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# Economic, environment and demographic elasticities of natural gas demand: A review

## Elasticidades económicas, ambientais e demográficas da procura de gás natural: Uma revisão

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**Abstract:** This paper conducts a comprehensive review of various estimates for natural gas demand responses. We consider a stream of empirical studies that have been conducted after 1950. The purpose of this paper is to provide the full image, synthesize and analyze the published studies in this field from the first experimental study to the beginning of 2022. In this study, we discuss the methods and techniques used, the application area, the variables, and data sources and data size. Most studies have investigated price and income elasticities; many fewer have focused upon demographic variables. This work will be of significant importance for future researchers aiming to analyze the demand for natural gas.

**Keywords:** Natural gas demand, price elasticity, income elasticity, energy.

**Resumo**: Este documento efectua uma análise exaustiva de várias estimativas das respostas da procura de gás natural. Consideramos uma série de estudos empíricos que foram realizados após 1950. O objetivo deste artigo é fornecer a imagem completa, sintetizar e analisar os estudos publicados neste domínio desde o primeiro estudo experimental até ao início de 2022. Neste estudo, discutimos os métodos e técnicas utilizados, a área de aplicação, as variáveis, as fontes de dados e a dimensão dos dados. A maioria dos estudos investigou as elasticidades do preço e do rendimento; muitos menos se centraram nas variáveis demográficas. Este trabalho será de grande importância para futuros investigadores que pretendam analisar a procura de gás natural.

**Palavras-chave**: Procura de gás natural, elasticidade-preço, elasticidade-renda, energia.

**Résumé** : Cet article procède à un examen complet de diverses estimations des réponses à la demande de gaz naturel. Nous considérons un flux d'études empiriques qui ont été menées après 1950. Le but de cet article est de fournir une image complète, de synthétiser et d'analyser les études publiées dans ce domaine depuis la première étude expérimentale jusqu'au début de 2019. Dans cette étude, nous discutons des méthodes et techniques utilisées, du domaine d'application, des variables, des sources de données et de la taille des données. La plupart des études ont étudié les élasticités-prix et les revenus ; beaucoup moins se sont concentrés sur les variables démographiques. Ces travaux revêtiront une importance significative pour les futurs chercheurs visant à analyser la demande de gaz naturel.

**Mots-clés** : Demande de gaz naturel, élasticité des prix, élasticité des revenus, énergie.

## 1. INTRODUCTION

Considering the various economic and environmental benefits of natural gas compared to coal and oil, around one-fourth of the world's primary energy is met from natural gas [1] . It is used for heating, industrial activities, transport and electricity generation. Among all fossil fuels, natural gas is the cleanest fossil fuel it emits a lower amount of carbon dioxide ($CO_2$) and other pollutants like nitrogen oxides ($NO_x$) and sulfur dioxide ($SO_2$) and particulars. Moreover, gas-fired electricity production plants present low investment costs and provide faster start-up and thus add flexibility to the power generation system. Given the increasing prominence of natural gas in the world economy, research on natural gas demand has grown considerably in recent years. This interest in studying natural gas consumption has led to a critical set of studies since the second half of the 20$^{th}$ century.

Natural gas demand has increased considerably in recent years. It has the most substantial increase in world primary energy consumption and projected to grow from 3,4 Trillion Cubic Meter (TCM) to 5,7 TCM [2]. With the growing demand for energy in general and particularly for natural gas reaching already 4.6% in 2018 [3], driven especially by the recent demographic growth and the opportunities offered by natural gas, the analysis of natural gas consumption has become crucial, not only to understand the main factors that determine natural gas demand responses, but also to measure the magnitude of elasticities. This helps producers to manage and adjust their future supply and also policy makers to predict the demand, make reasonable decisions and adapt their energy and environmental policies based on robust tools and thus achieve the sustainability of the energy system. Because the energy field is full of risks and uncertainties, policymakers have a significant interest in determining the approximate magnitude of gas demand responses and other relevant information to make intelligent decisions.

Many works have studied the demand for natural gas in different areas [4-16]. These investigations emphasized the determinants of gas consumption in the world, regional, national and city level, in all sectors including residential, commercial and industrial level. Soldo [17] has presented an overview of different natural gas forecasting approaches from the first theoretical study of Hubbert [18] in 1949 to the year of 2010. He made an interesting review on natural gas demand and supply forecasts where he analyzed and synthesized insights about applied areas, used data, forecasting horizons and models and tools. However, the elasticity studies along with data size, data sources were not included in the review.

Our paper aims to analyze and synthesize published research on elasticity estimations regarding natural gas demand. This paper is organized as follows: Section 2 presents an overview of natural gas elasticity studies. Section 3 provides an overview of applied areas and methodological approaches. Section 4 is an overview of data, including the period covered, and data sources of the analyzed works, and Section 5 provides the main results and findings. The final section concludes.

## 2. OVERVIEW OF THE LITERATURE

Providing projections of energy markets trends over the years by policy organizations is critical to understand and interpret simulation results for different energy use scenarios. The models used for conducting these evaluations are applied to evaluate the potential energy implications of introducing various policy options in energy markets.

