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The impact of price persistence on greenhouse gas emissions: A fractional integration approach

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ABSTRACT

This study explores the characteristics of price persistence and greenhouse gas emissions in the EU27. We use fractional integration, which is a more general approach than the classical methods based on stationary/unit roots tests since fractional degrees of differentiation are permitted. For gas emissions, the findings indicate that mean reversion occurs in the majority of the series. For prices, mean reversion take place in the cases of Italy, Spain, Portugal, and Greece. For the rest of the countries, the differencing parameter is found to be 1 or significantly above 1, thus rejecting mean reversion. These findings are not only statistically significant but also highly policy-relevant: identifying whether shocks are temporary or permanent directly informs the design of appropriate responses. Temporary shocks may be addressed through short-term, cyclical interventions, whereas permanent shocks call for structural and long-term policy measures.

1. Introduction

Price persistence has re-emerged as a serious economic problem. Central bankers prioritize maintaining a stable price level, which necessitates a thorough grasp of price dynamics, including persistence. Although Fischer [1] provided one of the early discussions on the importance of price stability, more recent works have substantially advanced the debate. For instance, Caporale et al. [2] examine the persistence of inflation in the EU27 in the aftermath of recent shocks, showing that price dynamics remain highly sensitive to geopolitical and global health crises. Their findings highlight the continuing relevance of persistence for monetary policy and provide a more up-to-date foundation for the present study.

At the same time, the European Union’s commitment to the Paris Agreement [3] and the European Green Deal, which targets climate neutrality by **2050**, have placed renewed emphasis on understanding the economic mechanisms that drive greenhouse gas (GHG) emissions. Price dynamics are one such mechanism. Because prices influence consumption, production, and investment decisions, their persistence can have significant implications for the pace and effectiveness of the EU’s decarbonization efforts. Persistent price shocks—especially in energy markets—can either accelerate or delay the transition toward low-carbon activities, depending on how households and firms adjust their behavior.

Air pollution remains a pressing concern for humanity, and the broad impact of price persistence on consumer and business decisions raises the question of its relationship with environmental outcomes. To illustrate these economic–environmental linkages more clearly, it is useful to consider the channels through which persistent prices influence greenhouse gas emissions. Price persistence plays a key role in shaping emissions through its impact on economic decisions over time. Persistent increases in energy prices can lead to a reduction in energy demand, changes in consumption patterns, and a reallocation of resources toward less carbon-intensive activities. They may also encourage investment in cleaner technologies and renewable energy, as firms and households respond to the expectation of sustained higher costs. On the other hand, persistent inflationary pressures may reduce purchasing power and overall consumption, which can contribute to lower emissions in the

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short run, but may also hinder long-term investment in green projects by increasing financing costs. Understanding these mechanisms is essential for evaluating how persistent price dynamics translate into environmental outcomes.

Inflation and environmental outcomes may seem unrelated at first glance; nevertheless, they are connected through their shared exposure to energy markets and external shocks. Both price dynamics and greenhouse gas (GHG) emissions respond strongly to events such as geopolitical conflicts or global pandemics, which simultaneously disrupt energy supply, alter consumption patterns, and affect production structures. In this sense, persistence provides a common analytical lens: just as persistent inflation shocks imply long-lasting consequences for monetary policy, persistent emission shocks suggest that environmental disturbances may not dissipate without structural intervention. This highlights the value of studying persistence jointly in economic and environmental contexts.

Although persistence has been extensively investigated in macroeconomic and financial contexts—most notably in studies of inflation dynamics, interest rates, and output fluctuations—empirical evidence on the persistence of greenhouse gas emissions remains relatively scarce. Much less attention has been devoted to the temporal behavior of GHG emissions themselves, and in particular to the potential nexus between inflation shocks, energy price volatility, and emissions. This lack of evidence leaves an important gap in understanding whether environmental shocks behave similarly to macroeconomic shocks, or whether they follow distinct persistence patterns with different implications for long-term policy design.

Although numerous studies have examined inflation persistence [1,2] and environmental dynamics ([4,5]; Setyadharma et al., 2020) separately, few have explicitly analyzed how persistent price shocks interact with greenhouse gas emissions within an integrated empirical framework. Existing research tends to focus on either macroeconomic or environmental dimensions, often overlooking their joint temporal behavior. By combining fractional integration methods with the policy context of the EU's 2050 climate neutrality goals ([3]; European Commission, 2019), this study bridges these two strands of literature. In doing so, it contributes to the emerging field of sustainable macroeconomics by providing empirical evidence on whether persistent inflationary dynamics can influence the trajectory of decarbonization across EU countries.

Furthermore, linking persistence to policy frameworks such as the EU's 2050 climate neutrality target and the Paris Agreement provides a stronger theoretical foundation for the study. Persistent inflationary and environmental shocks require structural rather than temporary policy responses, making persistence a key analytical bridge between macroeconomic stability and long-term sustainability. By explicitly situating persistence within these policy goals, this study contributes to understanding how durable economic dynamics can either support or hinder the achievement of climate objectives.

A key strength of this study lies in its ability to distinguish between temporary and permanent shocks in greenhouse gas emissions and inflation dynamics. By identifying whether shocks are mean-reverting or persistent, the results provide direct guidance for policy design. Specifically, if shocks are temporary, short-term or cyclical policy responses may be sufficient; conversely, if shocks are permanent, structural and long-term measures are required to address their lasting effects. This distinction underscores the relevance of long-memory analysis for policymakers, as it enables the formulation of tailored strategies that are aligned with the underlying persistence of the shocks. The current study provides information on greenhouse gas emissions levels in all of the 27 European Union member countries (EU27) across a sample period that includes both the COVID-19 outbreak and the Russia invasion of Ukraine. In particular, the study will look at whether there was any temporal variation in the degree of persistence of greenhouse gas emissions as a result of the price changes.

While price dynamics have long been a subject of analysis in macroeconomic and financial contexts Adamolekun, 2024 [6]; [7,8], relatively little attention has been devoted to examining price persistence in relation to GHG emissions. However, understanding the degree of persistence in emissions-related prices is crucial, as it can significantly influence the expectations and behavior of economic agents in response to climate policies. Although a few studies have investigated the relationship between inflation and environmental indicators such as air pollution, they are typically limited in scope, focusing either on a single country or sector (e.g., Setyadharma et al., 2020 for Indonesia [5]; for agriculture and industrial production) or on a subset of countries within a specific region. Grolleau and Weber [4] show that increases in core inflation can be associated with reductions in CO_2 emissions, suggesting that inflationary dynamics may influence environmental outcomes in ways that are not always straightforward. This evidence reinforces the importance of analyzing inflation and emissions jointly rather than in isolation.

The objectives of this work can be summarized as follows: i) are GHG emissions per capita in Europe persistent?, ii) are prices, measured by Harmonised Consumer Price Index in Europe also persistent?, iii) based on the above two questions, is the nature of shocks in the series transitory or permanent, and iv) how are price persistence and GHG emissions in the EU27 related, particularly in the context of recent exogenous shocks such as the COVID-19 pandemic and the Russia-Ukraine war?

In this study, *price persistence* refers to the degree to which shocks to the Harmonised Index of Consumer Prices (HICP) have lasting effects over time. Specifically, persistence measures whether deviations in the general price level—covering a broad basket of goods and services rather than specific carbon or energy prices—tend to dissipate (mean reversion) or remain permanent. A highly persistent price process implies that shocks have enduring effects on the price level, whereas low persistence indicates that shocks are transitory and prices revert to their previous trajectory. Put more intuitively, price persistence reflects how long households and firms continue to feel the impact of a price shock: whether it fades relatively quickly or becomes embedded in the economy.

The contribution of this paper is twofold. First, it is, to our knowledge, the first study to apply the fractional integration approach to examine the persistence of greenhouse gas emissions across all 27 European Union countries. While previous research has used similar methods to analyze persistence in macroeconomic and financial variables, their application to environmental series—particularly emissions—remains very limited. Second, this paper provides novel evidence by focusing on a period that captures two unprecedented global shocks: the COVID-19 pandemic and the Russian invasion of Ukraine. This dual-crisis context offers a unique opportunity to evaluate whether such large-scale disruptions altered the temporal behavior of emissions and, consequently, the policy space available for achieving the EU's climate neutrality target.

Our article includes several novel contributions.

- First, we consider GHGs emissions per capita on a quarterly basis. This high-frequency data approach allows for a more detailed and time-sensitive examination of emissions trends, improving the detection of variations in persistence.
- Second, the method used is more comprehensive than the traditional ones, which are based on the distinction between I(0) stationarity and I(1) non-stationarity. This method supports both fractional and integer degrees of differentiation.
- Third, it provides a direct measure of persistence in the form of the predicted fractional differencing parameter d.
- Finally, it discusses whether the consequences of the impact are temporary or permanent, as well as the nature of the dynamic adjustment process. These facts are critical for policymakers to be able to make sound decisions.

The current study has some limitations that can indicate paths to be taken by future research. Specifically, our analysis adopts a univariate framework, which limits the ability to explore the specific channels through which prices may influence greenhouse gas emissions. However, this approach is also a deliberate methodological choice. By isolating the persistence properties of each series without the confounding effects of multivariate interactions, the study provides a transparent and robust benchmark for future extensions. This design strengthens the internal validity of the persistence estimates and establishes a clear empirical foundation for subsequent studies employing multivariate or cointegrated frameworks.

The rest of the paper is organized as follows. In Section 2, we discuss the latest studies related to the association of gas emissions and price persistence. In Section 3, we present the model – fractional integration and the empirical results. In Section 4, we concisely discuss the data set, outlining them by utilizing a time series plot, and in Section 5 the results are discussed; finally, in Section 6 we present our concluding remarks.

