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Navigating the Path to Sustainable Energy Consumption: A Second-Generation Panel Cointegration Approach to Measuring Price and Income Elasticity of Energy Demand in Europe

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ABSTRACT

Achieving United Nations Sustainable Development Goals of affordable and clean energy and climate action requires a deep understanding of energy consumption patterns and their responsiveness to various macroeconomic variables. This study investigates the long-run price and income elasticities of electricity and natural gas demand across European Union member states, disaggregating consumption into household and non-household sectors. Employing second-generation panel cointegration techniques, including Common Correlated Effects Mean Group (CCEMG) estimators, we address cross-sectional dependence and unobserved common factors to provide robust elasticity estimates. Our findings reveal that energy product prices exhibit negative but rather inelastic effects on demand, with household sectors showing greater sensitivity than non-household sectors. Sectoral income, however, plays a more dominant role, significantly influencing long-term energy consumption trends across both the sectors. These results underscore the necessity of differentiated policy approaches, where price-based incentives enhance household energy efficiency, while income-driven strategies support sustainable industrial growth. The study contributes to the literature on energy demand modeling and provides policymakers with actionable insights for designing effective energy pricing and sustainability policies. Future research should explore the impact of technological advancements and regulatory interventions on energy consumption elasticity in the context of evolving energy markets.

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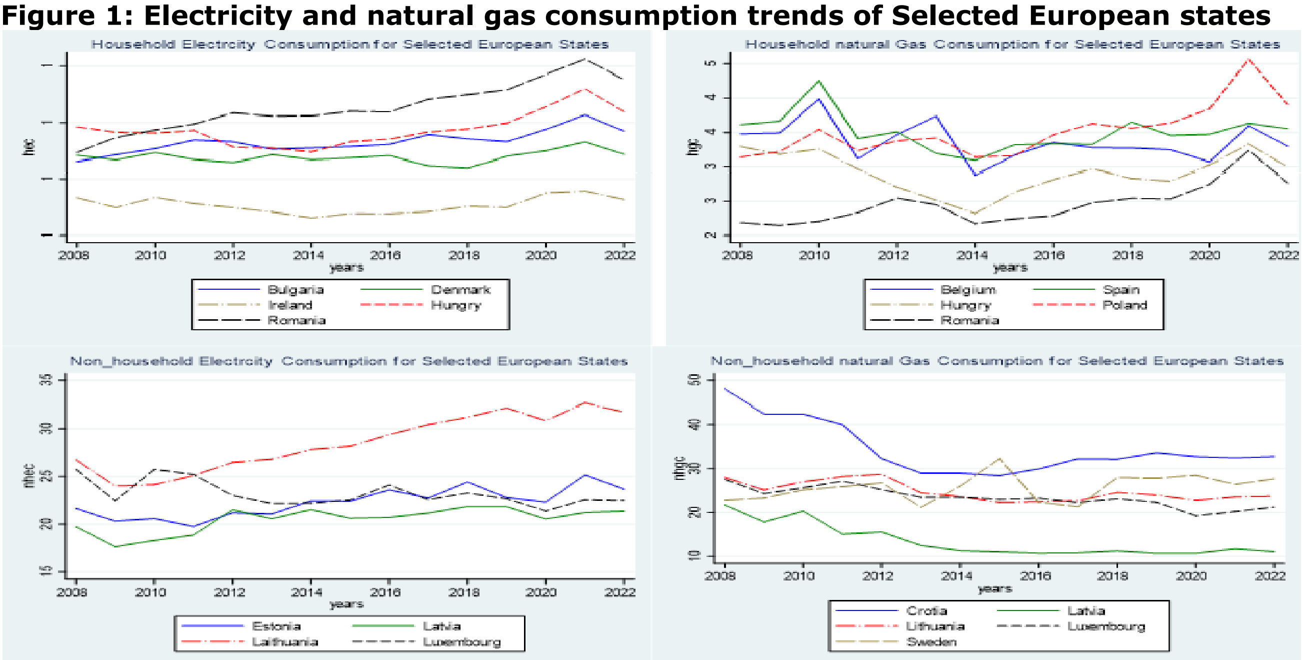
1. Introduction

The energy demand in Europe has increased dramatically during last three decades for all of its prominent economies. The rising trends of energy demand started becoming visible from early 1990s and gained peak by mid of 2000. Such a sharp rise in region-wide energy demand raises few important concerns about the subject; including which sectors of the economy are the largest consumers, most highly demanded energy product, changes occurring to the energy product prices over the years, responsiveness of energy consumption levels towards various instances of tax imposition, the ongoing levels of energy efficiency and how to optimize them further, and many others. The most basic aspects of energy consumption in Europe have been studied for more than half a century and are still under investigation; price and income elasticities are few of them. The fundamental importance is to examine how the changes occurring in energy products prices and sectoral income levels affect the energy consumption and production behaviors in an economy, so that their future patterns could be planned in a more responsible manner(Antonio F. Erias & Emma M. Iglesias, 2022; Malka et al., 2023).

