governments' response to the Covid health crisis. LOCK_DOWN corresponds with the monthly average of the stringency index reformulated by Ref. [33] while using the methodology available in Ref. [50]. This reformulated version of this index limits the policy measures established to minimize social interaction and control the virus expansion. It was also included an iteration effect of the LOCK_DOWN variable multiplied by a variable capturing the peak-day in each countries' natural gas demand (Peak), creating the variable named LOCK_DOWNxPeak.

4. Results

4.1. Own-price, cross-price, and income elasticities

In relation to the estimation procedure, since in (1) we have a dynamic panel where $N = 25$ and $T = 186$, our T is much larger than N. Therefore, we should not use the methodology of [51,52] that requires large N. The bias from using fixed effects with lagged dependent variables is small when T is large [53]. Therefore, we choose to estimate (1) by fixed effects[16] and computing standard errors as in Ref. [53], which allow any correlation across countries and general serial correlation across time. Standard errors as in Ref. [53] are robust to very general forms of cross-sectional (spatial) and temporal dependence when the time dimension becomes large (as in our panel with large T). This nonparametric technique of estimating standard errors does not place any restrictions on the limiting behaviour of the number of panels. The results are provided in Table 3, where we use the notation that when a variable is followed by ".Lu" it means that we have introduced lag "u" of that variable following (1). *Dumon*$_1$, …., *Dumon*$_{12}$ refer to the dummy variables of months from January to December, and Ducountry$_x$ refers to the dummy of country x where we have obtained statistically significant effects in Table 2 for Italy (IT), Denmark (DK), Estonia (EE), Portugal (PT), Austria (AT), France (FR), and Latvia (LV). From Table 3 we see

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[8] If the country is the one that is taken as the reference to avoid the dummy-variable trap, then it will be $\alpha_{8,0}$.

[9] If the country is the one that is taken as the reference in order to avoid the dummy-variable trap, then it will be $(\sum_{j_{12}=0}^{u_{10}} \alpha_{8,j_{12}})/(1 - \sum_{j_1=1}^{u_1} \alpha_{1,j_1})$.

[10] If the country is the ones that is taken as the reference to avoid the dummy-variable trap, then it will be zero.

[11] If the country is the one that is taken as the reference, to avoid the dummy-variable trap, then it will be zero.

[12] The short and long run effects for HDD and CDD are calculated analogously to the process described for the LOCK_DOWN variable.

[13] Austria, Belgium, Czechia, Denmark, France, Estonia, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Finland, Sweden, United Kingdom, Norway, and Turkey.

[14] Mining and quarrying; manufacturing; electricity, gas, steam, and air conditioning supply included in sections B, C and D of the Statistical Classification of Economic Activities in the European Community (NACE Rev.2).

[15] Formerly the National Climatic Data Center (NCDC).

[16] The Hausman test for random versus fixed effects, provides a p-value much smaller than 0.05 providing evidence that we should use the fixed effects estimator.

Table 3

Estimated results of (1) for natural gas demand. Within-$R^2 = 0,6972$.

Variable	Estimated value	Driscoll/Kraay Std. Err.	P > |t|
lnQg.L3	0.3126502	0.024378	0.000
lnPg.L3	−0.0776711	0.022085	0.001
lnPc	0.1098871	0.037503	0.004
lnIPI	0.0948095	0.040709	0.021
HDD	0.0006730	0.000028	0.000
CDD	0.0005202	0.000082	0.000
LOCK_DOWN	−0.0005367	0.000213	0.013
LOCK_DOWNxD_Peak	0.0012033	0.000183	0.000
Dumon1[a]lnPg	−0.0470562	0.009403	0.000
Dumon2*lnPg	−0.0684234	0.009296	0.000
Dumon3*lnPg	−0.0796867	0.009131	0.000
Dumon4*lnPg	−0.1116669	0.010189	0.000
Dumon5*lnPg	−0.1154291	0.008622	0.000
Dumon6*lnPg	−0.1192712	0.008009	0.000
Dumon7*lnPg	−0.0796206	0.007429	0.000
Dumon8*lnPg	−0.0646706	0.007372	0.000
Dumon9*lnPg	−0.0326096	0.004603	0.000
Dumon11*lnPg	0.0072274	0.004063	0.077
Dumon12*lnPg	−0.0209303	0.007178	0.004
DucountryIT*lnPg	0.0584084	0.028026	0.039
DucountryAT*lnPg	0.0663675	0.037031	0.075
DucountryDK*lnPg	0.1047190	0.047070	0.027
DucountryEE*lnPg	0.1996414	0.084928	0.020
DucountryFR*lnPg	0.1657307	0.077296	0.033
DucountryLV*lnPg	0.1304718	0.051493	0.012
DucountryPT*lnPg	−0.2435159	0.078246	0.002
DucountryPT*lnPc	0.2080728	0.123864	0.095
DucountryTK* LOCK_DOWNxPeak	0.0022538	0.000305	0.000
DucountryIT* LOCK_DOWNxPeak	−0.0000326	0.000012	0.009
_cons	4.2626482	0.205657	0.000