2. Literature review

2.1. Growth–emissions nexus

The interaction between macroeconomic stability and environmental sustainability remains insufficiently examined, particularly regarding the persistence of inflation and greenhouse gas emissions within the EU.

The economic model focused on maximizing economic growth is associated with serious environmental problems. Traditional economic models suggest that higher production levels—often associated with inflationary pressures—lead to increased energy consumption and emissions Zickfeld, Arora and Gillett, 2012 [9]; [10,11]. More environmentally friendly economic growth is therefore necessary to achieve a sustainable social and economic model Fleurbaey et al., 2014.[12]; [13].

Recent literature has increasingly focused on the role of macroeconomic, technological, and global factors in shaping environmental outcomes in developing and emerging economies. Several studies emphasize the effectiveness of renewable energy and globalization in mitigating environmental degradation. For example, Jahanger et al. [14] apply QARDL and spectral causality methods to the case of Mexico, finding that renewable energy and global integration can significantly reduce environmental pressures. Fiscal and monetary policies have also been examined as potential tools for sustainable development. Chishti et al. [15] analyze the BRICS economies and show that expansionary and contractionary fiscal and monetary policies intensify the harmful repercussions of CO_2 or ameliorate environmental quality, respectively. The study also finds that renewable energy helps improve atmospheric conditions by lowering CO_2 levels. In addition, the role of technological and financial innovation has received attention, with evidence suggesting that innovation shocks can strongly influence environmental quality [16,17]. These shocks are found to be particularly relevant in developing countries, where their effects may persist over time. Moreover, commercial policies have been shown to affect both consumption-based and production-based CO_2 emissions, highlighting the importance of trade and market design in achieving sustainability goals Weimin & Chishti, 2021 [18]. Salam et al. [19] highlight the environmental implications of trade and financial development in Belt and Road Initiative (BRI) countries. The findings indicate that trade between China and selected BRI countries does not have a statistically significant impact on CO_2 emissions. In contrast, financial development appears to be associated with a notable increase in emissions within these countries. Taken together, these contributions indicate that the environmental impact of growth depends critically on the policy framework and technological capacity of each economy, suggesting that structural differences may explain the heterogeneity observed across countries.

Unlike these previous studies focusing on single countries or specific groups, our analysis fills a clear gap in the literature by addressing the EU as a whole, which is highly relevant given its central role in global climate policy.

The economic model has some priorities apart from economic growth, such as price stability. The European System of Central Banks has to apply monetary policy in order to maintain an annual inflation rate at a maximum of 2 %.[1] In the aftermath of the pandemic and with the war in Ukraine, the impact on price levels is once again at the center of the economic authorities' concerns. However, few studies have explicitly linked these macroeconomic dynamics with environmental outcomes, leaving an open question about how monetary and environmental objectives interact.

While the literature extensively reviews inflation and greenhouse gas emissions separately, few studies examine the relationship between these two topics.

2.2. Inflation–emissions literature

The evolution of prices influences consumer and business decisions, which, in turn, significantly affect greenhouse gas emissions. On the one hand, some papers show a positive relationship between inflation and reductions in greenhouse gas emissions. For example, Grolleau and Weber [4] analyze the impact of inflation on CO_2 emissions and conclude that the result of an increase in core inflation is lower levels of CO_2 emissions. Similarly, Setyadharma [20] in Indonesia, Ahmad et al. [13] in Asian economies or Ullah et al. [21] in Pakistan propose that inflation may encourage investments in energy efficiency, resulting in reduced greenhouse gas emissions. Aishafeey and Saleh Saleh [22] focus on the United States, the European Union and China, employing a feedforward neural network model to calculate the inflation levels at which greenhouse gas emissions begin to decline in these regions.

On the other hand, other studies affirm that inflation negatively affects the environment because uncertainty discourages investments in energy efficiency and pollution control (Musarat et al., 2021 [23]; [24], among others). In line with this view, Jin et al. [25] find a negative relationship between inflation rates and CO_2 emissions, with higher inflation reducing fossil fuel consumption while promoting cleaner energy alternatives. Finally, Martin-Valmayor et al. [26] analyze the persistence of CO_2 emissions using fractional integration techniques in the US, illustrating the method's suitability for capturing long-memory behaviors in emissions data. Despite these efforts, the literature presents contrasting results depending on the context, which suggests that inflation's environmental effects are non-linear and mediated by factors such as income levels, institutional quality, and energy dependence. This lack of consensus highlights the need for integrated approaches that can jointly capture economic and environmental persistence.

Together, these studies underscore that not only the level of inflation but also its persistence and dynamic behavior are integral to understanding environmental outcomes—aligning closely with the analytical advantages of our fractional integration framework. Overall, these findings reveal a lack of consensus: while some contributions argue that inflationary pressures promote energy-saving behavior and efficiency gains, others highlight the negative effects of uncertainty on green investment.

The economic impact of major exogenous shocks such as the COVID-19 pandemic and the Russia–Ukraine war has been widely documented. These crises have generated strong and persistent effects on inflation, energy prices, and global supply chains ([27–29]; Harding et al., 2023). Empirical evidence shows that both shocks have contributed to upward inflationary pressures and heightened volatility in energy markets, particularly in Europe. This context provides a relevant background for

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[1] According to Article 127 of the Treaty on the Functioning of the European Union (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A12016E127, accessed 15 April 2024).

the present study, as it allows assessing whether such large-scale disruptions have also altered the persistence patterns of prices and greenhouse gas emissions in the EU.

2.3. Gaps: persistence and methodology

The impact of these shocks on global activity is negative. Numerous authors have analyzed the relationship between economic growth and greenhouse gas emissions using various approaches. Ansuategi and Escapa [30] studied the impact of the presence of intergenerational spillovers on this relationship. They concluded that it was determined by the time incidence of pollution, the engagement of social planners with the sustainability and the institutional capacity for intergenerational transfers. For the first time in many years, greenhouse gas emissions declined following the COVID-19 pandemic [31]. Regarding the impact of the Russia-Ukraine war on greenhouse gas emissions, some studies affirm that they declined relative to GDP [32], with negative trends in 19 EU countries and with the presence of long memory in many of them Imeri and Gil-Alana, 2024. However, other studies suggest that greenhouse gas emissions may increase significantly due to military activities [33–35].

Foundational studies on persistence and fractional integration provide the theoretical basis for our approach. Classical unit-root analyses (e.g., Ref. [36]) emphasized the distinction between I(0) and I(1) processes, while Granger & Joyeux [37] and Hosking [38] introduced fractional integration, allowing for long memory and intermediate dynamics. In environmental economics, the Environmental Kuznets Curve [39] suggested that emissions may not rise monotonically with income, highlighting potential mean reversion in the long run. Early works in energy economics also documented high persistence in energy consumption and prices (e.g., Ref. [40,41]), underlining the importance of distinguishing temporary from permanent shocks. These contributions strengthen the theoretical base of our analysis and justify the use of fractional integration to study persistence in prices and emissions.

Several studies have employed univariate time series methods to analyze the persistence and long-term behavior of CO_2 emissions, providing valuable insights into their underlying dynamics. Presno et al. [42] analyzed the stochastic convergence of per capita CO_2 emissions in 28 OECD countries, applying nonlinear stationarity analysis to assess whether emissions follow a mean-reverting pattern or exhibit permanent shocks. Similarly, Sadhukhan and Yadav [43] integrated time series analysis with machine learning to model daily industry-specific CO_2 emissions across multiple sectors and countries. Earlier, Camarero et al. [44] investigated the convergence of eco-efficiency in greenhouse gas emissions among EU member states, incorporating univariate time series methodologies to analyze emission dynamics.

Some studies have focused on analyzing the effects of external shocks. For example, Erdogan et al. [45] applied Fourier Lagrange Multiplier and Fourier wavelet unit root tests and found that global CO_2 emissions exhibit a unit root, indicating that external shocks have permanent effects. Similarly, Gil-Alana et al. [46] examined the time-series behavior of CO_2 emissions in G7 and BRICS countries using a long-memory approach with non-linear trends and structural breaks, identifying significant differences in the persistence of emissions across countries. Additionally, Pata and Aydin [47] employed eight different non-linear unit root tests on long-span CO_2 emissions data and found that while emissions had a unit root in the frequency domain for all G7 countries, they were only stationary for the UK. These findings collectively suggest that persistence is not uniform across regions and that structural and policy factors can significantly influence the degree of mean reversion in emissions.

Most of these contributions, however, rely on traditional unit root and stationarity tests that focus on the binary distinction between I(0) and I(1) processes (e.g., Ref. [45,46]). While these approaches provide useful insights, they do not capture the possibility of intermediate dynamics. Most studies also employ annual data, which may obscure short-term dynamics and limit the ability to capture rapid adjustments in emissions following economic or policy shocks (e.g., Ref. [42,47]).

Our contribution lies in addressing both limitations. First, we apply a fractional integration framework, which allows for both integer and fractional orders of differentiation. This provides a more comprehensive characterization of persistence and enables us to detect mean-reverting but highly persistent behaviors that conventional methods may classify incorrectly. Second, we use quarterly per capita emissions data, which provides a higher-frequency perspective and allows for a more detailed and time-sensitive examination of persistence, improving the detection of temporal variations that may otherwise be missed with annual observations.

Unlike earlier works that examine inflation dynamics or greenhouse gas emissions separately, our analysis explicitly addresses their interaction through the concept of persistence. In this way, we provide the first comprehensive application of fractional integration to the EU27, thereby filling a clear gap in the literature.

Price persistence is a major concern for central banks and understanding its relationship with air pollution is essential for promoting a more sustainable economic model. Fractional integration methodology allows us to consider cases of nonstationary data with mean reverting behavior, making it particularly valuable for policy measures aimed at sustainable and environmentally friendly economic growth. This is the goal of this paper, to study whether there has been any temporal variation in the degree of persistence in greenhouse gas emissions in response to price changes.