It is evidently seen that price-based incentives on various energy products tend to hold strong implications for behavioral responses of consumers as well as producers, thus, leading governments to device strategies at state level, targeting upon energy efficiency gains and minimizing negative energy-related externalities (Dogan, Hodžić, & Šikić, 2023; Ebaidalla, 2024; Nadiri, Gündüz, & Adebayo, 2024). To know the estimated value of income elasticity is gigantic importance for business. As welfare economics is of the view that carbon intensity of GDP should be minimized in the larger benefits of societies, economists urge to gauge the consequences of such policy actions for producers(Gu et al., 2023; Imran et al., 2024; Pata, Kartal, & Mukhtarov, 2024; Rahman, Sultana, & Velayutham, 2022). In EU member states, key energy-consuming sectors include (a) transport, which shared for 28.4% of total energy demand in 2019, rising to 31% by 2022. This sector primarily consumes petrol and diesel. (b) Households, responsible for 28% of energy use in 2019, saw a decline to 26.9% in 2022 but rebounded to 30% in 2023, driven by increased heating needs. Household electricity consumption rose by 0.8% between 2009 and 2019. (c) Industry, contributing 26.1% in 2019, fell to 25.1% by 2022, with an overall 13% decline from 2007 to 2019 due to efficiency improvements and carbon tax policies (Eurostat, 2023; International Energy Agency, 2023). Region-wide energy demand has declined since 2005, with a sharper drop post-2019. The shift towards renewable energy has accelerated, growing from 5.3% of the total energy mix in 1990 to 12.2% in 2022 (World Economic Outlook, 2024). Among EU nations, Sweden led with 49.7% of its energy from renewable in 2022, followed by Denmark (40.5%) and Finland (39.4%) (Eurostat, 2023). While, Finland has increased hard coal use, its reliance on peat, oil, and gas has decreased. Germany, France, the UK, and Italy are expanding their renewable energy share gradually to reduce dependence on non-renewable sources.

There is further disaggregation of sources of both renewable and non-renewable energies like hydro and thermal are main renewable energy sources whilst peat, coal, natural gas and fuels are non-renewable ones. Energy demand in European region displays a sharp rise during the period 1994 to 2005.

Figure 1: Electricity and natural gas consumption trends of Selected European states



From 2005 to 2016, the growth in energy demand was occurring at rather slow pace. However, from 2019 onwards, a noticeable fall is observed. Between the period 1990 and 2019, the larger share of non-renewable energy sources like solid fossil fuels dramatically decreased from 9.6% in 1990 to 2.1% in 2019. In contrast, the total share of renewable energy sources increased from 4.3% in 1990 to 10.9% in 2019. The share of natural gas was 18.8% in 1990 and in 2019; it was 21.3% (Eurostat, 2023). The energy sources which presently are in highest demand amongst EU member countries are oil and petroleum, electricity and natural gas sharing in percentage of the total energy consumption of the region as 37%, 22.8% and 21.3%, respectively. Basically, in our study, we are interested to investigate the long run price and income elasticities of electricity and natural gas consumption in both household and non-household sectors across the selected European Union members. It is necessary to know how price changes affect energy demand which is helpful for better prediction for future consumption trends and informs capacity planning for energy suppliers. Measuring sectoral responsiveness to price fluctuations provides critical insights for policymakers to anticipate welfare impacts and optimize energy use over time. This research aims to determine (a) whether energy prices and income levels significantly impact long-run demand across sectors and (b) whether elasticity estimates remain robust across different measurement approaches (Burke & Abayasekara, 2018; Miller & Alberini, 2016).

The novelty of the research in comprehensive approach relies on analyzing price and income elasticity of electricity and natural gas for selected EU member states. The EU member countries tend to share comparable demographic characteristics, economic features, and socio-economic structures. By employing advanced second-generation panel cointegration methods, this study tries to accounts the issue of cross-sectional dependency, allowing for robust estimation of long-run co-integrating relationships when panel cross-sections (countries) are found evidently affected by inter-dependencies. This methodological advancement addresses the limitations of traditional models in capturing inter-dependencies amongst countries with shared economic and demographic features. Furthermore, first-generation cointegration models are also tested, thus, providing readers with a unique comparative framework to gauge the sensitivity of estimated price and income elasticities to different econometric techniques. This dual approach not only attributes enhancing the reliability of the findings but also provides a deeper understanding of methodological implications in elasticity estimation across highly integrated economic regions like Europe. The next coming sections of the paper attribute as given: Section 2 of this paper provides a comprehensive review of the earlier studies in favor of produced estimating price and income elasticities of European household and non-household sectors, with special reference to electricity and natural gas consumption. Section 3 brings into discussion the empirical methodology followed and the sources our sample data set is extracted from. Section 4 comprises discussion of results and Section 5 offers summary and the key points of main conclusions drawn from the study.

2. Literature Review

Literature on energy demand patterns for the Europe claims a variety of economic, demographic, climate-related and even social factors responsible for determining the trend patterns of energy consumption. Amongst its economic determinants, household consumption is evidently seen to be receiving substantial effects from prices of energy products and sectoral income levels. Looking through the researches from the recent past, the energy consumption tends to be affected inversely by energy prices (Labandeira, Labeaga, & López-Otero, 2017; Miller & Alberini, 2016; S. Wang et al., 2024) and positively by household income level (Burke & Csereklyei, 2016; Schulte & Heindl, 2017)Though the intuitively correct effects of energy product prices and sectoral income levels are well understood and well established in literature, a vast amount of studies have also evidently found that energy consumer sectors do not save energy in spite of improved energy efficiency as was expected. Upon switching to more energy efficient appliances, their demand should demonstrate declining trends but it does not always happen. This is because consumers are of the view that they are now in a much better position to afford increased energy consumption. In literature, the phenomenon is known by the name of energy rebound effect. Recent studies done on energy efficiency gains has brought into limelight the practical importance of this effect with much emphasis on quantifying both periods of short-run and long-run rebound effects, besides investigating its economic, demographic, climatic and policy-related underlying drivers (Adetutu, Glass, & Weyman-Jones, 2016; Adha & Hong, 2021; Adha et al., 2021; Zhang & Peng, 2016).