[a] Note: E* represents the estimated values for any European country except FR, IT, LV, AT, PT, DK, and EE.

that all variables are statistically significant at least at 10% level. An F-test where the null hypothesis is that all variables are not statistically significant is rejected with a p-value less than 0.001.

From the results of Table 3, we have calculated in Table 4 and Table 5 the estimated short and long-run own price elasticities for all analysed European countries (denoted as E*) that are different from the seven countries mentioned above, as well as the proper estimated elasticities for those seven countries.

Results from Tables 4 and 5 show that, *first*, there is an European Standard Behaviour (ESB) with a strong-seasonal component that affects elasticities both in short and long run. We argue this behaviour is linked to the nature of natural gas demand in every moment of the year. In the period from October to February, during which heating demand represents a higher share of total demand, own-price fluctuations have limited effect on natural gas demand. Both short and long run estimated average own-price elasticities are negative, being higher in absolute terms in the long run and presenting signs and values coherent with the literature on the topic. As previously highlighted by literature [20], using a monthly data, instead of a daily dataset, results in lower estimated values in absolute terms than the ones estimated on our previous work with daily data [33].

Despite being statistically significant, Italy, and Austria's behaviours are quite similar to that of the ESB, presenting negative yearly average estimated own price elasticities in both the short and long run, but are slightly less sensitive to own-price changes (lower values in absolute terms).

Second, even though all countries present the same seasonal profile, we identify three cases that are different from the ESB:

1. France, Denmark, and Estonia have slightly positive short run average estimated own price elasticities, but with values close to zero. This behaviour has also impacted on long run results with estimated own price elasticities remaining positive but even closer to zero. We argue that these are linked to a higher weight of residential and commercial demand than the rest of the analysed countries. As previous literature has already highlighted [18], residential and commercial demand tend to be more inelastic than other natural gas uses. According to IEA, residential and commercial sector is the main consumption sector for these 3 countries, representing more than 50% of the natural gas final consumption.
2. Latvia presents a lower own price elasticity than the ESB, showing lower sensitivity to own price variations both in the short and long run, but for different reasons than France, Denmark, Estonia. According to IEA, 60% of its power generation is provided by renewable energy sources, mainly hydro, relying exclusively on natural gas as a back-up technology. We believe that not having an alternative technology to provide these crucial services to secure the supply reduces the demand's sensitivity to own price fluctuations.
3. In Portugal, natural gas showed the highest own-price elasticities of the European countries analysed, both in the short and long run. Natural gas is also used mainly in power sector in Portugal, representing more than 62% of the total demand on average during the period examined. Unlike Latvia, Portugal had different alternatives that compete to provide firmness and flexibility, crucial to facilitate renewable energy sources' integration and guarantee the back-up of the whole system. We argue that the nature of this consumption makes it quite sensitive to its own price and to other commodities, such as coal, that are highly substitutive. This is also supported by the fact that Portugal is the country with the highest natural gas and coal cross-price elasticities of the sample.