3. Methodology

Dealing with persistence in time series data, stationary and unit root tests (Dickey and Fuller, ADF; 1979; Phillips and Perron, PP, 1988; Kwiatkowski et al., KPSS, 1992; Elliot et al., ERS, 1996; etc) have been widely employed during the last 40 years. However, these traditional unit root methods may fail to capture the nuances of long-range dependence, potentially resulting in biased evaluations of policy effectiveness. To address these gaps, this study employs fractional integration techniques, offering a more flexible and robust framework for modeling the memory properties of emissions-related prices and assessing their long-term impact on GHG emissions. Note that fractional integration is characterized because the order of integration may be any real value and thus, it includes standard methods like stationary ARMA or unit roots as particular cases of interest when the orders of integration are 0 or 1 respectively.

The model under examination is:

$$y(t) = \alpha + \beta\, t + x(t), (1 - L)^d x(t) = u(t), \tag{1}$$

where y(t) is the observed time series data, α and β are unknown parameters related respectively to an intercept and a linear time trend, and x(t) is I(d) where d is a real value to be estimated along with the other parameters of the model; u(t) is uncorrelated with zero mean and constant variance. This latter assumption on u(t) can be extended to allow for weak (e.g., ARMA) autocorrelation; however, based on the small number of observations used in this application, adding more structure would produce wider confidence intervals and it seems that the time dependence can be well captured by the differencing parameter d. The fact that d may be any real value allows for fractional degrees of differentiation. In this context, the polynomial in L in Eq. (1) can be expressed in terms of its Binomial expansion such that:

$$(1 - L)^d = \sum_{j=0}^{\infty} \binom{d}{j} (-1)^j L^j = 1 - dL + \frac{d(d-1)}{2} L^2 - \ldots$$

and thus, the second equality in Eq. (1) can be written as

$$x(t) = d\, x(t-1) - \frac{d(d-1)}{2}\, x(t-2) + \ldots + u(t),$$

which is an infinite AutoRegressive (AR) representation of the model. From the above expression, it can be easily be that higher the value of d is, the higher the level of dependence across data, and thus the level of persistence is. In the same way, x(t) can also be expressed as an infinite Moving Average (MA) process, such that values of the differencing parameter d below 1 support the hypothesis of mean reversion with shocks having temporary effects, as opposed to what happens with $d \geq 1$ where there is no reversion to the mean and shocks have permanent effects. Note that the specification in (1) is more flexible and general than the classical ones based on stationarity or unit root models where integer orders of integration are simply considered. Moreover, depending on the range of values of d we can examine alternative hypothesis such as.

i) anti-persistence, if $d < 0$
ii) short memory or I(0) behaviour, if $d = 0$,
iii) long memory if $d > 0$,
iv) covariance stationary and long memory, if $0 < d < 0.5$,
v) nonstationary with a long memory pattern, if $0.5 \leq d < 1$,
vi) unit roots, or even
vii) explosive patterns ($d \geq 1$).

The estimation is conducted using a simple version of the Lagrange Multiplier test described in Robinson [48]. It basically consists of testing the null hypothesis

$$H_o : d = d_o, \tag{2}$$

in equation (1), where d_o is a given real value. This approach is very convenient because it has several salient features compared with other approaches. First, it is valid for any real value d_o, including values outside the stationary region ($d_o \geq 0.5$) and thus, it does not require preliminary differencing in case of nonstationary data; secondly, it has a standard null and local limit distributions, and this behavior holds independently of the inclusion of deterministic terms as is the case in the first equality in (1); moreover, it is the most efficient method in the Pitman sense against local departures from the null. Based on the asymptotic behavior of this test, it may be argued that it is not reliable in finite samples; however, in order to solve this issue, we rely on the critical values computed in Gil-Alana [49] so that the values computed in the confidence intervals are based on the critical values obtained by simulations in finite samples of the same size as those used in this application. The estimation and testing approach is conducted by using the codes developed in Fortran and that are available in Gil-Alana [50]. Code conversion to R is now under progress.

As earlier mentioned, the fact that u(t) is supposed to be uncorrelated can be violated and weak autocorrelation can be present in the data; however, based on the short number of observations examined in this application, the inclusion of weak autocorrelation may produce overparameterization in relation with the I(d) model, with various parameters competing for describing the time dependence in the data. Moreover, the version of the testing procedure used in this work is based on the assumption that u(t) is white noise and choose the optimal d-parameter for this particular specification. Thus, under H_o, (2), if the residual were still autocorrelated, no values of d_o would be found satisfying the null hypothesis (2).

4. Data description and empirical results

4.1. Data

In this analysis, the goal is to examine the greenhouse gas emissions from 27 European Union (EU) member nations on a quarterly basis, focusing on the amount of emissions per capita, meaning how much greenhouse gas is emitted per person. A key strength of this study is the use of a **high-frequency quarterly dataset** on greenhouse gas emissions per capita for all EU-27 countries. This level of temporal granularity is uncommon **in environmental economics research**, where annual data are the norm. The quarterly structure allows us to capture and analyze **short-term shocks**, such as those associated with the **COVID-19 pandemic** and the **Russia–Ukraine war**, which would be blurred or entirely missed in lower-frequency datasets. Consequently, the results offer a more nuanced view of persistence and mean reversion in emissions dynamics across European countries. These emissions are measured in tonnes (metric tons) of greenhouse gases, which contribute to global warming and climate change. The Kyoto Protocol, an international agreement, identifies seven specific greenhouse gases that are key contributors to climate change: Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulfur hexafluoride (SF_6) and Nitrogen trifluoride (NF_3). These gases are not equal in their contribution to global warming, so to make comparisons easier, their emissions can be converted to a standard measure known as carbon dioxide equivalents (CO2e). This allows the combined impact of all greenhouse gases to be understood as if they were just carbon dioxide, which is the most well-known greenhouse gas. The conversion helps assess the overall climate impact more accurately. The analysis focuses on greenhouse gas (GHG) emissions and consumer prices for the 27 European Union (EU) member states over 2010–2023. The main variable of interest is GHG emissions per capita, expressed in tonnes of CO_2 equivalent per person. These data are drawn from Eurostat's quarterly air emissions accounts by all NACE activities plus households (*dataset code: ENV_AC_AIGG_Q*). A custom table was created to extract the relevant series for all EU27 countries and the EU27 aggregate, available at:

https://ec.europa.eu/eurostat/databrowser/view/env_ac_aigg_q_custom_17907972/default/table.

(accessed May 15, 2024). The series are quarterly and used directly in tonnes per capita. They are log-transformed for econometric analysis.

Consumer price data are obtained from Eurostat's Harmonised Index of Consumer Prices (HICP, dataset code: PRC_HICP_MIDX), covering monthly data for the EU27 countries and aggregate over 2010–2023. The dataset can be accessed at:

https://ec.europa.eu/eurostat/databrowser/view/prc_hicp_midx_custom_16936828/default/table.

(accessed May 31, 2024). The HICP series are used in their original index form (2015 = 100).

Table 1 summarizes the data series, including sources, temporal and spatial coverage, units, and transformations applied. All retrieval steps, replication scripts and flowchart of data processing are documented in Appendix 1 and are also available in a public repository of GitHub.

By using this data, the analysis aims to understand trends in greenhouse gas emissions across EU countries and assesses how individual nations and the EU as a whole are contributing to global warming over time.

The descriptive data are shown in Table A1 in Appendix 2. The findings were computed using 56 observations (with the exception of Croatia which has only 54). Malta has the lowest tonnes per capita greenhouse gas emissions, at 0.95, while Luxembourg has the most, at 5.46. In addition, Luxembourg has the greatest average emissions (4.18), while Sweden and Malta has the lowest (1.42). The lowest evaluated value in the EU27 was 1.65 for the second quarter of 2020, while the highest was 2.70 for the fourth quarter of 2010. The dispersion of the results was 0.24, implying that tonnes per capita greenhouse gas emissions in the EU27 increased or decreased by 0.49.

4.2. Empirical results

We report the results of the model given by Eq. (1) for each series separately, in terms of the differencing parameter d, under the three classical set-ups of.

Table 1

Overview of data series: sources, coverage, units, and transformations.

Data Series	Source & Dataset Code	Temporal Coverage	Temporal Resolution	Spatial Coverage	Units	Transformations
Greenhouse gas emissions per capita	Eurostat: ENV_AC_AIGG_Q, *Air emissions accounts by all NACE activities plus households*, custom table link	2010Q1–2023Q4	Quarterly	EU27 + aggregate	Tonnes of CO$_2$e per capita	Log-transformed
Harmonised Index of Consumer Prices (HICP)	Eurostat: PRC_HICP_MIDX, custom table link	2010M1–2023M12	Monthly	EU27 + aggregate	Index (2015 = 100)	None

i) with no deterministic terms (i.e., with $\alpha = \beta = 0$ a priori). Results reported in column 2

ii) with an intercept only (i.e., with $\beta = 0$ a priori). Results reported in column 3, and

iii) with an intercept and a linear time trend. Results reported in column 4.

Along with the estimates we report the 95 % confidence intervals of the non-rejection values of d, and we mark in bold the selected specification for each series. This selection is based on the associated t-values for each deterministic term. Thus, if both the constant (α) and the time trend coefficient (β) are statistically significant, we choose the model with the two terms; however, if β is found to be insignificant, we choose the model with only an intercept; if this latter term is also insignificant, we choose the model with no terms.