Measuring consumers' reactions to electricity and gas price shocks is imperative for policymaking purposes, given that such responses depend on prevalent economic conditions. Elasticities of price and income provide a better perception to know about the impact on demand as price and income changes. In the short-run, energy demand remains inelastic or less elastic because of limited substitutability and habitual usage (Adetutu, Glass, & Weyman-Jones, 2016; Massié & Belaïd, 2024; Miller & Alberini, 2016). Long-run price elasticity tends to be larger as people adapt to use energy-saving technologies. Income elasticity changes as well; first, increased incomes lead to moderate increases in demand, but in the long-run, they spur higher consumption and investment in energy-efficient technologies (Gorus & Karagol, 2022; Liddle &

Hasanov, 2023). Elasticity tends to vary across industries—industrial and commercial consumers react differently from households (Burke & Yang, 2016; Cassetta, Nava, & Zoia, 2022; Labandeira et al., 2020). Economic changes and technological advancements further influence long-run elasticities (Ahakwa et al., 2023; Bakry et al., 2023; Gao, Peng, & Smyth, 2021; Lange & Berner, 2022).Beyond economic determinants, demographic factors such as urbanization and population growth also shape energy demand, with urban areas consuming more electricity and natural gas due to greater accessibility(Li et al., 2022; Liddle & Hasanov, 2023; Yadav & Mahalik, 2024). Similarly, social factors, such as cultural attitudes and environmental awareness, influence energy consumption patterns. A societal shift toward sustainability can reduce electricity and natural gas consumption as this develops consumer readiness to transition to alternative energy sources (Lomborg, 2020; Pata, Kartal, & Mukhtarov, 2024; Wang & Xu, 2021). Household composition and size further affect consumption patterns, as larger households benefit from economies of scale. Policy interventions are also found significantly driving the energy demand trends, particularly in long-run. Subsidies, energy taxes and other regulatory measures are evidently found affecting the energy demand by shaping consumer adjustment behavior given their constrained purchasing power. For example, energy pricing reforms that eliminate subsidies can enhance price elasticity by compelling consumers to adjust to higher costs. Investing in renewable energy sources and efficiency programs also alter demand by providing sustainable alternatives(S. Wang et al., 2024; Zakeri et al., 2023).

Ensuring the accuracy of estimated price and income elasticities requires sophisticated econometric techniques to address the complexities in energy demand data. Panel cointegration techniques, such as the Pedroni residual-based technique and after that, the famous Fully Modified Ordinary Least Squares (FMOLS) estimator, establish long-run relationships between energy demand, prices, and income. Error Correction Models (ECM) helps to differentiate short-run and long-run elasticities by capturing the speed of demand adjustment to price and income changes (Burke & Csereklyei, 2016; Massié & Belaïd, 2024; Pedroni, 2004; Pesaran, 2015). The Instrumental Variable (IV) approach addresses endogeneity concerns; ensuring explanatory variables remain uncorrelated with error terms. Fixed and random effects models control for unobserved heterogeneity, with fixed effects assuming time-invariant factors and random effects allowing variation across entities, particularly useful for cross-country analyses (Cialani & Mortazavi, 2018; Jamissen et al., 2024; Kröger et al., 2023; Labandeira, Labeaga, & López-Otero, 2017; Pesaran, 2015). In the presence of Cross-sectional dependency in panel data studies is crucial for robust model estimates, as unobserved common factors can make results bias. Second-generation panel cointegration models are widely used to account for such interdependencies. To address the issues like heterogeneity, endogeneity, non-stationary, and cross-sectional dependence, Smyth et al. (2021) used mean group and pooled mean group panel estimators and applied them to get rid the above mentioned issues. Their study of 65 countries (1960–2016) estimated price elasticities whose magnitude range between -0.1 and -0.4 and income elasticities magnitude lies between 0.6 and 0.8, underscoring the significance of cross-sectional dependence. Sohail, Ullah and Sohail (2025)analyzed both renewable and non-renewable energy consumption's impact on OECD export diversification (1990–2022), applying the CS-ARDL method to validate findings. Some other studies of Patel, Kautish and Shahbaz (2024); Tsemekidi Tzeiranaki et al. (2023); E. Wang et al. (2024), and Yadav and Mahalik (2024), have used advanced econometric techniques, such as Westerlund and Pedroni cointegration tests, Johansen-Fisher panel cointegration, FMOLS, and CS-ARDL, to ensure reliable energy demand elasticity estimates (Ragmoun, 2023, 2024; Ragmoun & Alfalih, 2025; Ragmoun & Ben-Salha, 2024).

There is a vast literature where, price and income elasticities of energy demand have been estimated by using different econometric techniques of interest. Recent research has focused on advanced econometric methods for more precise elasticity measurement. Elasticities vary significantly across sectors, economies, and energy types. Jamissen et al. (2024)found minimal price elasticity (-0.01 to -0.04) for natural gas in Germany during the Russia-Ukraine crisis, indicating inelastic demand. Liddle and Hasanov (2023)reported income and price elasticities lies between 0.8 and -0.09 in middle-income countries, reinforcing the weak price effect on energy demand. Gao, Peng and Smyth (2021) examined 65 countries, finding price elasticities of -0.1 to -0.3 and income elasticities of 0.6 to 0.8, with a declining income elasticity trend since the 1990s. The study of Csereklyei (2020)observed relatively greater magnitude of price elasticity in long-run for industrial sector (-0.75 to -1.01) than in households (-0.53 to -0.56), implying household electricity as a necessity. Burke and Yang (2016) highlighted strong long-run elasticities (-1.25 for price, 1.00 for income) in industry, emphasizing price policies' role. Similar trends are noted in enormous studies by Labandeira et al. (2020); Nepal, Musibau and Jamasb (2021); Shang et al. (2022), and Antonio F. Erias and Emma M. Iglesias (2022). Knowing the fact that elasticity estimates are highly sensitive to a variety of factors, our study is designed to carry a comprehensive estimation of the long-run effects of energy products; its related prices and income fluctuations on long-run energy consumption behaviors of selected European economies. This research conducts a panel data study of selected EU member states where each sample economy is disaggregated into household and non-household sectors and the elasticities are estimated individually for electricity and natural gas consumption trends of these sectors. We have taken special care of cross-sectional dependence plausibly existing amongst our sample countries and for this purpose second-generation CCEMG-based panel cointegration testing methods are employed, so that our estimated long-run elasticities are robust to inter-country unobserved common factors and cross-country inter-dependencies.