Despite these different behaviours, the yearly average short-run estimated own-price elasticities move within a range from −0.305 to 0.139, with the ESB settled in −0.06. Regarding the yearly average long-run estimated own-price elasticities, the range spans from −0.56 to 0.09, with the ESB settled in −0.2. These values are fully aligned with the previous literature described in the first section of this paper in both short and long run, and in Ref. [33].

As seen in Table 3, cross-price elasticity between natural gas and coal is statistically significant, showing that natural gas and coal are substitutive goods in Europe, both in short and long run. The results present signs and values coherent with what should be expected. As mentioned

Table 4

Estimated short-run own price elasticities.

	Month_1	Month_2	Month_3	Month_4	Month_5	Month_6	Month_7	Month_8	Month_9	Month_10	Month_11	Month_12
E*	−0.047	−0.068	−0.080	−0.112	−0.115	−0.119	−0.080	−0.065	−0.033	0.000	0.007	−0.021
FR	0.119	0.097	0.086	0.054	0.050	0.046	0.086	0.101	0.133	0.166	0.173	0.145
IT	0.011	−0.010	−0.021	−0.053	−0.057	−0.061	−0.021	−0.006	0.026	0.058	0.066	0.037
LV	0.083	0.062	0.051	0.019	0.015	0.011	0.051	0.066	0.098	0.130	0.138	0.110
AT	−0.040	−0.061	−0.072	−0.104	−0.108	−0.112	−0.072	−0.057	−0.025	0.007	0.014	−0.014
PT	−0.291	−0.312	−0.323	−0.355	−0.359	−0.363	−0.323	−0.308	−0.276	−0.244	−0.236	−0.264
DK	0.058	0.036	0.025	−0.007	−0.011	−0.015	0.025	0.040	0.072	0.105	0.112	0.084
EE	0.153	0.131	0.120	0.088	0.084	0.080	0.120	0.135	0.167	0.200	0.207	0.179

Note: E* represents the estimated values for any European country except FR, IT, LV, AT, PT, DK, and EE.

Table 5
Estimated long-run own price elasticities.

	Month_1	Month_2	Month_3	Month_4	Month_5	Month_6	Month_7	Month_8	Month_9	Month_10	Month_11	Month_12
E[a]	−0.181	−0.213	−0.229	−0.275	−0.281	−0.287	−0.229	−0.207	−0.160	−0.113	−0.102	−0.143
FR	0.060	0.029	0.012	−0.034	−0.040	−0.045	0.012	0.034	0.081	0.128	0.139	0.098
IT	−0.096	−0.128	−0.144	−0.190	−0.196	−0.202	−0.144	−0.122	−0.075	−0.028	−0.018	−0.058
LV	0.008	−0.023	−0.039	−0.086	−0.091	−0.097	−0.039	−0.017	0.029	0.077	0.087	0.046
AT	−0.171	−0.202	−0.218	−0.265	−0.270	−0.276	−0.218	−0.197	−0.150	−0.102	−0.092	−0.133
PT	−0.536	−0.567	−0.583	−0.630	−0.635	−0.641	−0.583	−0.561	−0.515	−0.467	−0.457	−0.498
DK	−0.029	−0.060	−0.077	−0.123	−0.129	−0.134	−0.076	−0.055	−0.008	0.039	0.050	0.009
EE	0.109	0.078	0.062	0.015	0.010	0.004	0.062	0.083	0.130	0.177	0.188	0.147

[a] Note: E* represents the estimated values for any European country except FR, IT, LV, AT, PT, DK, and EE.

above, only Portugal proved a statistically significant different behaviour with a higher cross-price elasticity due to fuel competition in power sector. By analysing the evolution of the consumption of natural gas and coal in Portugal (see Table 6), we can justify how coal and gas behave as substitute goods. Over the last 16 years, the natural gas and coal in Portugal evolved in a way to demonstrate a general trend between the decrease in coal and the increase in gas (and vice versa).

Extending the period of study has consequences on the cross elasticities by minimizing the impact of the fast-path early closure policies of coal plants in countries like Portugal, highlighted in Ref. [33]. This is also consistent with the evidence provided by this article since the Latvia case is a clear example of a lack of sensitivity of natural gas in the main consumer sector, and the unique back-up nature of the technology.