Tables A2 and A3 in Appendix 2 report the estimates of d and the 95 % confidence bands for the original data and the logged values respectively. In Tables 2 and 3, we display, again for the original data and the logged values, the estimated coefficients based on the selected specification for each series, reporting the estimate of d and its confident band, and the values for the intercept and the time trend coefficients along with their corresponding t-values. To facilitate interpretation, Table A5 in Appendix 2 provides a synthesized overview of the persistence and trend dynamics of greenhouse gas emissions across EU-27 countries, summarizing the main categories of behavior (temporary shocks, persistent shocks, and insignificant trends) in a compact format.

Table 2

Estimates of the coefficients in the selected models. Original data.

Series	d (95 % band)	Intercept (tv)	Time trend (tv)
AUSTRIA	−0.08 (−0.26, 0.27)	2.3696 (59.53)	−0.0092 (−7.39)
BELGIUM	−0.27 (−0.45, 0.05)	2.9842 (82.73)	−0.0135 (−11.07)
BULGARIA	0.32 (0.02, 0.82)	2.0305 (24.83)	–
CROATIA	0.21 (0.06, 0.45)	1.5504 (57.22)	–
CYPRUS	0.20 (0.08, 0.35)	2.8152 (31.26)	−0.0088 (−3.35)
CZECH REPUBLIC	−0.20 (−0.43, 0.15)	3.1354 (84.60)	−0.0129 (−10.65)
DENMARK	0.33 (0.12, 0.72)	4.6428 (37.06)	−0.0026 (−6.98)
ESTONIA	0.74 (0.56, 1.05)	4.6009 (13.38)	−0.0406 (−2.08
FINLAND	0.06 (−0.14, 0.47)	3.5164 (39.56	−0.0277 (−10.41
FRANCE	−0.45 (−0.66, −0.07)	2.0764 (169.14)	−0.0099 (−22.27)
GERMANY	−0.04 (−0.20, 0.25)	3.2719 (52.62)	−0.0183 (−9.53)
GREECE	0.24 (0.08, 0.45)	2.8759 (39.74)	−0.0147 (−6.95)
HUNGARY	−0.08 (−0.25, 0.22)	1.7185 (94.77)	–
IRELAND	0.54 (0.37, 0.83)	3.8857 (23.62)	–
ITALY	0.02 (−0.14, 0.33)	2.1672 (40.76)	−0.0088 (−5.44)
LATVIA	0.16 (0.02, 0.39)	1.5863 (67.78)	–
LITHUANIA	0.32 (0.15, 0.58)	1.8532 (23.71)	0.0076 (3.27)
LUXEMBOURG	0.09 (−0.10, 0.43)	4.8120 (34.77)	−0.0222 (−5.39)
MALTA	0.50 (0.36, 0.67)	1.9405 (16.82)	−0.0172 (−4.36)
NETHERLANDS	−0.05 (−0.20, 0.21)	3.5329 (50.19)	−0.0189 (−8.64)
POLAND	−0.19 (−0.39, 0.18)	2.6482 (170.96)	–
PORTUGAL	0.53 (0.40, 0.72)	1.7011 (26.28)	−0.0043 (−1.89)
ROMANIA	−0.29 (−0.48, 0.04)	1.5960 (88.55)	−0.0023 (−3.86)
SLOVAKIA	0.14 (−0.08, 0.51)	2.0762 (47.26)	−0.0062 (−4.83)
SLOVENIA	0.42 (0.23, 0.73)	1.9729 (30.42)	−0.0081 (−3.99)
SPAIN	0.18 (0.00, 0.50)	2.2465 (34.00)	−0.0062 (−3.20)
SWEDEN	0.16 (−0.03, 0.60)	1.7679 (50.58)	−0.0120 (−11.76)
EU-27	−0.19 (−0.39, 0.16)	2.5008 (92.84)	−0.0100 (−11.40)

The values in parenthesis in columns 3 and 4 are the t-values for the intercept and time trend coefficients respectively.

Table 3

Estimates of the coefficients in the selected models. Logged data.

Series	d (95 % band)	Intercept (tv)	Time trend (tv)
AUSTRIA	−0.11 (−0.30, 0.26)	0.8622 (49.37)	−0.0043 (−7.81)
BELGIUM	−0.27 (−0.46, 0.06)	1.0951 (78.08)	−0.0052 (−11.04)
BULGARIA	0.31 (0.01, 0.80)	0.7057 (17.81)	–
CROATIA	0.20 (0.05, 0.43)	0.4355 (26.10)	–
CYPRUS	0.16 (0.04, 0.32)	1.0255 (31.64)	−0.0032 (−3.37)
CZECH REPUBLIC	−0.18 (−0.38, 0.19)	1.1469 (79.04)	−0.0047 (−10.10)
DENMARK	0.36 (0.14, 0.75)	1.5432 (46.58)	−0.0067 (−6.73)
ESTONIA	0.78 (0.59, 1.10)	1.5338 (14.67)	−0.0124 (−1.86)
FINLAND	0.00 (−0.20, 0.40)	1.2689 (49.00)	−0.0100 (−12.68
FRANCE	−0.42 (−0.63, −0.03)	0.7331 (97-36)	−0.0055 (−20.37)
GERMANY	0.02 (−0.13, 0.31)	1.1961 (43.51)	−0.0068 (−8.25)
GREECE	0.22 (0.06, 0.43)	1.0594 (37.04)	−0.0059 (−7.09)
HUNGARY	−0.08 (−0.25, 0.22)	0.5361 (52.30)	–
IRELAND	0.52 (0.36, 0.81)	1.3503 (30.47)	–
ITALY	−0.01 (−0.18, 0.31)	0.7701 (29.85)	−0.0045 (−5.71)
LATVIA	0.15 (0.01, 0.38)	0.4589 (28.87)	–
LITHUANIA	0.30 (0.14, 0.54)	0.6172 (17.31)	0.0037 (3.53)
LUXEMBOURG	0.13 (−0.06, 0.44)	1.5756 (43.37)	−0.0054 (−5.05)
MALTA	0.50 (0.35, 0.67)	0.6708 (8.60)	−0.0117 (−4.39)
NETHERLANDS	−0.00 (−0.14, 0.26)	1.2733 (45.94)	−0.0065 (−7.78)
POLAND	−0.19 (−0.39, 0.18)	0.9700 (165.54)	–
PORTUGAL	0.50 (0.37, 0.69)	0.5848 (13.11)	−0.0028 (−2.03)
ROMANIA	−0.28 (−0.48, 0.09)	0.4634 (38.44)	−0.0015 (−3.80)
SLOVAKIA	0.14 (−0.10, 0.52)	0.7318 (30.88)	−0.0033 (−4.75)
SLOVENIA	0.42 (0.22, 0.72)	0.6830 (17.15)	−0.0047 (−3.78)
SPAIN	0.17 (−0.01, 0.49)	0.8054 (26.00)	−0.0029 (−3.18)
SWEDEN	0.13 (−0.07, 0.55)	0.5778 (28.50)	−0.0083 (−13.93)
EU-27	−0.15 (−0.34, 0.20)	0.9205 (66.39)	−0.0046 (−10.31)

The values in parenthesis in columns 3 and 4 are the t-values for the intercept and time trend coefficients respectively.

We start with the original data for the tonnes per capita greenhouse gas emissions. We observe in Table 2 that of the 27 countries, only six display statistically insignificant trends. These are Bulgaria, Croatia, Hungary, Ireland, Latvia and Poland. For the remaining 21 countries, the time trend coefficient is statistically significant, being negative in all cases except for Lithuania which presents a positive value (see last column in Table 4). The highest magnitude of the decreasing trend is found in the case of Estonia (−0.0406) followed by Finland (−0.0277), Luxembourg (−0.0222) and Netherlands (−0.0189) and Germany (−0.0183). The differencing parameter values vary substantially across countries. In half of the countries, we find statistical evidence of a positive d, supporting a long memory or long-term persistent pattern. These countries are Latvia (with d = 0.16), Spain (0.18), Cyprus (0.20), Croatia (0.21), Bulgaria (0.22), Slovenia (0.23), Greece (0.24),

Table 4
Estimated coefficients. HICP data.

Country	No terms	An intercept	An intercept with a linear time trend
AUSTRIA	0.97 (0.87, 1.09)	4.486 (718.50)	0.0023 (6.18)
BELGIUM	1.12 (0.99, 1.31)	4.486 (500.18)	0.0023 (1.91)
BULGARIA	1.28 (1.17, 1.43)	4.550 (1029.11)	0.0024 (1.87)
CROATIA	1.21 (1.06, 1.42)	4.530 (538.90)	0.0012 (2.25)
CYPRUS	0.96 (0.80, 1.28)	4.515 (1099.11)	0.0021 (2.55)
CZECH REPUBLIC	1.24 (1.13, 1.45)	4.521 (657.63)	–
DENMARK	1.07 (0.94, 1.24)	4.525 (911.27)	0.0014 (2.70)
ESTONIA	1.38 (1.20, 1.61)	4.448 (775.57)	–
FINLAND	1.26 (1.13, 1.46)	4.494 (1271.01)	0.0018 (1.96)
FRANCE	1.18 (1.07, 1.34)	4.527 (1105.27)	0.0017 (2.31)
GERMANY	1.18 (1.04, 1.39)	4.516 (822.57)	0.0019 (1.98)
GREECE	0.83 (0.70, 0.96)	4.564 (417.83)	0.0010 (2.68)
HUNGARY	1.47 (1.29, 1.75)	4.473 (1076.47)	–
ITALY	0.65 (0.54, 0.77)	4.510 (478.11)	0.0015 (9.11)
LATVIA	1.43 (1.23, 1.70)	4.518 (863.97)	–
LITHUANIA	1.22 (1.11, 1.37)	4.515 (920.77)	0.0028 (2.63)
MALTA	0.92 (0.50, 1.40)	4.477 (366.50)	0.0017 (2.67)
NETHERLANDS	0.95 (0.83, 1.11)	4.501 (521.13)	0.0021 (3.90)
POLAND	1.40 (1.27, 1.59)	4.514 (1277.99)	–
PORTUGAL	0.77 (0.65, 0.91)	4.517 (611.46)	0.0015 (7.08)
ROMANIA	1.26 (1.16, 1.43)	4.444 (979.64)	0.0034 (2.84)
SWEDEN	1.27 (1.17, 1.43)	4.557 (964.12)	–
SLOVAKIA	1.54 (1.37, 1.80)	4.512 (1241.05)	–
SLOVENIA	0.92 (0.83, 1.05)	4.519 (804.78)	0.0018 (6.18)
SPAIN	0.69 (0.59, 0.81)	4.523 (562.80)	0.0015 (8.98)
EU-27	1.07 (0.98, 1.20)	4.514 (965.78)	0.0020 (4.03)

The values in parenthesis in columns 3 and 4 are the t-values for the intercept and time trend coefficients respectively.