3. Data and Methodology

As previously it has been stated that the main theme of producing this research is to know the long-run elasticities of energy consumption trends prevailing in the selected European states against its two key determinants; price of the energy products (two products; as electricity and natural gas) and sectoral (already taken two sectors; household and non-household) income level. In literature, the percentage change in demand for various energy products is measured in the form of long-run- as well as short-run elasticity(Burke & Csereklyei, 2016; Csereklyei, 2020; Gao, Peng, & Smyth, 2021; Martins et al., 2024; Pellini, 2021; Tran, Sahu, & Kumar, 2023; Weißenburger et al., 2024).It is a widely agreed perception that electricity consumption tends to respond rather slowly to price changes, as it always time taking to adjust and alter the stock of electrical appliances and energy-using durable goods (Labandeira et al., 2020; Li & Li, 2024; Miller & Alberini, 2016). Therefore, in our analysis will pay more attention to estimating long-run energy demand elasticities, short-run elasticities will also be calculated by default though, given the underlying dynamics of the econometric estimators used here. The (long-run) energy consumption responses against energy product price and these sctoral income level can be described through the below given formulation:

$$C_{ij,st} = \alpha + \beta P_{i,t} + \gamma I_{ijs,t} + \varepsilon_{ijs,t} \quad (1)$$

Where, $'C'$ is energy consumption volumes, $'P'$ is prices of energy products, $'I'$ is sectoral income, 'i' is our two subject energy products that is electricity and natural gas, 'j' is our two subject consumer sectors that is household and non-household, 's' is for cross-sections (countries) included in the panel and 't' is for time sub-script

As said earlier, we empirically estimate our hypothesized relationship for EU member states, our study sample therefore comprises a mix of 20low-, middle and upper-middle and high-income European states including Bulgaria, Latvia, Romania, Spain, Lithuania, Estonia, Poland, Portugal, Hungry, Croatia, Luxembourg, Ireland, Denmark, Netherlands, Austria, Belgium, France, Sweden, Germany and Italy. Our sample study period spans over 15 years, ranging from 2008 to 2022. Country level data for energy consumption of two products electricity and natural gas and, their respective prices are sourced from Eurostat database. The price data for both energy products are given as bi-annual time-series. We therefore adopted simple (standard) averaging method to generate an annual time-series price variable for each of our sample countries. Electricity price data is recorded in Euro/kWh unit. The data series is subject to a serious inconsistency as in the second half of year 2007, there is a methodological break in the series. Such an abrupt shift in data tends to cause critical discrepancies in our model estimates as almost all the dynamic panel estimators misleads the time-series characteristics of data sets to a larger extent (Csereklyei, 2020).

In order to avoid any such possibility, we take sample data set ranging from 2008 to 2023. Energy consumption is our model regressand where regressors are electricity and natural gas the two energy products studied individually. For households and non-household sectors, annual consumption of electricity and natural gas is measured in thousand tons of oil equivalence and is also sourced from Eurostat. Sectoral income in this study refers to the total income generated within specific sectors of the economy. Here, annual sectoral income for households and non-household sectors is a proxy through sectoral value added measured at constant market prices of 2015 and the data series has been collected from United Nations Conference on Trade and development (UNCTAD) database.

Regarding the choice of econometric testing methods, from earlier literature on this subject, it is a notable fact that price and income elasticiticies for electricity and natural gas consumption and, other energy goods tend to vary substantially given the chosen econometric testing method followed. For instance, it is evidently found in earlier works that cross-sectional estimators tend to yield larger elasticity values relative to the models offering partial adjustment mechanisms(Burke & Abayasekara, 2018; Khastar, Aslani, & Nejati, 2020). Similarly, by modeling unobserved heterogeneity through inducing cross-sectional fixed effects, the elasticities tend to reduce substantially (Miller & Alberini, 2016).

Before estimating the income and price elasticities of energy demand, it is essential to first establish whether a significant and intuitively correct long-run causal relationship exists for energy demand against its two hypothesized drivers. This involves testing for cointegration, as it is imperative to confirm that the variables move together over time, despite short-term fluctuations. Identifying such a relationship is critical, as it would be less meaningful to workout price and income elasticity's without knowing the true status of long-run co-movement and the underlying dynamics of the model variables.

3.1. Estimation of Long-Run Association between Model Variables

For establishing a long-run relationship amongst variables, we employ the residual-based cointegration testing procedure of Pedroni (1999). In its inherent dynamics, the estimator assumes that cross-sectional are not interlinked with individual effects when series are unit root at level, I (1). Characterized properties by asymptotic and finite sample, the estimator sallow having characteristics of heterogeneous long-run cointegrating vectors as well as heterogeneity in the long-run dynamics. The estimator comprises two distinct sets of residual-based test statistics. The first one comes from pooling the residuals yielded through within-group regressions. The second set of test statistics pool the residuals between the groups, nevertheless, similar to the first set, the set of tests are having properties as standard, normal and asymptotically distributed. The set of all these tests comprise estimators allowing the averaging of the estimated coefficients of individual countries of our panel. All the test statistics of this technique can lead efficiently model short-run specific dynamics; specific fixed effects; deterministic trends and, specific slope coefficients individually (Pedroni, 2004).

3.2. Estimating the Long-Run Elasticities

After having established valid long-run co-integrating relationship amongst model variables (if there exists any), the next is to obtain coefficients of long-run elasticity of energy consumption against two of its determinants by using Panel Fully Modified OLS (PFMOLS). In econometric literature, the test is established as a co-integration regression estimator devised to capture plausible long-run association between variables integrated of order one. The estimator is found effectively capable to taking control of cross-sectional heterogeneity. Model coefficient estimated through PFMOLS can be treated as long-run elasticities of energy consumption against the product prices and sectoral income levels.