To make projections of natural gas use, it is imperative to understand and update key response parameters contained in these models. Among these parameters, specifying determinants of natural gas use behavior is often one of the most challenging. Determining, for example, how gas demand responds to price and income changes is crucial in projecting gas use for any specific scenario. In fact, elasticity studies in the natural gas field are interested to learn the sensitivity of natural gas consumption to a change in its determinants, considering the objective to examine and predict their possible impact. Verhulst [19], worked on a set of equations, including the demand equation, to examine the demand for natural gas in French gas industry taking into consideration price and income responses for a sample of 46 firms. Assuming that the consumer’s demand for natural gas is following a Cobb-Douglas function, he analyzed price and income elasticities. However, the first experimental study of demand analysis, using panel data estimators, was conducted by Balestra and Nerlove [4] in the residential and commercial sectors. They used econometrics parameters by applying an Ordinary Least Square model (OLS). After a period of time, Tinic et al. [20] determined a demand function for natural gas in rural Alberta and then measured the price eleasticity to evaluate the rural gasification plan economically. In 1977, Berndt and Watkins [5] estimated two separate equations representing natural gas demand in the residential and commercial sectors in Ontario and British Columbia by generalizing the econometric model developed earlier by Balestra and Nerlove [4]. Pindyck [21] investigated price and income elasticities for residential natural gas demand in OECD countries. Bloch [22] studied the demand for natural gas in the residential sector, particularly the demand used for space heating for 151 US Families. In 1981 Beierlein et al. [23] analyzed electricity and natural gas demand for the residential, commercial and industrial sectors of the northeastern United States. Based on Consumer Expenditure Survey, Barnes et al. [24] studied the short-run demand for natural gas. In 1983, Liu [25] estimated the own-price and cross-price elasticities of natural gas demand in the residential, commercial and industrial sectors in the USA. With an error components model and several equations, Blattenberger et al. [26] studied natural gas availability and household energy demand. Lin et al. [27] studied the behavior of residential, commercial and industrial demand for natural gas, electricity and heating oil in the United States. Green [28] estimated price and income elasticities of household gas and electricity demand in the Northeast and the South of the US. In 1989 Estrada and Fugleberg [29] estimated own-price elasticities for natural gas and cross-price elasticities between natural gas and other fuels in France and West Germany. Baker et al. [30] modeled household demand for gas and electricity in Great Britain. Maddala et al. [31] estimated the elasticities of the residential demand for electricity and natural gas in the United States. Haas and Schipper [32] investigated residential energy demand and the role of efficiency in explaining the consumption behavior in OEC countries. In 2002 Krichene [33] analyzed natural gas and oil markets by examining demand and supply elasticities in the world. Berkhout et al. [34] drove an econometric study in which they analyze residential demand for energy, emphasizing on natural gas and electricity consumption in the Netherlands. Labandeira et al. [35] studied the first residential energy demand system in Spain. In 2008, Asche et al. [7] studied the dynamic of household natural gas demand in European countries, by estimating short and long-run elasticities. In 2009, Yoo et al. [36] estimated the demand function for natural gas in the household sector in Seoul. In 2010 Erdogdu [8], forecasted future growth in natural gas demand and examined short and long-run price and income elasticities of sectorial demand for natural gas in Turkey, Meier and Rehdanz [37] investigated the residential demand for heating in Great Britain. Payne et al. [38] studied residential natural gas demand in the state of Illinois by estimating the long-run and short-run elasticities. In the same year, Alberini et al. [11] analyzed electricity and natural gas demand in the residential sector in the United-States, Andersen et al. [39] studied the responsiveness of natural gas demand to price and output changes in the industrial sector for some of the Organization for Economic Cooperation and Development(OECD) countries, Bernstein and Madlener [9] examined the demand for natural gas in the residential sector in selected OECD countries, Wadud et al. [10] tried to understand the aggregate demand for natural gas in Bangladesh by using a dynamic econometric model. In 2012, Dagher [40] estimated the dynamic of price and income elasticities of natural gas demand in the residential sector in the state of Colorado by applying a general Autoregressive Distributed Lag model. Bilgili [41] analyzed natural gas consumption function by evaluating the sensitivity of per capita natural gas consumption regarding natural gas prices and per capita income using a panel data in some OECD countries. On the basis of a dynamic panel data model, Santos [42] studied the responsiveness of gasoline, ethanol and compressed natural gas demand to price and income in the short and long run in Brazil. In 2014, Yu et al. [43] investigated price and income elasticities of natural gas demand in the household sector in urban China, Kani et al. [44] used a smooth transition regression model (STR) to analyze the consumption function of natural gas in Iran for the period 1971-2009, Bianco et al. [45] tried to develop a new model for the long term forecasting of nonresidential natural gas demand and estimated short and long run natural gas consumption elasticities with respect to price and income in Italy, Dilaver et al. [12] applied the structural time series technique to annual data over the period 1978 to 2011 in order to investigate the responses of income and natural gas prices on the aggregate demand for natural gas in OECD-Europe countries. In 2015 Harold et al. [13] studied the most influential factors on natural gas consumption in the household sector in Ireland by using a micro-econometric analysis, Orlov [46] estimated the elasticity of natural gas across various sectors of the Russian Economy, Khan [47] investigated the short and long-run dynamics of natural gas consumption for the residential, commercial, industrial, transport and electricity sectors in Pakistan over the period 1978-2011. In 2016, Burke and Yang [14] estimated the long-run price and income elasticities of the aggregate natural gas consumption in 44 countries by using national data, Sun and Ouyang [48] investigated the price and income elasticities of the consumption of natural gas, electricity and transport fuels in the household sector inside China. In 2018, Ota et al. [49] studied empirically the demographic impacts on electricity and natural gas consumption in the residential sector in 45 prefectures in Japan between 1990 and 2010, Gautam and Paudel [50] investigated the demand function of natural gas in the residential, commercial and industrial sectors in the Northeastern United States over the period 1997-2016 by using five techniques including Dynamic Fixed Effects (DFE), Mean Group (MG), Pooled Mean Group (PMG), Common Correlated Effect Mean Group (CCEMG), and Augmented Mean Group (AMG), Liu et al. [15] analyzed the demand for natural gas by studying the factors impacting natural gas consumption in the household sector of 30 provinces in China by applying a Generalized Least Squares (GLS) Method between 2006 and 2015, Zhang et al. [16] analyzed the demand for natural gas by investigating the long-run price and income elasticities in various sectors in China using an Autoregressive Distributed Lag (ARDL) model. Chai et al. [51] performed a met-regression analysis on previous studies on estimating price elasticities of natural gas to set up a benchmark value of elasticities, Zeng et al. [52] investigated the response of natural gas consumption to a price change in the household sector and analyzed the mean factors impacting the demand for natural gas in China. Malzi et al. [53] investigated residential natural gas demand in OECD countries by analyzing the main factors influencing natural gas consumption in these countries, including price, income, urbanization and demographic factors.

## 3. APPLIED AREAS AND METHODOLOGICAL APPROACHES

Historical studies on natural gas demand carried out different methods and techniques to estimate the demand function in different areas and particularly to examine the sign and magnitudes of elasticities on the international level, regional level, national level, city area, firm level and individual customer's level. In this section, we will describe different methods and approaches used in the literature along with different application areas.

Verhulst [19] studied the manufactured gas demand in the French gas industry by applying a logistic equation or logistic growth curve. He used the demand equation, production equation and equilibrium equation to compute the elasticities of the demand. Since the 1960s, statistical approaches have started to develop and begun to investigate the demand of natural gas. In 1966, Balestra and Nerlove [4] used statistical tools and time series data to analyze the demand for natural gas and electricity in the United States. Tinic et al. [20] evaluated rural gasification plan in Alberta (Canada) by developing three separate demand functions based on a survey of rural residents. Each function is based on a specific methodology, but analyzed to develop an overall demand curve. Berndt and Watkins [5] used non-linear technique which is a generalization of the dynamic model developed by Balestra and Nerlove [4] to estimate natural gas demand function in the regional level (British Columbia and Ontario).

**Table 1** Overview of published papers

| Publishing year | References |
|---|---|
| 1950 | Verhulst [19] |
| 1966 | Balestra and Nerlove [4] |
| 1973 | Tinic et al. [20] |
| 1977 | Berndt and Watkins [5] |
| 1979 | Pindyck [21] |
| 1980 | Bloch [22] |
| 1981 | Beierlein et al. [23] |
| 1982 | Barnes et al. [24] |
| 1983 | Liu [25] |
| 1983 | Blattenberger et al. [26] |
| 1987 | Lin et al. [27], Green [28] |
| 1989 | Estrada and Fugleberg [29], Baker et al.[30], Al-Sahlawi, M. A. [6] |
| 1997 | Maddala et al. [31] |
| 1998 | Haas and Schipper [32] |
| 2002 | Krichene [33] |
| 2004 | Berkhout et al. [34] |
| 2006 | Labandeira et al. [35] |
| 2008 | Asche et al. [7] |
| 2009 | Yoo et al. [36] |
| 2010 | Erdogdu [8], Meier and Rehdanz [37] |
| 2011 | Payne et al. [38], Alberini et al. [11], Andersen et al. [39], Bernstein and Madlener [9], Wadud et al. [10] |
| 2012 | Dagher [40] |
| 2013 | Santos [42] |
| 2014 | Bilgili [41], Yu et al. [43], Kani et al. [44], Bianco et al. [45], Dilaver et al. [12], Harris et al. [65] |
| 2015 | Harold et al. [13], Orlov [46], Khan [47] |
| 2016 | Burke and Yang [14], Sun and Ouyang [48] |
| 2018 | Ota et al. [49], Gautam and Paudel [50], Liu et al. [15], Zhang et al. [16], Chai et al. [51], Zeng et al. [52] |
| 2019 | Malzi et al. [53] |
| 2020 | Zhou et al. [54b], Lin et al. [55b] |
| 2021 | Rubaszek et al. [56b] Kostakis et al. [58b] |
| 2022 | Javid et al. [60b] Li et al. [62b] |