Lithuania (0.32), Denmark (0.33), and they are particularly large in the cases of Malta (0.50), Portugal (0.53), Ireland (0.53) and Estonia, with $d = 0.74$. In fact, for the latter country, the unit root hypothesis ($d = 1$) cannot be rejected. In the rest of the cases, though most of the d's are positive, the hypothesis of short memory or I(0) behavior cannot be rejected.

Next we look at the logged-transformed data for the tonnes per capita greenhouse gas emissions. Results are displayed across Table 3. First, we see that the time trend is statistically significant for the same 21 countries as with the original data and qualitatively the same results are obtained. That is, the trend is insignificant for Bulgaria, Croatia, Hungary, Ireland, Latvia and Poland. It is significantly positive for Lithuania and the highest decreasing trends are found in the cases of Estonia (-0.0124) and Finland (-0.0100). For the differencing parameter, d, is found to be positive in 11 countries, the same as with the original data except for Spain where the I(0) cannot now be rejected, and the highest degrees of persistence are found in Portugal and Malta (with d equal to 0.50), Ireland (0.52) and particularly Estonia (0.78) where again the I(1) hypothesis cannot be rejected.

Finally, looking at the aggregate data for the EU27 countries, the estimate of d is -0.19 with the original data, and -0.15 with the logged values, the I(0) hypothesis cannot be rejected in any of the two cases, and the time trend is significantly negative in the two examined series (see the bottom rows in Tables 2 and 3).

These cross-country differences in persistence and trends can be linked to economic structure, energy mix, and national policy responses. Countries such as Estonia, Malta, Portugal, and Ireland, which show high persistence ($d > 0.5$), tend to have smaller or less diversified energy systems and slower transitions toward renewable energy sources, leading to more inertia in emission reductions. In contrast, economies like Germany, Finland, and the Netherlands display significant negative trends and lower persistence, reflecting earlier adoption of clean technologies, stronger carbon pricing, and more stringent environmental regulations. Moreover, the higher persistence observed in certain Southern and Eastern European economies may signal structural constraints in industrial adjustment or limited fiscal capacity to support large-scale decarbonization. These findings suggest that the estimated persistence parameter (d) captures not only statistical features but also structural and institutional rigidity, offering insights for the design of differentiated yet coordinated EU climate policies.

These findings are broadly consistent with Grolleau and Weber [4], who suggest that inflationary dynamics and structural rigidities can delay environmental improvements, and with Martin-Valmayor et al. [26], who document strong persistence in CO_2 emissions for advanced economies. By linking these empirical results to previous evidence, our analysis reinforces the idea that persistence reflects not only statistical memory but also institutional and policy inertia, shaping the effectiveness of decarbonization efforts across countries.

The results for the HICP are given in Tables A4 (for the estimates of d for the three cases of no terms, an intercept, and an intercept with a linear time trend), and in Table 4 for the estimated coefficients of the selected models. The results are heterogeneous across countries, finding evidence of mean reversion, i.e., statistical evidence of $d < 1$ in four Southern countries (Italy ($d = 0.65$), Spain (0.69), Portugal (0.77) and Greece (0.83)). The unit root cannot be rejected in Austria, Belgium, Cyprus, Denmark, Malta, Netherlands and Slovenia since $d = 1$ is included in the intervals for these countries. For the rest of the countries, the estimates of d are significantly above 1: Germany and France (1.18), Croatia (1.21), the Czech Republic (1.24), Lithuania (1.22), Romania and Finland (1.26), Sweden (1.27), Bulgaria (1.28), Poland (1.40), Latvia (1.43), Hungary (1.47) and Slovakia (1.54).

To complement the regression analysis, Figure 1 (in Appendix 3) reports the estimated differencing parameter (d) for greenhouse gas emissions per capita across the EU27, while Figure 2 provides the corresponding estimates for HICP. In Figure 1, green bars denote persistence or permanent shocks, whereas red bars indicate mean reversion. In Figure 2, green bars correspond to mean reversion ($d < 1$), gray bars to a unit root ($d = 1$), and orange bars to explosive behavior ($d > 1$). To further illustrate the statistical results, Figures 3 (also in Appendix 3) presents the time-series evolution of greenhouse gas emissions per capita (measured in tonnes) for four representative EU member states: Germany, Spain, Estonia, and Lithuania. The comparative plot (Figures 3) highlights cross-country differences in both the level and trajectory of emissions. This figure enables readers to visually connect the econometric results with the observed emission trajectories, thereby reinforcing the interpretation of persistence, mean reversion, and explosive tendencies across the EU. Figure 4 (in Appendix 3) illustrates the steady decline in EU27 per-capita emissions since 2010, punctuated by temporary downturns in 2020 and 2022. The gradual reversion toward trend following such shocks supports the finding of a high degree of persistence ($d \approx 0.8$) in the aggregate series. Figure 5 (in Appendix 3) depicts the year-over-year percentage change in EU27 per-capita emissions. The pronounced drop in 2020Q2 followed by a gradual rebound illustrates how shocks are absorbed over multiple quarters. This slow reversion is consistent with the estimated fractional order of integration, indicating high persistence in emission dynamics and the necessity for sustained policy interventions to achieve permanent reductions.

Summarizing the results of the two variables, there is some overlap in the countries that show mean reversion in the HICP data (Italy, Spain, Portugal, Greece) and those showing long memory in the greenhouse gas emissions (Spain, Greece, Portugal). However, countries such as Italy show mean reversion in HICP, while not being listed as showing significant trends in the greenhouse gas data. Countries such as Germany, France, and Finland show long-term persistence in the HICP data, with values of d above 1, and similarly, countries such as Germany and Finland show significant negative trends in their greenhouse gas emissions, though the values of the differencing parameter d in the emissions data do not directly correspond in the same way.

Finally, though not reported in detail, we also conducted several robustness checks using alternative estimation approaches to verify the stability of our results. Specifically, we employed Sowell's [51] maximum likelihood estimator in the time domain, Robinson's [52] log-periodogram semiparametric method, and the local Whittle semiparametric estimator of Shimotsu and Phillips [53]. These techniques were selected because they capture different aspects of long memory behavior and are widely used to validate fractional integration estimates. Across methods, the qualitative results remained broadly consistent—countries identified as having high persistence or long memory under the main specification retained similar classifications under the alternative estimators. Minor variations in the magnitude of the differencing parameter (d) were observed, especially when adjusting the short-run components in Sowell's [51] method or the bandwidth parameters in the semiparametric estimators, but these differences did not alter the overall conclusions. This robustness strengthens the credibility of the empirical findings and confirms that the main results are not driven by a specific estimation technique. In addition, various Ljung-Box Q-test statistics conducted on the residuals suggest that they are white noise, with no additional serial correlation. On the other hand, the potential presence of structural breaks in the data has not been investigated. This may be done by using the procedures developed in Gil-Alana (2005, 2008) for known and unknown breaks respectively; however, the implementation of these methods would produce subsamples with very few observations for a rigorous analytical work. Alternative approaches like those based on non-linear deterministic terms will be employed in future papers.

5. Conclusions

This study provides new and comprehensive evidence on the persistence of greenhouse gas emissions and consumer price dynamics across the EU-27, using high-frequency (quarterly and monthly) data and fractional integration techniques. By applying a unified methodological framework, the analysis identifies both temporary and long-lasting shocks, offering fresh insights into the temporal behavior of environmental and inflationary processes.

The results reveal a striking contrast between environmental and price persistence. Greenhouse gas emissions generally show significant downward trends across most EU countries, though the degree of persistence varies widely. In some member states—such as Estonia, Ireland, Malta, and Portugal—emissions exhibit long memory, indicating that shocks have enduring effects. This persistence underscores structural rigidities in energy systems and industrial patterns, suggesting that rapid decarbonization is hindered by deeper economic and policy inertia. These findings are broadly consistent with prior evidence showing that both institutional rigidities and energy dependence can delay environmental improvements [4,16,17]. Similarly, the strong persistence identified in certain EU economies aligns with Martin-Valmayor et al. [26], who document long memory in CO_2 emissions for advanced economies, and with Imeri & Gil-Alana [54], who find lasting effects of shocks on emissions across the EU. In contrast, the short-memory behavior and declining trends found for countries such as Germany, Finland, and the Netherlands resonate with earlier studies linking technological innovation and stricter environmental regulation to faster mean reversion in emissions Camarero et al., 2014; [14].

In contrast, the aggregated EU-level results display short memory with a clear negative trend, implying gradual convergence and supporting the view that coordinated EU policies, such as the European Green Deal, are fostering emission reductions.