3.3. Testing for Cross-Sectional Dependence

Validity of cointegration results are subject to their robustness against cross-sectional independence; a feature potentially found absent in panel data sets comprising cross-sections belonging to a common region (Pedroni, 2004). Cross-sectional dependence refers to the correlation between variables across different entities or simply observations from different countries or entities are not independent, where the correlation may not be directly causal but influenced by common factors. Failure to address this may give rise to misleading results, given the possibility of substantial impact it may expel the properties of asymptotic and finite sample of some important inference procedure in panel data estimators, it is complex procedure to address that results are more reliable and unbiased (Demetrescu & Homm, 2016; Pesaran, 2015). As a second step in our estimation procedure, we therefore determine the actual status of cross-sectional dependency amongst our chosen sample countries by applying the method of cross-sectional dependence (CSD) test proposed by Pesaran, Schuermann and Weiner (2004).

3.4. Estimating Long-Run Energy Consumption Behavior using Second Generation Cointegration Models

The presence of significant CSD in our sample data set will necessitates the re-estimation of our long-run energy consumption model by employing Common Correlated Effects Mean Group (CCEMG) based second-generation cointegration estimators. These estimators are devised to address the problem of CSD, frequently found in panel data sets comprising countries belonging to the same region. Efficiently capable of controlling for the cross-sectional dependence amongst panel entities, the CCEMG based cointegration models stand superior to their first-generation counterparts as they ensure more rigorous and consistent results when the sample data is significantly characterized by unobserved common factors. CCEMG estimators in panel data models work by incorporating cross-section averages of independent and dependent variables to account for cross-sectional dependence. It allows heterogeneous slope coefficients across different units while controlling for unobserved common factors. CCEMG tests are robust to non-stationary panels and provide consistent estimates when panels are large. From the family of CCEMG based second-generation cointegration testing methods, these studies employ five popular estimators. In their basic intuition, all these five estimators serve the same common objective, of accounting for unobserved common factors; nevertheless, they are slightly differentiated from each other, particularly in terms of their underlying dynamics.

(i) *Common Correlated Effects (CCE) Estimator:* The CCE estimator test proposed by Pesaran, Schuermann and Weiner (2004)found highly efficient for processing the large panels when the cross-sections are found significantly affected by common factors which otherwise are difficult to identify.

$$y_{it} = \alpha_i + \beta_i' x_{it} + \delta_i' z_t + u_{it}$$

Where y_{it} and x_{it} are the dependent and the vector of model rgressors, respectively. z_t Accounts for unobserved common factors and u_{it} is the identically and independentlydistrivbuted error term. Sincez_t cannot be observed directly, the test allows the use of proxies of y_{it} and x_{it} in place of unobserved effects.

(ii) *Dynamic Common Correlated Effects (DCCE) Estimator:* It is basically derived from CCE estimator indicating common factors in panel data analysis affecting individual units over time. These factors, which could be unobserved variables or shared trends among units, vary over time rather than remaining static. DCCE models are applied to address these common factors while analyzing the panel data, particularly to resolve the issue of omitted variable bias and are efficient for differentiating between individual-specific effects and the common effects. The test offers treatment to dynamic panel data models under autoregressive scheme that is the lags of dependent serve as model regressors. The model is found to perform best where the panel is characterized by both dynamics and CSD features simultaneously.

$$y_{it} = \alpha_i + \varphi y_{it-1} + \beta_i' x_{it} + \delta_i' z_t + u_{it}$$

Here, the lag value of the model dependent variable (y_{it-1}) is included as the model'sregressor. The unobserved common factors seek representation in DCCE estimator from the augmentation of both the current dependent variable and the past values of the dependent variable as the model regressors.

(iii) *Common Correlated Effects Pooled (CCEP) Estimator:* Like DCCE estimator, CCEP test is also derived from CCE estimator. The model is found to perform best when slope coefficients of individual cross-sections are assumed to be homogeneous.

$$\Delta y_{it} = \alpha_i + \beta_i' x_{it} + \rho' \overline{A_{it}} + u_{it}$$

A_{it}represents the vector of cross-sectional averages of regressors to account for cross-sectional dependence.

(iv) *Cross Sectional Error Correction Model (CS-ECM):* The estimator is specifically designed to model both short- and long-run dynamic relationships for inter-dependent cross-sections. This advance estimator is found highly efficient for capturing the plausible existence of cointegrating relationships i.e. when variables tend to integrate in but are subject to misalignments (from equilibrium) in short-run.

$$\Delta y_{it} = \alpha_i + \mu_i(y_{it-1} - \beta' x_{it-1}) + \sigma' \Delta x_{it} + \rho' \overline{A_{it}} + u_{it}$$

Where μ_i serves as the error correction coefficient and capturing the convergence speed of model variables from short-run misalignment towards its long-run equilibrium.

(v) *Cross Sectional Autoregressive Distributed Lag (CS-ADL) Estimator:* Similar to CS-ECM, this test also serves the purpose of modeling dynamic relationship amongst variables over shorter and longer time horizons. Taking its fundamental features from conventional ARDL bound testing approach to cointegration, the test take averages of cross-sectional to control CSD. The test accommodates flexible lag structure, thus, allowing dynamic relationship between variables across varying time periods.

$$\Delta y_{it} = \alpha_i + \sum_{p=0}^{P} \beta_p x_{it-p} + \sum_{q=1}^{Q} \gamma_q y_{it-q} + \sum_{p=0}^{P} \pi_p \overline{x_{t-p}} + \sum_{q=1}^{Q} \tau_q \overline{y_{t-q}} + u_{it}$$

Where $\overline{x_{t-p}}$ and $\overline{y_{t-q}}$ are responsible for calculating averages of cross sections of model regressor and regrassend, respectively.For validating the role of energy product prices and sectoral income levels as key determinants of long-run energy consumption patterns, the use of five distinctively different tests of second generation panel data analysis techniques brings two major benefits to this study (i) five different tests offer three different approaches to cointegration. This will facilitate us to investigate long-run consumption trends against its key determinants in a more holistic manner, and (ii) robustness and consistency of estimates obtained from one test could be established across other estimators in a more inclusive way.