To estimate natural gas demand functions, Bloch [22] performed a time series model for the combined cross-section of 151 Twin River families individually. Beierlein et al. [23] estimated the demand for natural gas and electricity for the residential, commercial and industrial sectors in the regional level by using a combination of the error components model and seemingly unrelated regressions (EC-SUR). Their study improved the estimates over the use of only Ordinary Least Square or the error components technique. Besides, Lin et al. [27] used an error components model including nine equations estimated simultaneously by the Avery’s error components and seemingly unrelated regressions technique as well as individually by the ordinary least squares and error components model. This helped to investigate the short and long-run price and income elasticities of the overall natural gas demand in US regions and sub-regions along with the speed of adjustment. Barnes et al. [24] investigated the short-run demand for natural gas in the individual customer’s level in the United States using the instrumental variable method based on the technique used by Hausman, Kinnucin and McFadden [54]. Liu [25] developed a simultaneous-equations model and its reduced form to estimate natural gas demand elasticities in US regions. Blattenberger et al. [26] applied a logarithmic Koyck version of the Houthakker-Taylor flow adjustment model to model energy demand on the 48 states of USA. Green [28] assumed a linear functional form of the model to investigate the demand for heating in the regional level. Estrada and Fugleberg [29] developed a system of equations by adopting a model based on translog functions to study price elasticities of natural gas consumption in France and West Germany. This method consists of using indirect cost functions and indirect utility functions instead of using the production or utility function and their conditions of optimization to study the behavior of producers and consumers. Besides, Pindyck [21] studied the structure of world energy demand for different fuels and sectors using a translog cost function for the industrial sector and an indirect utility function for the household sector. Baker et al. [30] developed a theoretical model using a two-stage budgeting framework. This method helps in designing an adequate econometric specification of the energy demand equations. Maddala et al. [31] investigated the short-run and long-run elasticities of household demand for natural gas and electricity in 49 states by using a standard dynamic linear regression (DLR) model by applying an iterative estimator approach. Krichene [33] analyzed crude oil and natural gas demand and supply in the world level by developing a simultaneous demand and supply model, including the estimation level and the error correction. Berkhout et al. [34] used a two-stage budgeting model [55]for household energy use to study the impact of an energy tax on household electricity and natural gas demand in the Netherlands. This model has two main characteristics regarding household preferences [56-58] called price aggregation and decentralisability [59]. Haas and Schipper [32] estimated price and income elasticities of residential energy demand in OECD countries by adopting a standard dynamic constant elasticity function of demand, the Structure and Intensity (STRINT) approach and the imperfect price-reversibility approach. Asche et al. [7] used fixed effects and shrinkage estimators to study the natural gas demand elasticities in 12 European countries. The shrinkage estimator produces a more sensible and tighter range of country-specific own price elasticities in terms of sign, significance and magnitude compared to the country-specific estimators. Also, Andersen et al. [39] estimated the short and long run price and output elasticities of natural gas demand in the industrial sector in some European countries using a shrinkage estimator to allow heterogeneous demand responses across industries for each country. Yoo et al. [36] applied a sample selection model to estimate natural gas demand for the city of Seoul in South Korea with three tests including Z-test for non-response bias likelihood ratio test and t-test sample selection bias. To obtain short and long run price and income elasticities and also to forecast future growth in natural gas demand in Turkey, Erdogdu [8] used ARIMA modeling. Meier and Rehdanz [37] investigated the main determinants of space heating behavior in the residential sector of Great Britain by applying a log-linear estimation and a random-effects model to derive price and income elasticities for Britain as a whole as well as for different types of household. Payne et al. [38] investigated the household demand for natural gas in the state of Illinois using an Autoregressive Distributed Lag (ARDL) bounds testing approach. In contrast, Zhang et al. [16] used an ARDL to study the elasticities of natural gas demand in various sectors of China. This technique allows for the simultaneous modeling of the short and long-run dynamics, providing short and long-run elasticity estimates associated with residential natural gas demand. Moreover, Bernstein and Madlener [9] applied the same approach to analyze the household demand in twelve OECD countries. They checked for the robustness of the long-run estimates by applying the Fully Modified Ordinary Least Squares (FMOLS) and Dynamic OLS (DOLS) estimators. Dagher [40] studied the dynamic of household natural gas demand elasticities at the utility level in Colorado using the very general Autoregressive Distributed Lag technique. This dynamic model allows a full set of current and lagged variables to enter the equation in order to model the dynamics of the demand function. To study the dynamic of the overall demand for natural gas in the Northeastern United States, Gautam and Paudel [50] tried five alternative estimators: dynamic fixed effects (DFE), mean group (MG), pooled mean group (PMG), common correlated effect mean group (CCEMG), and augmented mean group (AMG). Bilgili [41] used panel cointegration analysis to estimates the long run relationship between the demand for natural gas, income and natural gas prices in eight OECD countries. Bilgili [41] adopted the FMOLS and DOLS methods in order to correct endogeneity and serial correlations in panel data. Alberini et al. [11] investigated electricity and natural gas consumption in the residential level in the largest metropolitan areas in the United States adopting both a static econometric model and a dynamic model called system GMM estimator developed by Blundell and Bond [59]. Malzi, et al. [53] used the same method to estimate household demand function of natural gas by investigating the factors influencing natural gas consumption in 29 OECD countries. Also, Santos [42] used a GMM Arellano-Bond [61] estimator to investigate the short and long run estimation of gas demand for Brazil. For modeling the demand function of natural gas in the national level in Bangladesh, Wadud et al. [10] adopted a log-linear Cobb Douglas function. Yu et al. [43] and Liu et al. [15] applied the Feasible Generalized Least Squares (FGLS) technique [62-63], to specify natural gas consumption function in the national level of China. This model is specified to control for heteroskedasticity and panel correlation. Kani et al. [44] studied the demand function for natural gas in Iran applying a Smooth Transition Regression (STR) model which is adequate to analyze asymmetric cycles of variables and fit the regime switch mechanisms properly for evaluating the nonlinear dynamism of variables. Bianco et al. [45] examined natural gas consumption function in Italy by using the classical form of a standard dynamic constant elasticity function of consumption. Dilaver et al. [12] investigated the determinants of the aggregate natural gas consumption in OECD-

Europe countries by using a Structural Time Series Model (STSM). This method allows for the stochastic Underlying Energy Demand Trend (UEDT). Harold et al. [13] analyzed residential natural gas demand in Ireland using a micro-econometric analysis of the daily consumption. Orlov [46] applied a comparative static, single-country, multi-sector Computable Generation Equilibrium model (CGE) to investigate the elasticites of natural gas demand in Russia. In fact, CGE models have the advantage to capture the interrelations between output and factors markets. Khan [47] investigated the short and long-run dynamics of natural demand in Pakistan by using a sectoral model based on an OLS estimator. Chai et al. [51] analyzed the empirical studies on price elasticities of natural gas demand in different studies using fixed effects and ordinary least square models. Burke and Yang [14] examined the short and long run elasticities for the overall natural gas demand in 44 countries around the world by adopting three panel estimators: Between estimator, Pooled Ordinary Least Squares and the fixed effects estimator with year dummies. Sun and Ouyang [48] measured the price and expenditure elasticities of residential energy demand in China by applying the Almost Ideal Demand System model, whereas Labandeira et al. [35] extended this model by adopting a quadratic household demand model to investigate household energy demand in Spain. Ota et al. [49] investigated the impact of demographic variables on residential electricity and natural gas demand at the prefecture level in Japan by using fixed effects, Prais-Winsten (PW) and first difference (FD) techniques. Zeng et al. [52] applied the instrumental variable method and conducted a two-stage least squares (2SLS) approach to estimate the price elasticity of natural gas demand and factors impacting the consumption in the residential sector in China. 2020 Zhou et al. [54b] forecasted natural gas consumption using a novel discrete grey model considering nonlinearity and fluctuation.