In the case of prices, represented by the Harmonised Index of Consumer Prices (HICP), the majority of EU member states display values of the differencing parameter $d \geq 1$, with several countries exhibiting explosive or near-unit-root behavior. This suggests that recent inflationary pressures—amplified by the COVID-19 pandemic and the Russia–Ukraine war—are persistent and resistant to mean reversion, complicating the European Central Bank's stabilization efforts. However, a subset of Southern economies (Italy, Spain, Portugal, Greece) shows mean-reverting inflation, suggesting more transitory price dynamics in those cases.

The findings reflect differing adjustment mechanisms: the mean reversion in HICP suggests temporary price shocks that adjust back to equilibrium, whereas the long memory in greenhouse gas emissions signals slow structural change driven by industrial composition, energy dependency, and policy inertia. The results are consistent with prior research on the persistence of CO_2 emissions Imeri & Gil-Alana, 2024; [4,31], confirming a declining trend in emissions across the EU from 2010 to 2023, with lowest seasonal values typically recorded in the fourth quarter of each year.

While the study's univariate design limits the exploration of causal channels between prices and emissions, it provides a transparent baseline for understanding persistence dynamics, thereby laying the groundwork for future multivariate and policy-oriented analyses. In fact, future research should address these issues, answering the same questions as those examined in this work within the context of fractional cointegration, using a multivariate framework such as Johansen and Nielsen's [55,56] fractional CVAR (FCVAR) model. This approach will permit us to determine if there exist long run equlilibrium relationships between prices and GHG emissions, an issue that has not been investigated in the present paper. Nonlinear structures in the deterministic part of the model, such as Chebyshev polynomials in time [57], Fourier functions [58], or neural networks, within a fractional integration structure, i.e., replacing the first equality in Eq. (1) by these nonlinear structures could be considered as further extensions of the present work.

This study makes several novel contributions to the literature on environmental and macroeconomic persistence. First, it provides the first comprehensive EU-27–wide analysis of greenhouse gas emissions persistence jointly examined with consumer price dynamics, bridging two strands of literature—environmental economics and monetary analysis—that are rarely combined. Second, it employs high-frequency data (quarterly for emissions and monthly for prices), allowing for a more granular assessment of short-term and long-term dynamics than studies based on annual data. Third, it applies fractional integration methods to capture degrees of persistence beyond the conventional I(0)/I(1) dichotomy, thus offering a more flexible and realistic characterization of both environmental and inflationary processes. Finally, by linking persistence estimates to policy design, the study extends prior research by highlighting how long-memory behavior in emissions and prices can inform differentiated, evidence-based EU climate and energy strategies. Together, these contributions reinforce the paper's originality and provide a solid foundation for future multivariate and policy-oriented research in the field of sustainable macroeconomics.

Beyond these empirical insights, the persistence patterns observed across EU member states can be interpreted through structural and theoretical lenses. Countries with stronger persistence in greenhouse gas emissions—such as Estonia, Ireland, Malta, and Portugal—tend to exhibit energy systems that remain heavily dependent on fossil fuels, slower industrial decarbonization, and more rigid fiscal structures. In contrast, countries with short-memory behavior often display diversified energy portfolios and more flexible regulatory environments. This heterogeneity aligns with theoretical expectations that structural rigidities and energy path dependence lead to long-memory processes in environmental and price dynamics. Importantly, the estimated persistence coefficient (*d*) captures statistical persistence rather than purely economic persistence; thus, $d > 1$ should not be interpreted as explosive growth, but rather as reflecting underlying adjustment frictions and inertia in policy or technology adoption. From a macroeconomic standpoint, these findings underscore the potential for improved coordination between monetary and climate policy at the EU level, particularly as inflation and emissions shocks may share structural origins in energy and fiscal systems. Recognizing these shared persistence patterns can help design synchronized policies that promote both price stability and decarbonization.

5.1. Policy implications

The heterogeneous persistence and trend patterns uncovered in this study suggest that policy responses to greenhouse gas emissions within the EU should be differentiated and tailored to country-specific emission dynamics. Countries with evidence of high persistence and long memory (e.g., Estonia, Ireland, Malta, Portugal) require sustained and long-term climate policies. Temporary measures will be insufficient due to the lasting impact of shocks, and thus, structural reforms—such as permanent carbon pricing mechanisms, long-term investment in clean infrastructure, and binding emissions targets—are essential to ensure enduring emission reductions.

Countries exhibiting significant downward trends and trend-stationary behavior (e.g., Germany, France, the Netherlands) should focus on maintaining and fine-tuning existing policies that have proven effective. Ensuring policy continuity and resilience to external shocks will be key to sustaining progress. For those with stagnant or insignificant trends, including several Central and Eastern European member states, more proactive industrial transition programs, innovation incentives, and regulatory strengthening are needed to initiate meaningful emission reductions.

At the EU level, these findings reinforce the importance of a differentiated yet coordinated climate strategy, consistent with the objectives of the European Green Deal and the Fit for 55 package. The persistence patterns identified here suggest that EU funding, incentives, and regulatory support should be aligned with each member state's emission dynamics. Successful national policies—such as renewable energy promotion in Germany or carbon taxation in France—could serve as adaptable models for countries with more persistent emissions. Such policy diffusion would enhance convergence toward the EU's collective goal of climate neutrality by 2050.

Recognizing the diversity in emission persistence and trends highlights the importance of long-term, consistent, and adaptive policy measures. Such an approach will be instrumental in achieving the EU's climate neutrality goals and ensuring sustainable environmental and economic outcomes.

Furthermore, the results carry important implications for the interaction between monetary stability and environmental sustainability. Persistent inflation, as reflected in the HICP series, can raise the cost of capital and thereby influence the pace of the green transition. Elevated borrowing costs may discourage investments in renewable energy, energy efficiency, and low-carbon technologies—particularly in countries where emissions exhibit strong persistence. Conversely, stable price dynamics—supported by effective monetary coordination—can create a more favorable environment for green investment and innovation.

This implies that European Central Bank (ECB) monetary policy, while primarily aimed at ensuring price stability, indirectly affects the EU's capacity to meet its Paris Agreement and climate neutrality objectives. Integrating the insights from persistence analysis into macroeconomic policy design can help ensure that anti-inflationary measures do not inadvertently slow down the decarbonization process. A more coherent framework—where monetary, fiscal, climate, and energy policies are aligned—could enhance the EU's resilience to short-term shocks such as those triggered by the COVID-19 pandemic or the Russia–Ukraine war.

In this context, price persistence and emission persistence should not be viewed as independent phenomena but as interconnected dimensions of Europe's broader macro-financial and environmental stability. Coordinated fiscal and monetary support for the clean energy transition, coupled with flexible inflation management, would allow the EU to advance toward both price stability and its long-term climate objectives in a mutually reinforcing manner.

Credit author statement

The corresponding author, LAGA took care of the conceptualization, methodology, formal analysis and writing, The first named author, AI proposed the original idea, carried out with the investigation and final supervision, The second author, GCQ was responsible of data curation, methodology and interpretation of the results.

Declaration of competing interest

There is no conflict of interest with the publication of the present manuscript.

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Appendices.

Appendix 1. Data retrieval and processing

This appendix documents the sources, retrieval steps, and processing applied to the datasets used in this study.

1. *Greenhouse Gas (GHG) Emissions per Capita*

- Source: Eurostat – Air emissions accounts by NACE activities and households
- Dataset ID: env_ac_aigg_q
- Access Link: https://ec.europa.eu/eurostat/databrowser/view/env_ac_aigg_q__custom_17907972/default/table?lang=en
- Coverage: Quarterly data, 2010Q1–2023Q4

- Units: Tonnes CO_2 equivalent per capita
- **Conversion**: No additional conversion to CO_2-equivalent or per capita terms is required, as this is provided directly by Eurostat.
- Steps:

1. Access the Eurostat Data Browser at the above link.
2. Select All EU-27 member states + EU27 aggregate.
3. Choose 2010Q1–2023Q4.
4. Download in CSV format.

2. *Harmonised Index of Consumer Prices (HICP)*

- Source: Eurostat – HICP (2015 = 100)
- Dataset ID: prc_hicp_midx
- Access Link: https://ec.europa.eu/eurostat/databrowser/view/prc_hicp_midx__custom_16936828/default/table?lang=en
- Coverage: Monthly data, 2010M1–2023M12
- Units: Index (2015 = 100)
- Steps:

1 Access the Eurostat Data Browser at the above link.
2 Select All EU-27 member states + EU27 aggregate.
3. Choose 2010M1–2023M12.
4 Download in CSV format.

3. *Data Availability*

Data and codes used in this application are available in the following repository 10.5281/zenodo.17396874 at https://zenodo.org/uploads/17396874.

- GitHub link: https://github.com/amirimeri/EU27_GHG_Replication

Appendix 2. Additional tables

Table A1
Descriptive Statistics for tones per capita Greenhouse gases

Country	N. obs	Minimum	Maximum	Mean	Std. Dev.
AUSTRIA	56	1.61	2.71	2.11	0.24
BELGIUM	56	1.82	3.54	2.60	0.37
BULGARIA	56	1.55	2.52	2.05	0.22
CROATIA	54	1.32	1.76	1.54	0.10
CYPRUS	56	1.93	3.26	2.54	0.25
CZECH REP.	56	2.10	3.40	2.76	0.32
DENMARK	56	3.01	4.95	3.88	0.46
ESTONIA	56	1.95	4.86	3.67	0.89
FINLAND	56	1.81	4.21	2.72	0.53
FRANCE	56	1.27	2.31	1.79	0.23
GERMANY	56	1.88	3.45	2.75	0.39
GREECE	56	1.85	3.04	2.44	0.28
HUNGARY	56	1.40	2.04	1.72	0.18
IRELAND	56	2.77	4.34	3.75	0.31
ITALY	56	1.34	2.46	1.91	0.24
LATVIA	56	1.32	1.91	1.59	0.11
LITHUANIA	56	1.69	2.68	2.08	0.20
LUXEMBOURG	56	3.03	5.46	4.18	0.54
MALTA	56	0.95	2.27	1.42	0.37
NETHERLANDS	56	2.11	3.87	2.99	0.43
POLAND	56	2.26	3.03	2.65	0.24
PORTUGAL	56	1.23	1.85	1.62	0.13
ROMANIA	56	1.20	1.93	1.53	0.16
SLOVAKIA	56	1.49	2.29	1.90	0.15
SLOVENIA	56	1.66	2.53	2.06	0.18
SPAIN	56	1.22	2.05	1.75	0.17
SWEDEN	56	1.10	2.03	1.42	0.21
EU27	56	1.65	2.70	2.21	0.24

Note: EU27 denote 27 European Union member countries.