4. Results and Discussion

Before proceeding the formal estimation of the long-run cointegrating relationship, it is mandatory that the data should be stationary or to establish the true order of integration at 1st difference amongst variables of the model. For this purpose, we apply Fisher-ADF non-parametric panel unit root test procedure which was proposed by Maddala and Wu (1999). Our unit root testing results reveal that the model series are subject to unit root process. Table 1 shows the test results acquired from Pedroni residual-based co-integration test. For Household electricity consumption, almost four test statistics out of seven tend to be significant at one percent level of statistical significance more preferring. Talking about natural gas consumption for this sector, results are even more encouraging. Five out of seven tests favor the existence of valid cointegrating relationship amongst model variables. Except for panel rho statistics, which comes up with relatively weaker degree of statistical significance, all other four tests prove high significant at one percent level of statistical significance.

Pedroni test results for non-household sector show cointegration existing with even better amount of statistical evidence. For electricity consumption, six out of seven statistics and for natural gas consumption five out of seven test statistics are significant. These results validate our initial hypothesis, proving the importance of energy product prices and sectoral income levels as two crucial determinants of energy consumption of two products; electricity and natural gas consumption for both household and non-household sectors. The results in table 2 given below report the estimated long-run elasticities of price and income elasticities for two energy product across two sectors. Discussing the price elasticities first, for both energy products; electricity and natural gas, the product prices tend to bear negative impact on household energy consumption for both products. The intensity of magnitude of this effect is 7 percent and 10 percent (approximately) for electricity and natural gas, respectively. Similarly, for non-household sector, both the energy products tend to affect the sectoral energy consumption negatively; nevertheless, the long-run price elasticities are substantially lesser for this sector that is 4 percent (approximately) for both electricity and natural gas.

The cross-sector disparity in magnitude of elasticities can be attributed to low relative dependence of Europe on natural gas and related resources, thus, rendering consumers less sensitive to its price changes. Sectoral income levels in contrast appear to play more substantial role in determining energy consumption trend patterns across both the sectors. After estimating the long-run elasticity coefficients, energy consumption of products; electricity and natural gas for household sector is responding to sectoral income changes by 35 percent and 31 percent, respectively.

Table 1: Pedroni co-integration testing results for electricity and natural gas consumption of household and non-household sector

Sectors/ Energy Products	AR Coefficients – Common (Within Dimension)				AR Coefficients – Individual (Between Dimension)			Does a valid long run relationship exist?
	Panel v Stat.	Panel rho Stat.	Panel PP Stat.	Panel ADF Stat.	Group rho Stat.	Group PP Stat.	Group ADF Stat.	
H.H_Elect.	0.317	-0.798	-4.504***	-4.727***	1.105	-7.331***	-6.337***	Yes
H.H_Nat.Gas	1.353	-1.453*	-4.589***	-4.272***	0.370	-6.678***	-5.768***	Yes
N.H.H_Elect.	1.464*	-1.649**	-8.629***	-5.031***	0.745	-8.849***	-6.426***	Yes
N.H.H_Nat.Gas	0.001	-1.925**	-9.159***	-9.387***	-0.005	-12.299***	-10.962***	Yes

*NOTE: 1%, 5% and 10% represents the statistical significance levels with marks as ***, ** and *, respectively.*

Table 2: Panel FMOLS testing results for obtaining long-run coefficients for energy prices and sectoral incomes

Sectors/Energy Products	Long-Run Coefficients		Does valid long-run relationship hold?
	Household	Non-Household	
Price_Elect.	-0.075** (0.031) [-2.448]	-0.044* (0.023) [-1.887]	Yes
Price_Nat.Gas	-0.126* (0.064) [-1.951]	-0.038 (0.036) [-1.042]	Mixed Evidence
Income_Elect.	0.351*** (0.042) [8.297]	0.246*** (0.026) [9.446]	Yes
Income_Nat.Gas	0.315** (0.153) [2.059]	0.091* (0.054) [1.666]	Yes

*NOTE:(i) 1%, 5% and 10% represents the statistical significance levels with marks as ***, ** and *, respectively.*
ii) S.Ess and t-values are given in () and [], respectively

For non-household sector, electricity and natural gas consumption demonstrates lesser degree of sensitivity that is 25 percent and 9 percent, respectively. These findings commensurate with earlier works on this line of research, reporting lesser degree of consumption response by industry, transport, commercial and public sectors against shifts occurring in sectoral incomes (Filippini & Hunt, 2011; Labandeira et al., 2020). On the whole, our model estimates are much in line with previous works, strongly endorsing the earlier researches on this subject performed for European states (A.F. Erias & E.M. Iglesias, 2022; Liu et al., 2022; Nepal, Musibau, & Jamasb, 2021; Zhao, Jiang, & Shao, 2022).

The findings discussed above however do not turn out to be robust against cross-sectional dependence. Results from Pesaran and Friedman CSD tests[1] suggest highly significant presence of CSD amongst our panel countries, and that also with intense magnitude. This renders our above estimated models somewhat less dependable, thus, necessitating to re-estimate our hypothesized to get reliable and valid long-run relationship between energy consumption and its determinants using second generation CCE panel cointegration estimators.