## 4. DATA

Previous studies used various data to investigate the elasticities of natural gas demand. The Period and data sources depend on the model used and the application area. Estimating natural gas elasticities was investigated using different input variables.

### 4.1. Period

Verhulst [19] used data of the fourth quarter of 1945. Balestra and Nerlove [4] used annual data from the period 1950 to 1962. Berndt and Watkins [5] collected data from 1959 to 1974. Bloch [22] collected data over the period 1971 - 1976 to study natural gas demand. Beierlein et al. [23] used annual data from 1967 to 1977 while Liu [25] collected data from the period 1967-1978. Barnes et al. [24] used individual household data from 1972-1973. Pindyck [21] covered the period from 1955 to 1974. Blattenberger et al. [26] collected annual state level data over the period 1960-1975. The study of Lin et al. [27] covers the period 1960-1983, whereas Green [28] used annual household data over the period 1974-1979. To estimate price elasticities Estrada and Fugleberg [29] use annual observations covering the period 1960-1983. Baker et al. [30] used annual residential data from the period 1972-1983. The study of Maddala et al. [31] covers the period 1970-1990 while the study of Haas and Schipper [32] covers the period 1970-1993. Krichene [33] took a very long period covering 1919 to 1999. Berkhout et al. [34] used data for natural gas over the years 1992-1999. In their estimation, Labandeira et al. [35] studied three periods using quarterly data covering 1973-1974, 1980-81 and 1985-1995 and Erdogdu [8] used quarterly data covering the period 1988-2005. Asche et al. [7] covered the period from 1960 to 2002. Meier and Rehdanz [37] derived price and income elasticities using the period from 1991 to 2005. The model of Payne et al. [38] covers the period 1970 to 2007 while Alberini et al. [11] covered the period from 1997 to 2007. Andersen et al. [39] used data from 1978 to 2003. Bernstein and Madlener [9] used time series data covering the period 1980 to 2008. Wadud et al. [10] studied natural gas demand in Bangladesh covering the period 1981-2008. Dagher [40] used monthly data for the period January 1994 to September 2006. Bilgili [41] studied the elasticities for the period of 1979 – 2006. Santos [42] collected monthly data covering the period ranging from July 2001 to December 2010. Yu et al. [43] studied natural gas demand in china between the period 2006 and 2009, while Kani et al. [44] used data for the period 1971-2009 to study the demand in Iran. Bianco et al. [45] considered historical data for the explanatory variables between the period 1990 to 2011. Dilaver et al. [12] used annual data over the period 1978 – 2011. Harold et al. [13] considered daily data covering the period from 1st December 2009 to 30th May 2019. Yoo et al. [36] used data for the year 2005 while Sun and Ouyang [48] used data for January 2013. Khan [47] and Burke and Yang [14] used data over the period of 1978-2011 to study the demand for natural gas in Pakistan and in the world, respectively. Zhang et al.[16] used data from the period 1992 to 2012. Ota et al. [49] considered data every 5 years during the period from 1990 to 2010. Gautam and Paudel [50] used panel data over the period between 1997 and 2016. Liu et al.[15] covered the period 2006-2015. Zeng et al. [52] adopted a cross-section data of residential natural gas consumption for the year 2014. Malzi et al.[53] considered annual data from the period 2005 to 2016. Zhou et al. [54b] used data from 2005 to 2017. Javid et al. [60b] covered the period 1972–2019 and Li et al. [62b] used data from 1991–2020.

### 4.2. Data sources

Balestra and Nerlove [4] used data from the Stanford Research Institute. Verhulst [19] obtained data from the result of a survey made by the Professional Office of Gas in Paris at the beginning of 1946. These data concern the operation of 46 gas firms in the fourth quarter of 1945. The data used by Balestra and Nerlove [4] was compiled by Stanford Research Institute on the basis of published statistics and other information available at the institute. Tinic et al. [20] collected data from rural residents using questionnaires with a sample size of 4000 interviewers. Other complementary data were obtained from bulk dealers and oil companies within a separate survey. Berndt and Watkins [5] used data from the National Income and Expenditure Division, Prices Division of Statistics Canada, and data from the Ministry of Transport. Bloch [22] exploited data from the Center for Environmental Studies at Princeton University. Beierlein et al. [23] used data provided by the Census Bureau’s northeastern region. Barnes et al. [24] exploited data from 1972-1973 Consumer Expenditure Survey (CES) made by the Bureau of Census. Liu [25] obtained data from State Energy Data Report, 1960-1978, DOE/EIA, and various issues of Statistical Abstract of the US and also from Galliker [66]. Blattenberger et al. [26] used data published in Brown's Directory of North American Gas Companies and the 1960 and 1970 Census of Population and also in the Bureau of Labor Statistics. Lin et al. [27] gathered data from several sources including Gas