Table A2
Estimates of d. Original data

Series	No terms	An intercept	A linear time trend
AUSTRIA	0.79 (0.61, 1.07)	0.23 (0.10, 0.42)	**−0.08 (-0.26, 0.27)**
BELGIUM	0.69 (0.51, 0.98)	0.17 (0.04, 0.34)	**−0.27 (-0.45, 0.05)**
BULGARIA	0.83 (0.64, 1.11)	**0.32 (0.02, 0.82)**	0.31 (−0.01, 0.82)
CROATIA	0.84 (0.67, 1.08)	**0.21 (0.06, 0.45)**	0.22 (0.06, 0.46)
CYPRUS	0.72 (0.57, 0.91)	0.21 (0.10, 0.34)	**0.20 (0.08, 0.35)**
CZECHK REP.	0.79 (0.61, 1.08)	0.25 (0.13, 0.44)	**−0.20 (-0.43, 0.15)**
DENMARK	0.86 (0.69, 1.10)	0.48 (0.37, 0.67)	**0.33 (0.12, 0.72)**
ESTONIA	0.87 (0.72, 1.11)	0.76 (0.62, 1.04)	**0.74 (0.56, 1.05)**
FINLAND	0.77 (0.69, 1.03)	0.39 (0.29, 0.52)	**0.06 (-0.14, 0.47)**
FRANCE	0.76 (0.69, 1.03)	0.25 (0.13, 0.41)	**−0.45 (-0.66, -0.07)**
GERMANY	0.79 (0.69, 1.08)	0.35 (0.25, 0.51)	**−0.04 (-0.20, 0.25)**
GREECE	0.84 (0.69, 1.05)	0.42 (0.34, 0.53)	**0.24 (0.08, 0.45)**
HUNGARY	0.73 (0.69, 1.04)	**−0.08 (-0.25, 0.22)**	−0.08 (−0.26, 0.24)
IRELAND	0.81 (0.69, 1.05)	**0.54 (0.37, 0.83)**	0.55 (0.38, 0.84)
ITALY	0.77 (0.59, 1.04)	0.24 (0.12, 0.42)	**0.02 (-0.14, 0.33)**
LATVIA	0.75 (0.58, 0.97)	**0.16 (0.02, 0.39)**	0.13 (−0.03, 0.39)
LITHUANIA	0.78 (0.60, 1.02)	0.44 (0.33, 0.62)	**0.32 (0.15, 0.58)**
LUXEMBOURG	0.77 (0.58, 1.06)	0.27 (0.13, 0.46)	**0.09 (0.10, 0.43)**
MALTA	0.86 (0.73, 1.03)	0.59 (0.51, 0.70)	**0.50 (0.36, 0.67)**
NETHERLANDS	0.75 (0.58, 1.03)	0.29 (0.19, 0.45)	**−0.05 (0.20, 0.21)**
POLAND	0.78 (0.58, 1.10)	**−0.19 (-0.39, 0.18)**	−0.19 (−0.41, 0.19)
PORTUGAL	0.91 (0.74, 1.14)	0.57 (0.46, 0.74)	**0.53 (0.40, 0.72)**
ROMANIA	0.81 (0.80, 1.10)	−0.07 (−0.23, 0.21)	**−0.29 (-0.48, 0.04)**
SLOVAKIA	0.89 (0.71, 1.16)	0.34 (0.19, 0.56)	**0.14 (-0.08, 0.51)**
SLOVENIA	0.90 (0.73, 1.14)	0.53 (0.41, 0.75)	**0.42 (0.23, 0.73)**
SPAIN	0.80 (0.63, 1.05)	0.24 (0.09, 0.47)	**0.18 (0.00, 0.50)**
SWEDEN	0.81 (0.65, 1.04)	0.44 (0.36, 0.54)	**0.16 (-0.03, 0.60)**
EU-27	0.81 (0.64, 1.09)	0.28 (0.17, 0.45)	**−0.19 (-0.39, 0.16)**

The values in parenthesis indicate the 95 % confidence intervals for the differencing parameter d. In bold, the selected specification for each country.

Table A3
Estimates of d. Logged data

Series	No terms	An intercept	An intercept and a linear time trend
AUSTRIA	0.74 (0.55, 1.04)	0.23 (0.10, 0.43)	**−0.11 (-0.30, 0.26)**
BELGIUM	0.69 (0.50, 0.99)	0.18 (0.05, 0.36)	**−0.27 (-0.46, 0.06)**
BULGARIA	0.75 (0.54, 1.07)	**0.31 (0.01, 0.80)**	0.30 (−0.02, 0.80)
CROATIA	0.67 (0.49, 0.91)	**0.20 (0.05, 0.43)**	0.20 (0.05, 0.45)
CYPRUS	0.70 (0.55, 0.89)	0.19 (0.08, 0.32)	**0.16 (0.04, 0.32)**
CZECH REPUBLIC	0.81 (0.62, 1.11)	0.26 (0.14, 0.45)	**−0.18 (-0.38, 0.19)**
DENMARK	0.89 (0.72, 1.14)	0.50 (0.39, 0.72)	**0.36 (0.14, 0.75)**
ESTONIA	0.91 (0.74, 1.17)	0.80 (0.64, 1.10)	**0.78 (0.59, 1.10)**
FINLAND	0.80 (0.62, 1.09)	0.41 (0.31, 0.55)	**0.00 (-0.20, 0.40)**
FRANCE	0.64 (0.46, 0.94)	0.26 (0.15, 0.42)	**−0.42 (-0.63, -0.03)**
GERMANY	0.80 (0.63, 1.12)	0.37 (0.26, 0.54)	**0.02 (-0.13, 0.31)**
GREECE	0.83 (0.68, 1.03)	0.42 (0.34, 0.54)	**0.22 (0.06, 0.43)**
HUNGARY	0.47 (0.29, 0.87)	**−0.08 (-0.25, 0.22)**	−0.08 (−0.27, 0.23)
IRELAND	0.85 (0.68, 1.08)	**0.52 (0.36, 0.81)**	0.53 (0.36, 0.82)
ITALY	0.68 (0.50, 0.98)	0.24 (0.11, 0.43)	**−0.01 (-0.18, 0.31)**
LATVIA	0.51 (0.27, 0.78)	**0.15 (0.01, 0.38)**	0.11 (−0.03, 0.37)
LITHUANIA	0.68 (0.45, 0.93)	0.43 (0.33, 0.60)	**0.30 (0.14, 0.54)**
LUXEMBOURG	0.85 (0.66, 1.14)	0.29 (0.15, 0.49)	**0.13 (-0.06, 0.44)**
MALTA	0.76 (0.65, 0.91)	0.59 (0.51, 0.71)	**0.50 (0.35, 0.67)**
NETHERLANDS	0.79 (0.60, 1.08)	0.31 (0.20, 0.47)	**−0.00 (-0.14, 0.26)**
POLAND	0.78 (0.57, 1.10)	**−0.19 (-0.39, 0.18)**	−0.19 (−0.41, 0.18)
PORTUGAL	0.82 (0.66, 1.02)	0.55 (0.43, 0.71)	**0.50 (0.37, 0.69)**
ROMANIA	0.51 (0.21, 0.88)	−0.06 (−0.22, 0.22)	**−0.28 (-0.48, 0.09)**
SLOVAKIA	0.84 (0.66, 1.14)	0.34 (0.20, 0.57)	**0.14 (-0.10, 0.52)**
SLOVENIA	0.84 (0.67, 1.09)	0.52 (0.40, 0.74)	**0.42 (0.22, 0.72)**
SPAIN	0.76 (0.58, 1.01)	0.24 (0.09, 0.47)	**0.17 (-0.01, 0.49)**
SWEDEN	0.72 (0.57, 0.95)	0.47 (0.39, 0.57)	**0.13 (-0.07, 0.55)**
EU-27	0.78 (0.60, 1.08)	0.29 (0.17, 0.47)	**−0.15 (-0.34, 0.20)**

The values in parenthesis indicate the 95 % confidence intervals for the differencing parameter d. In bold, the selected specification for each country.