Regarding the estimated short and long run income elasticities, calculated results based on Table 3 show an estimated short-run income elasticity of 0.09 and an estimated long-run income elasticity of 0.14 in line with previous studies in terms of sign but presenting lower values than previous works such as [26] or [6]. As [20] stated, lower values of estimated income elasticities could be related to the impact of energy efficiency policies and a more updated database.

Finally, in relation to the climatic variables, we also calculated Table 7 from the results of Table 3, where HDD and CDD have been shown to be statistically significant in our analysis, both with a positive effect on gas demand. Our results in Table 7 are fully aligned with the existing literature, suggesting that each additional HDD increases the monthly natural gas consumption in 0.07% in the short run and 0.1% in the long run. CDD also has a positive effect on monthly gas consumption, increasing, per additional CDD, 0.05% in the short-run and 0.08% in the long-run.

Understanding demand behaviour is crucial for policy makers in tailoring future measures to maximise their contributions to reach climate goals whilst minimizing economy distortions. We show that when policymakers use price-based tools to influence natural gas demand in Europe, these policies are more effective from March to August – which is when our estimated own-price elasticities present higher values in absolute terms – both in the short and the long-run. Contrary to what is stated in Ref. [33], the importance of this observation, despite being relevant for energy policy design, is reduced since natural gas demand has proved itself as inelastic at any time period. Nonetheless, in order to fully compare the results obtained in both articles, it is vital to comprehend the timeframe in which consumption decisions are taken. As previously highlighted, natural gas consumption in the power sector has been more price-sensitive than other types of consumption when there are other technologies available to compete. Whereas in the residential sector, the decision is only whether or not to turn on the heat (therefore to consume natural gas) as there is no alternative to meet energy need in the short term, in the long term, seeking an alternative requires an investment decision. We argue that these different behaviours are a result of the timeframe in which natural gas consumption decisions are taken [33]. should reflect sectorial behaviour more accurately for sectors such as power since shorter timeframe consumption decisions should not only present higher own-price elasticity but also be more impacted by the seasonal profile of the own-price elasticities. Under these circumstances, the use of price-based tools such as taxes to tackle climate change can distort competition, sending a wrong signal to the market that could encourage more polluting fuels consumption and jeopardize part of the environmental benefits. To avoid these potential distortions, pricing mechanisms should be defined coherently, covering all fossil fuels, and basing them on the carbon emission content, instead of using energy consumption as a proxy of the environmental impact. The same design could be applied to those sectors in which consumption decisions are taken in a longer timeframe, but the inelastic behaviour of gas demand described in this paper limits the environmental impact which may come with redistributive implications.

Table 6
Evolution of consumption of natural gas and coal in Portugal (Million tonnes of oil equivalent). Source [54].

Years	Coal	Natural Gas
2005	3.3	3.8
2006	3.3	3.7
2007	2.9	3.8
2008	2.5	4.1
2009	2.9	4.1
2010	1.6	4.5
2011	2.2	4.5
2012	2.9	3.9
2013	2.6	3.7
2014	2.7	3.5
2015	3.3	4.1
2016	2.8	4.4
2017	3.2	5.5
2018	2.7	5.0
2019	1.4	5.3
2020	0.6	5.2

Table 7
Estimated short and long run effects for HDD and CDD.

Short-run effects	Estimated value	Long-run effects	Estimated value
HDD	0.0006730	HDD	0.0009791
CDD	0.0005202	CDD	0.0007568

The intensifying climate policy ambition in the coming decades, despite renewable energy penetration, will be a determinant factor on the growing role of natural gas to meet power sector needs. The closure of the big part of the firm generation (mainly nuclear and coal) as well as the physical limitations to develop non-polluting firm technologies (hydro is close to its maximum potential in many European countries and batteries are still an expensive option) reinforce the need of back-up technologies. Natural gas remains the only technology that can provide these services, at least in the short and medium term, while reducing its own-price sensibility. This fact – together with the current European power market design (pay-as-cleared) – can result in higher power prices when gas-fired power plants operate should taxes or other type of price-based tools are implemented in the future. In this context, price-based mechanisms would become highly effective measures in terms of tax collection but would have a limited influence on consumer behaviours.