Table 3A: Results for second-generation panel cointegration estimators Household electricity consumption

	CCE	Dynamic-CCE	CCE-Pooled	CS-ECM	CS-ARDL
Price	-0.185*	-0.097***	-0.130**	-0.1518**	0.648
	(0.10)	(0.015)	(0.06)	(0.039)	(0.626)
Sectoral income	0.210** (0.106)	0.381*** (0.147)	0.259* (0.147)	0.392*** (0.083)	0.499* (0.301)
Constant	-3.889*** (1.417)	-2.432 (2.875)	4.000** (1.976)	-	-

*NOTE: S.Es are given in ().1%, 5% and 10% represents the statistical significance levels with marks as ***, ** and *, respectively*

The results obtained from all five estimators of second-generation panel cointegration testing approach yield convincing amount of statistical suggesting significant cointegration

[1]*Detailed results for two tests can be provided on request.*

existing for household electricity consumption and its two determinants. Specifically, the CCE, Dynamic-CCE, CCE-Pooled, and CS-ECM results show valid relationship exists. The results suggest that if electricity consumption in short-run deviate from equilibrium; it gradually achieves equilibrium in long-run with its periodic movements in addition to the significant periodic adjustments of households' variables energy products' prices and income. The coefficient of long-run elasticity produced by all four tests against electricity prices series is holding an intuitively correct sign and tends to range from 10 to 18 percent (approximately). These estimates are fairly comparable with those coming from recent studies done on residential sector electricity demand electricity in Europe (Erdal, 2017; Papageorgiou, Saam, & Schulte, 2017).

In comparison to prices, sectoral income turns out to be imparting even larger long-run impact on electricity consumption of household sector. The dominant role of the variable can be witnessed from the long-run coefficient of income series which ranges from 0.210 to 0.499. These results validate our earlier findings obtained through Pedroni co-integration testing method which yielded a significant long-run association amongst model variables. Thus, controlling cross-sectional dependence which evidently was found present amongst our sample countries, our results remain unchanged supporting the significant role of energy product prices and sectoral income levels in determining trend patterns of energy consumption in our subject European states.

Table 3B: Country-specific results for selected second-generation panel cointegration estimators Household electricity consumption

	Germany	Ireland	Italy	France	Austria	Netherlands	Sweden	Luxembourg	Belgium	Denmark	Portugal
CCE Estimator											
Prices	0.202**	-0.489	-0.005*	-0.441**	-1.770***	0.114***	-0.409*	-0.131	-0.033*	-0.557**	-0.629*
	(0.095)	(0.381)	(0.003)	(0.208)	(0.670)	(0.054)	(0.232)	(0.374)	(0.0187)	(0.263)	(0.357)
Sectoral income	0.514**	1.025*	0.075*	0.273**	-1.633***	-0.914*	0.978	3.201*	0.308**	1.394*	0.827
	(0.242)	(0.710)	(0.043)	(0.155)	(0.718)	(0.519)	(1.239)	(1.819)	(0.145)	(0.792)	(1.111)
Constant	-11.871*	-2.23**	-4.558	-10.108*	2.84***	0.333	-12.946*	5.589**	-5.700*	0.702	-15.351***
	(6.745)	(1.052)	(5.047)	(5.616)	(1.092)	(3.236)	(7.110)	(2.612)	(3.239)	(3.562)	(6.670)
Dynamic CCE Estimator											
Prices	-8.654**	0.445	-0.020*	-1.537*	-0.539*	-0.040**	-1.315**	-0.542*	-0.039**	-0.865**	-1.529
	(0.409)	(0.389)	(0.011)	(0.873)	(0.306)	(0.019)	(0.611)	(0.308)	(0.017)	(0.034)	(1.027)
Sectoral income	0.619**	0.281*	0.059*	2.069**	0.875*	1.095***	2.096	0.303*	1.288***	0.296	3.683*
	(0.292)	(0.159)	(0.034)	(0.976)	(0.497)	(0.415)	(1.581)	(0.172)	(0.479)	(2.000)	(2.009)
Constant	-9.188*	-5.58**	-2.550	-33.024*	-2.881	4.14***	-12.835	2.568	-10.973***	3.886	-16.653
	(5.220)	(2.633)	(2.572)	(18.66)	(4.109)	(1.533)	(9.428)	(9.579)	(3.854)	(3.028)	(12.224)

NOTE:+98/86 S.Es are given in (). 1%, 5% and 10% represents the statistical significance levels with marks as ***, ** and *, respectively.

Table 4: Results for second-generation Panel co-integration estimator Household Natural Gas Consumption[2]

	CCE	Dynamic-CCE	CCE-Pooled	CS-ECM	CS-ARDL
Price	-0.685***	-0.283*	-0.138*	-0.442***	-2.408
	(0.137)	(0.171)	(0.083)	(0.102)	(0.259)
Sectoral income	0.384*	1.575**	0.858***	0.567*	0.391***
	(0.218)	(0.771)	(0.325)	(0.322)	(0.083)
Constant	-4.626*	-3.791	-9.000**	_	_
	(2.419)	(3.712)	(5.122)		

*NOTE:S.Es are given in ().1%, 5% and 10% levels of statistical significance are marked with ***, ** and *, respectively*

Similarly, in the case of electricity consumption, the estimated results for natural gas consumption also validate our postulated relationship. All five CCEMG estimators authenticate significant long-run causal relationship between household natural gas consumption and its determinants. The effect is induced from both price and income series, given the fact that both series bear sizeable coefficient value, with intuitively correct signs and desirable degree of statistical significance.

[2]*Country specific results for CCE estimators can be provided on request.*

Table 5: Results for second-generation panel cointegration estimators Non-household electricity consumption[3]

	CCE	Dynamic-CCE	CCE-Pooled	CS-ECM	CS-ARDL
Price	-0.050*	-0.071*	-0.020**	-0.047*	0.201
	(0.037)	(0.0532)	(0.0116)	(0.035)	(0.154)
Sectoral income	0.348*	0.151**	0.235***	0.234***	0.436**
	(0.141)	(0.091)	(0.069)	(0.085)	(0.203)
Constant	-15.872***	2.437	-1.000	_	_
	(2.519)	(3.803)	(2.645)		

*NOTE: S.Es are given in ().1%, 5% and 10% represents the statistical significance levels with marks as ***, ** and *, respectively.*

CS-ARDL is the only estimator which yields relatively weaker support as here the price series tends to contribute no more proper significant effects in the long-run. These findings are linked closer with earlier works from Europe. It appears from our results that sectoral income tends to impart more pronounced effects in driving the trend patterns of household natural gas consumption. This is because our estimated long-run coefficients from prices series range from -0.138 to -0.685 whereas the magnitude of sectoral income variable varies from 0.384 to 1.575. For non-household electricity consumption, the amount of econometric evidence we obtain is rather stingy. Upon examining co-integration for non-household electricity consumption against product prices, though we obtain considerable amount of evidence for an intuitively correct long-run association, nevertheless, the magnitude as well as the degree of statistical significance of this causal relationship is rather less substantial. The smallest of the long-run coefficient for non-household electricity consumption against its prices is -0.020 and the largest one is -0.071. These results imply the lower relative sensitivity of non-household sector towards electricity prices.