Facts, the Statistical Year Book of the Electric Utility Industry, Basic Petroleum Data Book, National Petroleum News Factbook, Survey of Buying Power (1960-1983) and Galliker [66]. Green [28] exploited the Annual Housing Survey (AHS), 1974-1979 made by the US Department of Housing and Urban Development. Estrada and Fugleberg [29] gathered data from the United States Department of Energy, the International Energy Agency and the OECD Statistics. Baker et al. [30] used annual Family Expenditure Survey (FES) of Great Britain to collect detailed information from individual households about expenditure on different types of fuels; they also collect data from UK Energy Statistics and the reference book Whitaker's almanac to get data on the temperature. Maddala et al. [31] exploited data from US Energy Information administration (1993), National Oceanic and Atmospheric Administration, US department of Commerce and the Bureau of Economic Affairs. Haas and Schipper [32] gathered data from OECD statistics and Energy Information Administration. Krichene [33] obtained data from the Cambridge Energy Research Associates, commodity yearbook, Commodity Research Bureau, International Energy Agency, International Monetary fund, International Historical Statistics, OPEC-Annual statistical Bulletin, US Bureau of Mines and US Department of Energy. Berkhout et al. [34] used data provided by a survey of EnergyNed, a Federation of all energy companies in the Netherlands and the Dutch Bureau of Statistics. Labandeira et al. [35] used data from the International Energy Agency, Spanish Tax Agency, the Spanish Ministry of Economy and the Oilgas 2001 Encyclopedia. Asche et al. [7] obtained data from the International Energy Agency and Eurostat. Yoo et al. [36] used data provided by a survey of households conducted in 2005 and restricted to Seoul. In this study a total of 380 households were surveyed. Erdogdu [8] used data from the International Energy Agency. Meier and Rehdanz [37] exploited a British Household Panel Survey (BHPS) for the period of 1991-2005. Payne et al. [38] collected data from the US Energy Information Administration, the US Bureau of Labor Statistics (BLS) and the US Bureau of Economic Analysis (BEA). Alberini et al. [11] used various sources of data including American Housing Survey (AHS), a longitudinal study conducted by the Department of Housing and Urban Development and the International Energy agency. Andersen et al. [39] obtained data from the International Energy Agency. Bernstein and Madlener [9] got data from the International Energy agency, OECD statistics and European Statistical Office (Eurostat). Wadud et al. [10] gathered data from the national Oil and Gas Company in Bangladesh (Petrobangla), Bangladesh Bureau of statistics and the World Bank. Dagher [40] used data provided by Xcel Energy's service territory in Colorado. Bilgili [41] exploited data from the International Energy agency and OECD statistics. Santos [42] got data from the National Agency of Oil and Biofuel, Brazilian Institute of Geography and Statistics (IBGE) and the Brazilian National Treasury. Yu et al. [43] used data provided by the Ministry of Housing and Urban–Rural Development, National Development and Reform Commission, China Coal Resource, China Urban Life and Price Yearbook and China Meteorological Data Sharing Service System to calculate the Heating Degree Days particularly. Kani et al. [44] used data from the Ministry of Economic Affairs and Finance. Bianco et al. [45] exploited data from European Statistical Office (Eurostat), Italien Ministry of Economic Development, Italian Statistical Office (ISTAT) and IL Meteo. Dilaver et al. [12] got data for all variables from the International Energy Agency. Harold et al. [13] obtained data from the Ireland's Smart Metering Gas Consumer Behavioral Trial run from 1st December 2009 to 30th May 2011. Orlov [46] exploited data from version 8.1 of the Global Trade Analysis (GTAP) database that represents the global economy in 2007. Khan [47] used various data from the Hydrocarbon Development Institute of Pakistan, the Pakistan economic survey 2008-2009/ 2012-13 / 2013-14, the State Bank of Pakistan and the International Monetary Fund. Burke and Yang [14] used data available at the International Energy Agency, World Bank, the US Energy Information Administration, Research and Expertise on the World Economy and data from Feenstra et al. [64], Harris et al. [65]. Sun and Ouyang [48] and Zeng et al. [52] exploited data from China's Residential Energy Consumption Survey (CRECS) that covers households at different income levels and from different regional and social groups. CRECS, includes ten provinces in East, Central and Western China, and covers energy consumption of 1032 household samples in January 2013. It contains six important components including household demographics, dwelling characteristics, household appliances, space heating and cooling, private transportation and energy consumption. Ota et al. [49] gathered data from several sources including the Energy Consumption Statistics of the Research Institute of Economy, Trade and Industry Economic and Social Research Institute, the Statistics Bureau in the Ministry of Internal Affairs and Communications and the Ministry of Land, Infrastructure Transport and Tourism. Gautam and Paudel [50] used data from the Energy Information Administration, National Oceanic and Atmospheric Administration (NOAA), the U.S. Department of Labor and the U.S. Department of Commerce, Bureau of Economic Analysis. Liu et al.[15] used data from the Ministry of Housing and Urban-Rural Development of the People's Republic of China, the National Bureau of Statistics, the Development and Reform Commission of all capitals and municipalities and the State Electricity Regulatory Commission, while Zhang et al. [16] used the China Energy Statistics Yearbook, the National Development and Reform Commission, the International Statistical Yearbook and the CEIC Data. Malzi et al.[53] exploited data from two sources, the International Energy Agency and the World Bank. Data used by Lin et al. [55b] was sourced from China Statistical Yearbook, Price Yearbook of China, Daqing Statistical Yearbook, and CEIC database. Kostakis et al. [58b] used data from Eurostats and ELSTAT.

## 5. Results

The results for natural gas elasticities as reported in the literature are diverse and sometimes contradictory. This is due to the different data used, techniques and geographic contexts of the research. Most of research studies reviewed in this paper have tried to check the responsiveness of the demand to price and income.

### *5.1. Price elasticities*

The responsiveness of natural gas consumption to price varies considerably over studies. Some studies found a strong responsiveness such as Verhulst [19], Berndt and Watkins [5], Pindyck [21], Baker et al. [30], Burke and Yang [14], Zhang et al. [16], Bernstein and Madlener [9], Bilgili [41], Alberini et al. [11], Santos [42], Yu et al. [43], Kani et al. [44]. Others found low responsiveness like Balestra and Nerlove [4], Bloch [22], Barnes et al. [24], Green [28], Berkhout et al. [34], Krichene [33], Andersen et al. [39], Erdogdu [8], Payne et al. [38], Dagher

[40], Gautam and Paudel [50], Wadud et al. [10], Liu et al. [15], Bianco et al. [45], Dilaver et al [12], Khan [47], Labandeira et al. [35] Zeng et al. [52], Lin et al. [55b], Rubaszek et al. [56b] and Javid et al. [60b].

Verhulst [19], Berndt and Watkins [5], Baker et al. [30], Bernstein and Madlener [9], Bilgili [41], Alberini et al. [11], Yu et al. [43], Kani et al. [44] found that natural gas demand is price elastic and is negatively correlated with its own prices. Pindyck [21], Santos [42], Burke and Yang [14] reported a long-run own-price elasticity of -1.7 for residential natural gas demand. Zhang et al. [16] have shown that Natural gas demand is price elastic in all sectors except for the industrial sector.

Balestra and Nerlove [4], Bloch [22], Barnes et al. [24], Krichene [33], Labandeira et al. [35], Erdogdu [8], Wadud et al. [10], Bianco et al. [45], Dilaver et al. [12], Khan [47], Zeng et al. [52] and Li et al. [62b] showed that the demand for natural gas is price inelastic due to the week responsiveness. Green [28] found natural gas prices to be inelastic in the residential sector, especially for home heating. Gautam and Paudel [50] found it to be inelastic in the long run in all sectors. Berkhout et al. [34] found energy tax to havea small impact in energy demand in the short run and the average price elasticity is -0.3. That is to say, the demand depends on variables other than prices. Andersen et al. [39], Dagher [40] revealed that natural gas demand is highly inelastic in the short and long run. Payne et al. [38] found that gas demand is price inelastic in the short and long run, and the speed of adjustment to the long run is about 1,42 years. Kostakis et al. [58b] found that residential natural gas demand is mostly price inelastic and almost income elastic.

In addition, some other studies have found the elasticity sometimes smaller and in other times greater than 1. Tinic et al. [20] argued that gas demand is price elastic when the price >0,85 Dollar but price inelastic at lower and considerably higher price levels. Beierlein et al. [23], Lin et al. [27], Liu [25], Asche et al. [7] found natural gas demand to be price inelastic in the short run but price elastic in the long-run. For Haas and Schipper [32], price elasticities differ for rising and falling prices. Demand is more elastic for rising prices but inelastic for falling prices. Chai et al. [51] revealed that natural gas demand increases with the decrease of the price in the short run and the increase of the price in the long run. Meier and Rehdanz [37] showed that renters and owner-occupied have a different reaction toward changes in price and income. Renters are more sensitive to price changes and decrease their consumption slightly compared to owner-occupied. Whereas, Sun and Ouyang [48] found that low income individuals are more sensitive to gas prices than other households.

### *5.2. Income elasticities*

Identically to price elasticity studies, research studies reveal that gas demand is income elastic in some contexts and inelastic in others.

Balestra and Nerlove [4], Krichene [33], Bernstein and Madlener [9], Wadud et al. [10], Bilgili [41], Santos [42], Kani et al. [44], Bianco et al. [45], Dilaver et al. [12], Khan [47], Burke and Yang [14], Kostakis et al. [58b] and Javid et al. [60b], found that gas demand is income elastic, particularly in the long run. For Haas and Schipper [32], Natural gas demand is income elastic, especially when we incorporate indicators of technological efficiency to estimate energy consumption.