4.2. Double-heating effect

As described by Ref. [33], lockdown measures have changed natural gas consumers' behaviour, increasing heating needs by forcing them to stay at home. This increase in the residential sector does not translate into a reduction in the heating needs of offices and working centres since they were required to remain open, generating a "*double heating effect*". The methodology used to assess the government response is the same utilized in Ref. [33], and is based on the work of the Oxford Covid-19 Government Response Tracker project as described in Ref. [50].

Contrary with what is described in Ref. [33], LOCK_DOWN variable has a negative impact on natural gas demand. We argue that the data aggregation on a monthly dataset changes the sign of the effect, reflecting the abnormal negative impact of the government measures to minimize social interaction on the natural gas consumption.

Based on the "*double-heating effect*" definition, it is likely that this effect has stronger impact on peak demand rather than on total demand. We have tested the impact of the lock down measures on the peak demand month after the World Health Organization (WHO) declared COVID-19 a pandemic, in March 2020.

Our analysis shows, when examining this effect under peak system requirements, lock down measures are statistically significant in Table 3, having a positive impact on natural gas consumption as described in Ref. [33], but presenting lower values due to using a monthly dataset. Despite this, this effect when meeting peak needs is higher in absolute terms than in normal conditions as expected based on the "*double-heating effect*" established definition.

Additionally, we included dummy variables to examine the impact of the double heating effect in countries whose natural gas share of the final energy consumption in the residential sector is higher than 50%.[17] From the five countries that fulfil this criterion (Italy, Netherlands, Slovakia, United Kingdom and Turkey, see Table 2), only Turkey and Italy present statistically significant behaviours that differ from the standard "*double-heating effect*" under peak requirements (see Table 8). While Turkey presents a higher double heating effect under peak needs, the impact in Italy is lower than the standard European behaviour. Consequently, we cannot affirm that presenting a higher natural gas shared in the final energy mix of the residential sector guarantees a higher double heating effect.

It is important to highlight that, even though social distancing measures are set to disappear as Covid health crisis is overcome, teleworking programs become permanent. This could perpetuate the "*double heating effect*" on demand with implications in terms of higher peak needs, and emissions. Thus, it is essential to maintain the momentum on energy efficiency measures, such as heaters renovation programs, not only to meet the new 2030 UE targets but also to minimize the long-term impacts on both the natural gas network design and on the environment.

5. Conclusion and discussion

We analyse a panel data of 25 European countries to provide novel estimates of own-price, cross-price, and income elasticities of natural-gas-demand from 2005 to 2020. We highlight that there is an ESB with a strong-seasonal component both in short and long runs. During the October–February period, when heating needs represent a higher share of total natural gas demand, gas price is not a determinant factor, showing an inelastic demand, especially in the short-term. As previously demonstrated by existing literature, both short and long run ESB estimated average own-price elasticities prove themselves to be negative with values ranging from -0.061 to -0.202, respectively. Our estimates -obtained with the most up-to-date dataset that is currently available, from 2005 to 2020- are extremely relevant both due to the major climate and energy transformation undertaken in the last two decades and considering explicitly the effects in gas consumption of lockdowns such as the ones derived from COVID-19 pandemic. We also identify three cases that separate themselves for the ESB:

- France, Denmark, and Estonia present slightly positive estimated elasticities with values close to zero. We argue that this behaviour is related to a higher weight of residential and commercial demand on total gas demand, since the residential and commercial sectors represents more than 50% of natural gas final consumption.
- Latvia presents a lower sensitivity to own-price variations than the ESB both in the short and long run. We argue that this is due to the role of natural gas as unique back up technology in its power generation mix.
- Portugal shows the highest own-price elasticities of the European analysed countries, both in short and long terms. We defend that, if power sector is the main natural gas consumer sector and there are different technologies to provide back-up services, the nature of this consumption makes it quite sensitive to its own price and to other commodities, such as coal, that are highly substitutive. This is also supported by the fact that Portugal is the country with the highest natural gas and coal cross-price elasticities of the sample.