Table 6: Results for second-generation panel cointegration estimators Non-household natural gas consumption[4]

	CCE	Dynamic-CCE	CCE-Pooled	CS-ECM	CS-ARDL
Price	-0.092**	-0.096*	-0.103**	-0.087**	-0.066
	(0.043)	(0.054)	(0.049)	(0.041)	(0.075)
Sectoral income	0.116**	0.246*	0.073*	0.086**	0.109*
	(0.054)	(0.140)	(0.042)	(0.039)	(0.054)
Constant	17.718***	-2.205**	3.000	_	_
	(3.002)	(1.04)	(3.965)		

*NOTE: S.Es are given in ().1%, 5% and 10% represents the statistical significance levels with marks as ***, ** and *, respectively.*

We receive empirical support for this lower degree of less precarious position of non-household sectors from literature also, where industry and commercial sectors' long-run energy consumption patterns in specific are found less responsive towards fluctuations occurring in prices of energy products (Cialani & Mortazavi, 2018; Liddle & Hasanov, 2023; Weißenburger et al., 2024).Looking at the relative position of sectoral income, the variable is once again extending sizable contribution in determining the trend patterns of sectors' energy consumption volumes. The contribution of sectoral incomes supersedes the role of electricity prices as we get substantial long-run coefficient values for sectoral income series ranging from 0.151 to 0.436. In the case of energy consumption product natural gas, the responsiveness of non-household sector in long-run is also rather weaker. Once again this is particularly true for natural gas prices. Although four out of five CCEMG estimators favorable in the presence of valid co-integrating association amongst natural gas consumption and its prices, the magnitude of this association is relatively small. We obtain the long-run elasticity of price series ranging from -0.066 to -0.103, a coefficient value pretty much comparable with what we obtained for household sector. Sectoral prices on the other hand are found to affecting the natural gas consumption patterns of the sector more substantially. All of our five CCEMG estimator suggest statistically significant role of sectoral income in explaining the trend behavior of natural gas consumption, with a long-run elasticity value ranging from 0.073 to 0.246. These findings are parallel to our estimates from earlier

[3]*Country specific results for CCE estimators can be provided on request.*
[4]*Country specific results for CCE estimators can be provided on request.*

situations where sectoral income tends to describe the long-run energy consumption patterns in more definite manner.

5. Conclusion

A thorough understanding of the role of energy product prices and sectoral income dynamics is imperative for analyzing the long-run patterns of energy consumption behavior across various European sectors. Such an approach is instrumental in advancing Europe's long-term objective of transforming themselves into energy-efficient and resilient economies. As European economies endeavor to optimize energy consumption in the pretext of resource conservation and sustainability, price fluctuations play a pivotal role in shaping sectoral energy demand. Elevated energy prices often incentivize industries to transition toward energy-efficient technologies, while sectoral income levels set out the scope to which different industries rely upon energy-intensive processes. The household and non-household consumer sectors exhibit distinct consumption patterns in response to price and income variations, necessitating a nuanced approach to policy formulation. The due recognition and the integration of price and income variables into region's energy policy frameworks, targeted intervention scan be devised and pursued that foster a balance between sustainable energy use and long-term economic growth. Our study provides a comprehensive and robust dissection of price and income elasticities of energy products consumption in long-run for household and non-household sectors across selected European Union member states. We applied a rigorous approach and started investigating the tendency of energy products; electricity and natural gas prices along with household and non-household sectoral income levels of explaining the trend patterns of electricity and natural gas consumption volumes using first-generation panel cointegration testing procedures. These conventional estimators however lack the ability of accounting the unobserved cross-sectional dependence which typically may exist if the study sample comprises countries belonging to a common region. We found evidence of strong existences of cross-sectional dependence, thus, paving our way to employ five different second-generation CCEMG-based panel cointegration estimators which are robust to inter-country dependencies.

The results obtained from conventional panel estimators highlight that household electricity and natural gas consumption exhibit substantial price and income elasticities of energy products. This is true for household sector in particular. A large majority of CCEMG estimators yield significant ability of energy product prices and sectoral incomes to integrate with electricity as well as natural gas consumption patterns in long-run. The robustness of the results is further validated through second-generation panel cointegration models. The effect is described by sectoral incomes more dominantly, since, the series is always found bearing a long-run elasticity coefficient with larger magnitude for both the sectors. The price elasticity of demand in long-run for non-household sector is notably lower, reflecting the sector's relatively inelastic response to price variations. However, income effect remains significant as well as substantial, indicating that sector's energy consumption volumes and its economic expansion go hand in hand over longer time horizons. Our findings underscore the importance of incorporating energy price policies and income-driven strategies into national and regional energy frameworks. The observed disparities in price and income elasticities across consumer sectors suggest the need for differentiated policy approaches, targeting efficiency gains in the household sector through price incentives and encouraging sustainable industrial growth through investment in energy-efficient technologies. These findings hold immense value for policymakers who work for if identifying the optimal energy consumption levels while balancing economic growth and sustainability objectives. Future research may extend this work by incorporating the effects of technological advancements, policy interventions, and behavioral shifts in energy consumption.

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