Verhulst [19] reported the income elasticity to be zero. That is to say, a change of income does not affect gas consumption. Baker et al. [30] found the income elasticity very small. In addition, Berndt and Watkins [5], Labandeira et al. [35], Dagher [40], Yu et al. [43], Gautam and Paudel [50], Liu et al. [15] proved gas demand to be inelastic in the short and long run.

Moreover, Beierlein et al. [23] have shown that natural gas consumption is income elastic in the industrial sector but inelastic in the residential and commercial sector. For Lin et al. [27] and Asche et al. [7], the demand is price and income inelastic in the short run but becomes elastic in the long-run.

### *5.3. The effect of temperature*

Generally, most studies reported that temperature is having a negative and significant impact on natural gas demand such as Berndt and Watkins [5], Payne et al. [38], Bernstein and Madlener [9], Bianco et al. [45], Harold et al. [13] and Kostakis et al. [58b]. For Gautam and Paudel [50] Heating Degree Days is having a significant positive impact on natural gas demand in the all sectors except for the industrial sector. Whereas Liu et al. [15] and Kani et al. [44] revealed that gas consumption has almost no impact on natural gas demand.

### *5.4. Substitutability effect*

In these reviewed papers, natural gas demand tends to be sensitive to a change in other fuel's prices, or what we economically call substitutability effect. For Chai et al. [51], Gautam and Paudel [50], there a substitutability effect between gas, electricity and oil in the short and long term. Zhang et al. [16] found that natural gas and other fuels are substitutable. Liu et al. [15] revealed that electricity prices have a positive effect on gas demand, while Zeng et al. [52] found that a substitution potential exists between gas and electricity. Estrada and Fugleberg [29] found that cross-price elasticities between gas and other fuels are higher in West Germany than in France because in West Germany consumers change their consumption faster with the fluctuations in relative prices of different energy sources. For Yu et al. [43], there is a substitution effect between gas and coal in North China and no effect in South China.

However, Ota et al. [49] found no cross-price effect between gas and electricity because gas demand is insensitive to a change in electricity prices. Erdogdu [8] showed that demand for gas is its own price and cross-price inelastic. While Khan [47] found that cross-price elasticities show a weak substitutability effect between gas and oil and Labandeira et al. [35] revealed a limited substitution between gas and electricity in urban areas.

### *5.5. Demographic and other factors*

Ota et al. [49] found that elderly population does not affect the demand for gas and the presence of nuclear families affects the consumption of gas negatively, while Malzi et al. [53] reported that the increase of the urbanization rate leads to more per capita consumption of natural gas in the residential sector. The ageing of the population decreases the use of per capita residential natural gas in OECD countries. When population density increases, per capita residential natural gas consumption decreases. Kostakis et al. [58b] stated that urbanisation and weather conditions affect residential natural gas demand.

In addition, Yoo et al. [36] have shown that the Size of the house, dwelling in an apartment and having a bed in an inner room increase natural gas consumption, while the size of the family decreases the consumption. For Harold et al. [13] Energy efficiency, the dwelling and socioeconomic characteristics of households are the most determinants of the demand for natural gas. However, for Berndt and Watkins [5], there is a significant effect of equipment stock on gas demand.

## *6.* Conclusion

In this study, we have presented the current state of the literature of natural gas demand elasticities from the second half of the 20th century to the beginning of 2022. Our first remark is that studies about natural gas demand are developing considerably in recent years because from 1950 to 2009, in 60 years there have been 21 published papers, whereas from 2010 to 2022, in last decade there have been 33 published papers. We tried to be comprehensive and include all the existing research. To our knowledge, we have surveyed all existing studies analyzing natural gas demand elasticities.

Overall findings from the studies investigated in this paper reveal that the literature produced conflicting results and there is no consensus either on the most impacting variable nor on the magnitude of the elasticities. In most case, it is tough and even impossible to set up an objective, unbiased comparison among studies. This is because each study presents a different context, different data and different approaches. Various authors considered various methodologies and variables. A variable that is neglected by an author is considered to be very important for another since the objectives are different.

Almost the majority of studies focus on the price and income variables as the main inputs and sometimes add some additional variables like weather, house and household characteristics. However, the demographic variables were overlooked by the prior literature.

The results of this literature review are of crucial importance for policy implications in energy economics, and the study serves as a basis for the debate about the adequate design and implementation of energy and environmental policies and also demonstrates that this topic still needs further attention in the future.

**Appendix A:** Summary of literature on applied models, application area, period and data source

| APPLIED MODEL | RESEARCHERS | APPLICATION AREA | PERIOD | DATA SOURCE |
|---|---|---|---|---|
| **Logistic growth curve** | Verhulst [19] | National level (France) | 1945 | Professional Office of Gas in Paris |
| **Dynamic model** | Balestra and Nerlove [4] | National level (US) | 1950 - 1962 | Stanford Research Institute |
| | Tinic et al. [20] | City level | Not applied | Survey of households in Alberta |
| **Non-linear technique** | Berndt and Watkins [5] | Regional level | 1959 - 1974 | National Income and Expenditure Division, Prices Division of Statistics Canada, Ministry of Transport |
| **Time series model** | Bloch [22] | Individual consumers level | 1971 - 1976 | Center for Environmental Studies at Princeton University |
| **Error components model and seemingly unrelated regressions** | Beierlein et al. [23] | Regional level | 1967 - 1977 | Census Bureau |
| **Instrumental variable** | Lin et al. [27] | National level (US) | 1960 - 1983 | Gas Facts, Statistical Year Book of the Electric Utility Industry, Basic Petroleum Data Book, National Petroleum News Factbook, Survey of Buying Power (1960-1983) |
| | Barnes et al. [24] | Customer's level | 1972 - 1973 | Bureau of Census |
| **Simultaneous-equations model** | Liu [25] | National level (US) | 1967 - 1978 | State Energy Data Report, Energy Informaiton Administration, Statistical Abstract of the US |

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| **Houthakker-Taylor flow adjustment** | Blattenberger et al. [26] | National level (US) | 1960 - 1975 | Brown's Directory of North American Gas Companies, Census of Population, Bureau of Labor Statistics |
| **Linear model** | Green [28] | regional level | 1974 - 1979 | US Department of Housing and Urban Development |
| **Translog functions** | Estrada and Fugleberg [29] | regional level (France and Germany) | 1960 - 1983 | United States Department of Energy, International Energy Agency and OECD Statistics |
| | Pindyck [21] | World level | 1955 - 1974 | Not applied |
| **Two-stage budgeting model** | Baker et al. [30] | Regional level | 1972 - 1983 | Family Expenditure Survey (FES) of Great Britain, UK Energy Statistics and reference book Whitaker's almanac |
| | Berkhout et al. [34] | National level (Netherlands) | 1992 - 1999 | Federation of all energy companies in the Netherlands and Dutch Bureau of Statistics. |
| **Iterative estimator approach** | Maddala et al. [31] | National level (US) | 1970 - 1990 | US Energy Information administration (1993), National Oceanic and Atmospheric Administration, US department of Commerce and Bureau of Economic Affairs |