Finally, we find that lockdowns highly impacted on natural gas demand confirming the "*double heating effect*" and it was especially important in Turkey, where natural gas has a very high share in the residential demand. Contrary with what is described in Ref. [33], lockdowns around Europe due to Covid-19 have a negative impact on natural gas demand. We argue that the data aggregation on a monthly dataset changes the sign of the effect, reflecting the abnormal negative impact of the government measures to minimize social interaction on the natural gas consumption. When studying peak requirements, lockdown impact turns positive and higher in absolute value than the one obtained for the standard conditions. This evidences that the teleworking has modified natural gas consumer patterns increasing demand under peak requirements. We also tested if there is a correlation between having a higher natural gas shared in the final energy mix of the residential sector and a higher double heating effect. Based on the obtained results, there is no evidence of any kind of correlation.

Understanding demand behaviour is crucial for policy makers to tailor future measures maximizing the contributions to reaching climate goals while minimizing economy distortions. As stated in Ref. [33], the importance of the seasonal profile of own-price elasticities, despite being relevant for energy policies design, gets reduced since natural gas demand has proved itself as inelastic, both in the short and long term. We argue that different sectorial behaviours are result of the timeframe in which natural gas consumption decisions are taken. Those consumptions whose decisions are based on shorted timeframe should not only present a higher own-price elasticity but also be more impacted by the seasonal profile of the own-price elasticities. Under these circumstances, the use of price-based tools (i.e. taxation, marked-based pricing tools, result-based climate finance mechanism, or any other regulatory measure) to tackle climate change can distort competition, sending a wrong signal encouraging more polluting fuels consumption and jeopardizing the environmental benefits. To avoid this, pricing mechanisms should be defined coherently, covering all fossil fuels, and basing them on the carbon emission content. When applying the same design to those sectors in which consumption decisions are taken in a longer timeframe, an inelastic gas demand limits the environmental impact while may come with redistributive implications.

Despite a growing renewable energy penetration and higher climate ambition, natural gas will uphold a key role in power sector, at least in the short and medium term. The closure of the substantial part of the firm generation fleet because of climate policy as well as the physical limitations to develop new non-polluting firm technologies reinforce the need of back-up technologies. Natural gas appears as the only technology that can provide these services, at least in the short and medium

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[17] Eurostat data base.

Table 8
Estimated short and long run effects for lockdown and peak days during lockdown.

Short-run effects	Estimated value	Long-run effects	Estimated value
E** LOCK_DOWN	−0.0005367	E** LOCK_DOWN	−0.0007809
E** LOCK_DOWNxD_Peak	0.0006666	E** LOCK_DOWNxD_Peak	0.0009698
IT LOCK_DOWNxD_Peak	0.0006340	IT LOCK_DOWNxD_Peak	0.0009224
TK LOCK_DOWNxD_Peak	0.0029204	TK LOCK_DOWNxD_Peak	0.0042488

Note: E** represents the estimated values for any European country except for IT, and TK.

term, reducing its own-price sensibility. This fact together with the current European power market design (pay-as-cleared) can result in higher power prices when gas-fired plants operate should price-based tools were implemented. In this context, price-based mechanisms would become highly effective measures in terms of tax collection, but with a limited influence on consumer behaviours.

The existence of a "*double-heating effect*", especially when peak demand requirements are presented, may have long-term policy implications if new consumption patterns due to teleworking get consolidated. This additional factor should be considered when natural gas peak demand needs are evaluated, both for the correct operation of the network and the adequate grid expansion planning. Energy efficiency measures could play a key role to minimize the potential impacts and contribute to achieve long term climate goals.

Credit author statement

Antonio F. Erias: Methodology, Investigation, Software, Formal analysis, Writing. Conceptualization, Writing – review & editing; Emma M. Iglesias: Methodology, Investigation, Software, Formal analysis, Writing. Conceptualization, Writing – review & editing.

Declaration of competing interest

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

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