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|---|---|---|---|---|
| **Simultaneous demand and supply model** | Krichene [33] | world level | 1919 - 1999 | Cambridge Energy Research Associates, commodity yearbook, Commodity Research Bureau, International Energy Agency, International Monetary fund, International Historical Statistics, OPEC-Annual statistical Bulletin, US Bureau of Mines and US Department of Energy. |
| **Structure and Intensity (STRINT) approach & imperfect price-reversibility approach** | Haas and Schipper [32] | Regional level (OECD) | 1970 - 1993 | OECD statistics and Energy Information Administration |
| **Fixed Effects model** | Asche et al. [7] | Regional level (Europe) | 1960 - 2002 | International Energy Agency (IEA) and Eurostat |
| | Chai et al. [51] | _ | Not applied | Not applied |
| | Burke and Yang [14] | World level | 1978 - 2011 | IEA, World Bank, US energy Information Administration, Research and Expertise on the World Economy |
| | Ota et al. [49] | National level (Japan) | 1990 - 2010 | Energy Consumption Statistics of the Research Institute of Economy, Trade and Industry Economic and Social Research Institute, Statistics Bureau in the Ministry of Internal Affairs and Communications and the Ministry of Land, Infrastructure Transport and Tourism. |

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| **Shrinkage estimation** | Andersen et al. [39] | Regional level (Europe) | 1978 - 2003 | IEA |
| **sample selection model** | Yoo et al. [36] | City level | 2005 | Survey of households in Seoul (2005) |
| **ARIMA** | Erdogdu [8] | National level (Turkey) | 1988 - 2005 | IEA |
| **Random effects model** | Meier and Rehdanz [37] | Regional level | 1991 - 2005 | British Household Panel Survey (BHPS) |
| **ARDL** | Payne et al. [38] | City level | 1970 - 2007 | US Energy Information Administration, US Bureau of Labor Statistics (BLS) and US Bureau of Economic Analysis (BEA). |
| | Zhang et al. [16] | National level (China) | 1992 - 2012 | Energy Statistics Yearbook, the National Development and Reform Commission, International Statistical Yearbook, CEIC Data |
| | Bernstein and Madlener [9] | Regional level (OECD) | 1980 - 2008 | IEA, OECD statistics and European Statistical Office (Eurostat). |
| | Dagher [40] | City level | 1994 - 2006 | Xcel Energy's service territory in Colorado |
| | Gautam and Paudel [50] | Regional level | 1997 - 2016 | Energy Information Administration, National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Labor and the U.S. Department of Commerce, Bureau of Economic Analysis |
| **Cointegration technique** | Bilgili [41] | Regional level (OECD) | 1979 - 2006 | IEA and OECD statistics |

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| **GMM model** | Alberini et al. [11] | Regional level | 1997 - 2007 | IEA, American Housing Survey (AHS), a longitudinal study conducted by the Department of Housing and Urban Development. |
| | Malzi et al. [53] | Regional level (OECD) | 2005 - 2016. | IEA, World Bank. |
| | Santos [42] | National level (Brazil) | 2001 - 2010 | National Agency of Oil and Biofuel, Brazilian Institute of Geography and Statistics (IBGE) and Brazilian National Treasury |
| **Log-linear Cobb Douglas function** | Wadud et al. [10] | National level (Bangladesh) | 1981 - 2008 | national Oil and Gas Company in Bangladesh (Petrobangla), Bangladesh Bureau of statistics, World Bank |
| **Feasible Generalized Least Squares (FGLS)** | Yu et al. [43] | National level (China) | 2006 - 2009 | Ministry of Housing and Urban–Rural Development, National Development and Reform Commission, China Coal Resource, China Urban Life and Price Yearbook, China Meteorological Data |

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|---|---|---|---|---|
| | Liu et al. [15] | National level (China) | 2006 - 2015 | Ministry of Housing and Urban-Rural Development of the People's Republic of China, National Bureau of Statistics, Development and Reform Commission of all capitals and municipalities and the State Electricity Regulatory Commission, |
| **Smooth Transition Regression (STR) model** | Kani et al. [44] | National level (Iran) | 1971 - 2009 | Ministry of Economic Affairs and Finance. |
| **Standard dynamic constant elasticity function** | Bianco et al. [45] | National level (Italy) | 1990 - 2011 | European Statistical Office (Eurostat), Italien Ministry of Economic Development, Italian Statistical Office (ISTAT), IL Meteo |
| **Structural Time Series Model (STSM)** | Dilaver et al. [12] | Regional level (OECD-Europe) | 1978 - 2011 | IEA |
| **Micro-econometric analysis** | Harold et al. [13] | National level (Ireland) | 2009 - 2019 | Ireland's Smart Metering Gas Consumer Behavioural Trial |
| **Computable Generation Equilibrium model** | Orlov [46] | National level (Russia) | 2007 | Global Trade Analysis (GTAP) database |
| **Sectoral model** | Khan [47] | National level (Pakistan) | 1978 - 2011 | Hydrocarbon Development Institute of Pakistan, Pakistan economic survey, State Bank of Pakistan and International Monetary Fund |

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| **Almost Ideal Demand System model** | Labandeira et al. [35] | National level (Spain) | 1973-1974/1980-81/1985-1995 | IEA, Spanish Tax Agency, Spanish Ministry of Economy and Oilgas 2001 Encyclopedia |
| | Sun and Ouyang [48] | National level (China) | 2013 | China's Residential Energy Consumption Survey (CRECS) |
| **Instrumental variable method** | Zeng et al. [52] | National level (China) | 2014 | China's Residential Energy Consumption Survey (CRECS) |
| **Novel discrete grey model** | Zhou et al. [54b] | Provincial level (China) | 2005-2017 | National Bureau of Statistics or International Organizations |
| **Autoregressive Distributed Lag (ARDL)** | Lin et al. [55b] | National level (China) | 1985–2017 | China Statistical Yearbook, Price Yearbook of China, Daqing Statistical Yearbook, and CEIC database |
| **Bayesian Structural Vector Autoregression** | Rubaszek et al. [56b] | National level (US) | 1978-2020 | World Bank Data, EIA and FRED database. |
| **Pseudo-panel static FGLS and dynamic GMM models** | Kostakis et al. [58b] | National data (Greece) | 2012-2019 | Eurostats and ELSTAT. |
| **Structural time series modeling (STSM)** | Javid et al. [60b] | National data (Pakistan) | 1972–2019 | Pakistan Energy Yearbook, Pakistan Economic Survey |
| **Parametric specifications** | Li et al. [62b] | National level (US) | 1991–2020. | EIA, US Bureau of Labor Statistics (BLS), US National Oceanic and Atmospheric Administration |

**Appendix B: Overview of the main results**

| Researchers | Input data | Key Findings |
|---|---|---|
| **Verhulst [19]** | per capita gas, Price, Income | Price elasticity of gas demand is negative (-3), whereas the income elasticity is zero. That is to say that a change of income does not affect gas consumption. |
| **Balestra and Nerlove [4]** | Price, population, income, stock of appliances, | The long-run price and income elasticities of gas demand is positive (0,6) |
| **Tinic et al. [20]** | Price | Gas demand is price elastic when the price >0,85$ but price inelastic at lower and considerably higher price levels. |
| **Berndt and Watkins [5]** | Price,population, income, DD | There is a significant effect of equipment stock on gas demand and the price has a very important impact on gas demand over the long-run. Gas demand is found to be income inelastic (-069).The temperature is haveing a positive impact on gas consumption (0,75) |
| **Bloch [22]** | Income, price, prices of substitutes, HDD | Natural gas is price elastic (-0,66) |
| **Beierlein et al. [23]** | Price, income | Natural gas demand is price inelastic in the short run but price elastic in the long-run. However, it is income elastic in the industrial sector but inelastic in the residential and commercial sector. |
| **Lin et al. [27]** | Price, income | The demand is price and income inelastic in the short run but becomes elastic in the long-run |
| **Barnes et al. [24]** | Price | Natural gas is price inelastic |
| **Liu [25]** | Price, income | Natural gas demand is much more price elastic in the long run than in the short run |
| **Blattenberger et al. [26]** | Income, price, prices of substitutes, HDD, CDD | The level and the change in natural gas availability affect the demand of other fuels especially oil and electricity. |
| **Green [28]** | Price | Natural gas is price inelastic in the residential sector especially for home heating |

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|---|---|---|
| **Estrada and Fugleberg [29]** | Price, income | The cross price elasticities between gas and other fuels are higher in West Germany than in France because in West Germany consumers change their consumption faster with the fluctuations in relative prices of the different energy sources. |
| **Pindyck [21]** | Price | reported a long-run own-price elasticity of -1.7 for residential natural gas demand |
| **Baker et al. [30]** | Price, income, house and household characteristics | Gas is largely price elastic and income elasticity is positive but small |
| **Berkhout et al. [34]** | Price, income, prices of substitutes, household behaviors | In the short run, energy tax is having a small impact in energy demand. Also the average price elasticity is -0,3. That means, the demand depends on variables other than prices. |
| **Maddala et al. [31]** | Price, income | |
| **Krichene [33]** | Price, income | The demand of gas is price inelastic in the short run and income elastic |
| **Haas and Schipper [32]** | Price, income, effeciency | Price elasticities differ for rising and falling prices. Demand is more elastic for rising prices but inelastic for falling prices. Also, energy efficiency is a crucial variable to analyze gas demand. Natural gas demand is income elastic especially when we incorporate indicators of technological effeciency to estimate energy consumption. |
| **Asche et al. [7]** | Price, income, HDD | Price and income elasticities are very inelastic in the short term but elastic in the long run. Besides, the substitution between fuels is very limited in the short term |
| **Chai et al. [51]** | price, prices of substitutes | Natural gas demand increases with the decrease of the price in the short run and the increase of the price in the long run. Also, there is a substitutional effect between gas, electricity and oil in the short and long term. |
| **Burke and Yang [14]** | Price, income | Natural gas demand is price and income elastic in the long run. |

| | | |
|---|---|---|
| **Ota et al. [49]** | Demographic characteristics (elderly, population) | Elderly population does not affect the demand for gas and the presence of nuclear families affects negatively the consumption of gas |
| **Andersen et al. [39]** | Price, income | Natural gas demand is highly inelastic in the short and long run |
| **Yoo et al. [36]** | Price, income, house and household characteristics | The Size of the house, dwelling in an apartment, having a bed in an inner room and the household income increase natural gas consumption while the size of the family and prices deacrise the consumption. |
| **Erdogdu [8]** | Price | The demand for gas is own price and cross price inelastic |
| **Meier and Rehdanz [37]** | Price, income, HDD | Renters and owner-occupied have a different reaction toward changes in price and income. Renters are more sensitive to price changes and decrease their consumption slightly compared to owner-occupied |
| **Payne et al. [38]** | Price, income, prices of substitutes, Temperature | Natural gas demand is price inelastic in the short and long run, and the speed of adjustment to the long run is 1,42 years |
| **Zhang et al. [16]** | Price, income, prices of substitutes | Natural gas demand is price elastic in all sectors except for the industrial sector. Natural gas and other fuels are substitutable |
| **Bernstein and Madlener [9]** | Price, income, temperature | Natural gas demand is negatively correlated with its own prices but positively correlated with the household's income and weather. |
| **Dagher [40]** | Price, income, Temperature | The responsiveness of natural gas demand to price and income is very low in the short and long run |
| **Gautam and Paudel [50]** | Price, income, HDD | Natural gas demand is price inelastic in the long run in all sectors. There is a substitutability effect between gas and fuel oil. HDD is having a significant impact on natural gas demand in the all sectors except for the industrial sector |
| **Bilgili [41]** | Price, income | Natural gas demand is found to be price and income elastic. |
| **Alberini et al. [11]** | Price, income | Gas demand is own price elastic |

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|---|---|---|
| **Malzi et al. [53]** | Price, income, demographic variables, HDD, CDD | the increase of the urbanization rate leads to more per capita consumption of natural gas in the residential sector. The ageing of the population decreases the use of per capita residential natural gas in OECD countries. When population density increases, per capita residential natural gas consumption decreases. |
| **Santos [42]** | Price, income | Gas is price and income elastic in the long run |
| **Wadud et al. [10]** | Price, income, population | Gas demand is income elastic and price inelastic |
| **Yu et al. [43]** | Price, income, prices of substitutes | Gas demand is price elastic and income inelastic. Also there is a substitution effect between gas and coal in North China and no effect in South China |
| **Liu et al. [15]** | Price, income, population, household characteristics, HDD | Natural gas demand is price and income inelastic. Also, electricity prices have positive effect on gas demand. In Addition, gas consumption has almost no impact on natural gas demand. |
| **Kani et al. [44]** | Price, income, Tempertaure, | Natural gas demand is price and income elastic and temperature has no impact. |
| **Bianco et al. [45]** | Price, income, temperature | Natural gas consumption is more income elastic than price. Temperature has a significant positive impact on gas consumption especially in the long run |
| **Dilaver et al. [12]** | Price, income | Natural gas consumption is more income elastic than price. |
| **Harold et al. [13]** | Weather, household characteristics, energy efficiency measures, | Energy efficiency, the dwelling and socioeconomic characteristics of households are the most determinants of the demand for natural gas. Also, the weather is having a very important influence on gas consumption |
| **Orlov [46]** | Price | It is beneficial to increase gas prices in order to achieve welfare gains. But unifying gas prices does not lead to maximal welfare gains. |
| **Khan [47]** | Price, income, prices of substitutes | Natural gas consumption is more income elastic than price. Also, Cross price elasticities show a weak substitutability effect between gas and oil |

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|---|---|---|
| **Labandeira et al. [35]** | Price, income | Gas demand is price and income inelastic. Also, there exist a limited substitution between gas and electricity in urban areas. |
| **Sun and Ouyang [48]** | Price, income | Low income individuals are more sensitive to gas prices than other households. |
| **Zeng et al. [52]** | Price, prices of substitutes, household characteristics | Natural gas demand is price inelastic. Also, family members would increase natural gas demand for heating and cooking. Moreover, a substitution potential exist between gas and electricity. |
| **Lin et al. [55b]** | | |
| **Rubaszek et al. [56b]** | Price, income, | The demand reacts more freely to changes in the real prices of U.S.<br>Also the market specific demand shocks explain a dominant fraction of natural gas prices variability |
| **Kostakis et al. [58b]** | Price, income, household characteristics, HDD | Residential natural gas demand is mostly price inelastic and almost income elastic. |
| **Javid et al. [60b]** | Price, income, | A large variation in the estimated elasticities. The significant differences in the long-run income and price elasticity of gas demand for each sector might be due to structural characteristics of each sector. |
| **Li et al. [62b]** | Price, employment, HDD | The US commercial natural gas demand is price inelastic and commercial natural gas shortage cost declines with the size of own-price elasticity estimates.<br>Also, the aggregate cost of a natural gas shortage can be reduced by demand response programs like those enabled by smart metering for managing electricity shortage |

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