Table A4
Estimates of d. HICP data

Country	No terms	An intercept	An intercept with a linear time trend
AUSTRIA	0.96 (0.79, 1.16)	0.97 (0.87, 1.08)	**0.97 (0.87, 1.09)**
BELGIUM	0.94 (0.80, 1.16)	1.11 (0.98, 1.32)	**1.12 (0.99, 1.31)**
BULGARIA	0.96 (0.79, 1.14)	1.26 (1.16, 1.41)	**1.28 (1.17, 1.43)**
CROATIA	0.95 (0.80, 1.16)	1.19 (1.05, 1.41)	**1.21 (1.06, 1.42)**
CYPRUS	0.95 (0.81, 1.16)	0.96 (0.79, 1.27)	**0.96 (0.80, 1.28)**
CZECH REPUBLIC	0.95 (0.81, 1.15)	**1.24 (1.13, 1.45)**	1.28 (1.15, 1.48)
DENMARK	0.95 (0.79, 1.16)	1.07 (0.94, 1.23)	**1.07 (0.94, 1.24)**
ESTONIA	0.95 (0.81, 1.16)	**1.38 (1.20, 1.61)**	1.39 (1.23, 1.64)
FINLAND	0.95 (0.80, 1.16)	1.26 (1.13, 1.44)	**1.26 (1.13, 1.46)**
FRANCE	0.95 (0.80, 1.16)	1.17 (1.07, 1.33)	**1.18 (1.07, 1.34)**
GERMANY	0.95 (0.81, 1.16)	1.16 (1.03, 1.35)	**1.18 (1.04, 1.39)**
GREECE	0.96 (0.80, 1.16)	0.81 (0.69, 0.95)	**0.83 (0.70, 0.96)**
HUNGARY	0.95 (0.81, 1.15)	**1.47 (1.29, 1.75)**	1.50 (1.33, 1.76)
ITALY	0.95 (0.79, 1.16)	0.65 (0.55, 0.77)	**0.65 (0.54, 0.77)**
LATVIA	0.95 (0.79, 1.15)	**1.43 (1.23, 1.70)**	1.44 (1.25, 1.73)
LITHUANIA	0.96 (0.80, 1.16)	1.20 (1.10, 1.36)	**1.22 (1.11, 1.37)**
MALTA	0.95 (0.79, 1.16)	0.92 (0.56, 1.41)	**0.92 (0.50, 1.40)**
NETHERLANDS	0.95 (0.79, 1.16)	0.95 (0.85, 1.11)	**0.95 (0.83, 1.11)**
POLAND	0.95 (0.79, 1.16)	**1.40 (1.27, 1.59)**	1.42 (1.30, 1.59)
PORTUGAL	0.95 (0.80, 1.16)	0.76 (0.63, 0.91)	**0.77 (0.65, 0.91)**
ROMANIA	0.95 (0.80, 1.16)	1.26 (1.15, 1.43)	**1.26 (1.16, 1.43)**
SWEDEN	0.95 (0.80, 1.17)	**1.27 (1.17, 1.43)**	1.31 (1.18, 1.46)
SLOVAKIA	0.94 (0.80, 1.16)	**1.54 (1.37, 1.80)**	1.56 (1.40, 1.82)
SLOVENIA	0.95 (0.80, 1.16)	0.92 (0.83, 1.05)	**0.92 (0.83, 1.05)**
SPAIN	0.95 (0.79, 1.16)	0.69 (0.58, 0.81)	**0.69 (0.59, 0.81)**
EU-27	0.95 (0.79, 1.15)	1.07 (0.98, 1.19)	**1.07 (0.98, 1.20)**

The values in parenthesis indicate the 95 % confidence intervals for the differencing parameter d. In bold, the selected specification for each country.

Table A5
Summary of Persistence and Trend Results for EU-27 Greenhouse Gas Emissions (Original and Log-Transformed Data)

Category	Original Data (2010Q1–2023Q4)	Log-Transformed Data (2010Q1–2023Q4)
Temporary shocks (mean reversion/ short memory, $d < 1$, I(0) not rejected)	Latvia, Spain, Cyprus, Croatia, Bulgaria, Slovenia, Greece, Lithuania, Denmark	Latvia, Cyprus, Croatia, Bulgaria, Slovenia, Greece, Lithuania, Denmark, Spain (*now I(0) cannot be rejected*)
Persistent shocks (long memory/near-unit root, shocks long-lasting)	Malta (0.50), Portugal (0.53), Ireland (0.53), Estonia (0.74, I(1) cannot be rejected)	Malta (0.50), Portugal (0.50), Ireland (0.52), Estonia (0.78, I(1) cannot be rejected)
Insignificant time trend	Bulgaria, Croatia, Hungary, Ireland, Latvia, Poland	Bulgaria, Croatia, Hungary, Ireland, Latvia, Poland
Notable positive/negative trends	Strongest decreases: Estonia (−0.0406), Finland (−0.0277), Luxembourg (−0.0222), Netherlands (−0.0189), Germany (−0.0183). Positive trend: Lithuania.	Strongest decreases: Estonia (−0.0124), Finland (−0.0100). Positive trend: Lithuania.

Appendix 3. Additional figures

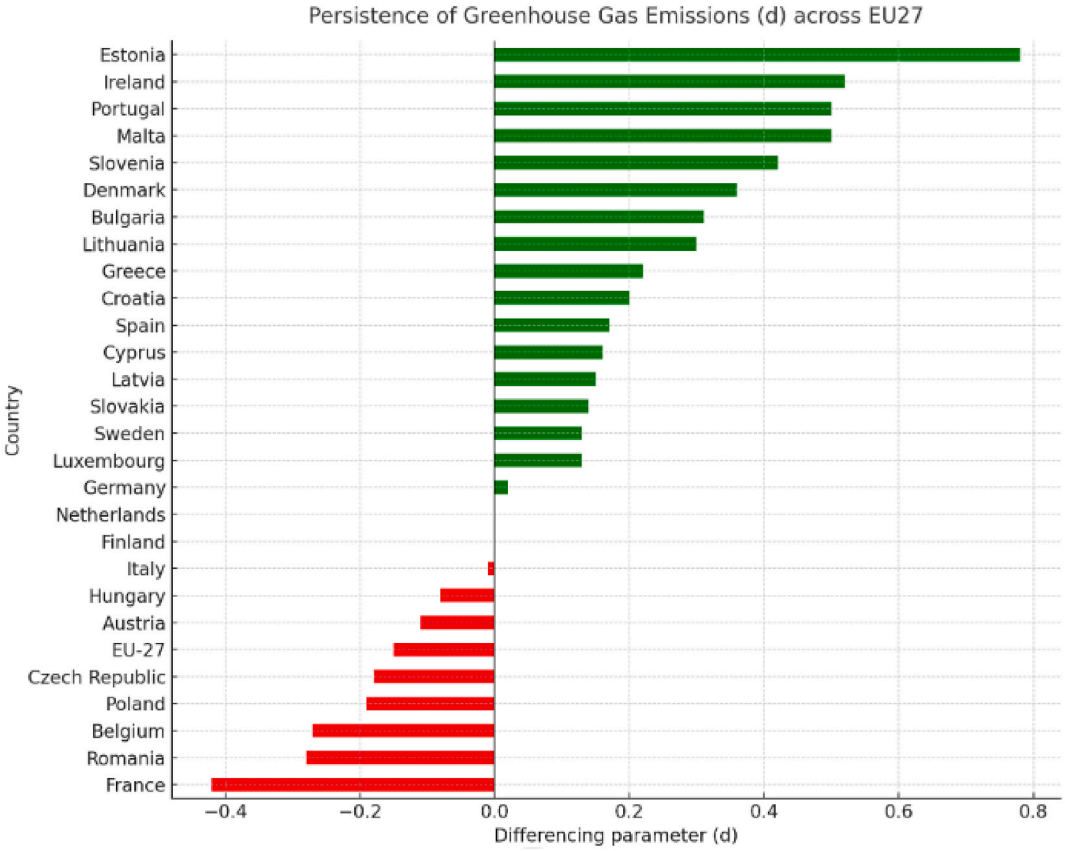

Fig. 1. Estimated differencing parameter d for greenhouse gas emissions persistence across EU27 (2010Q1–2023Q4)

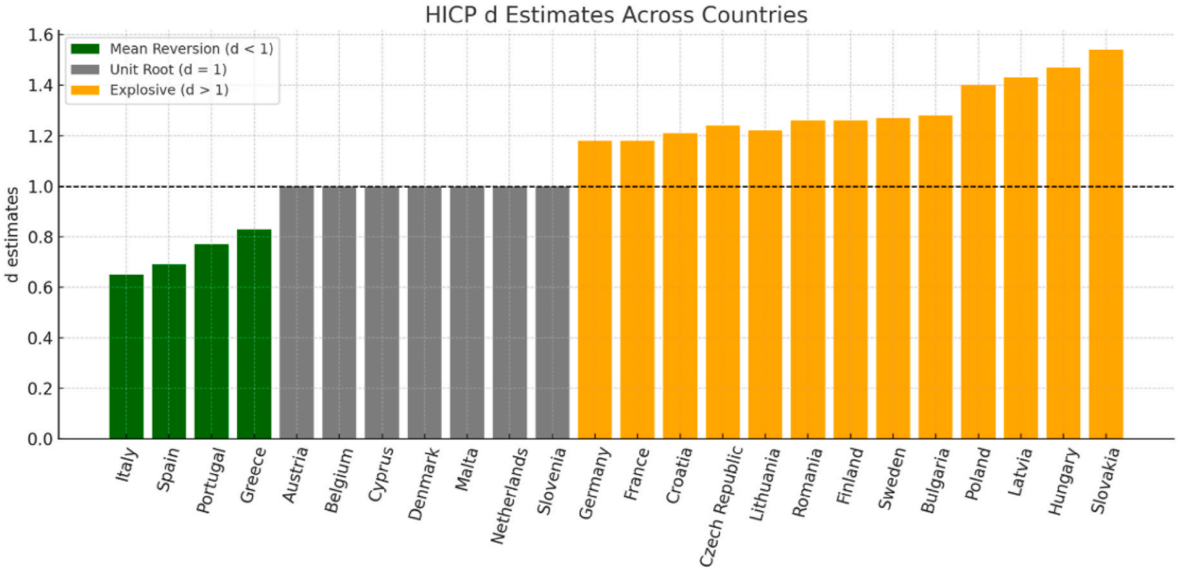

Fig. 2. Estimated differencing parameter d for HICP persistence across EU27 (2010M1–2023M12)

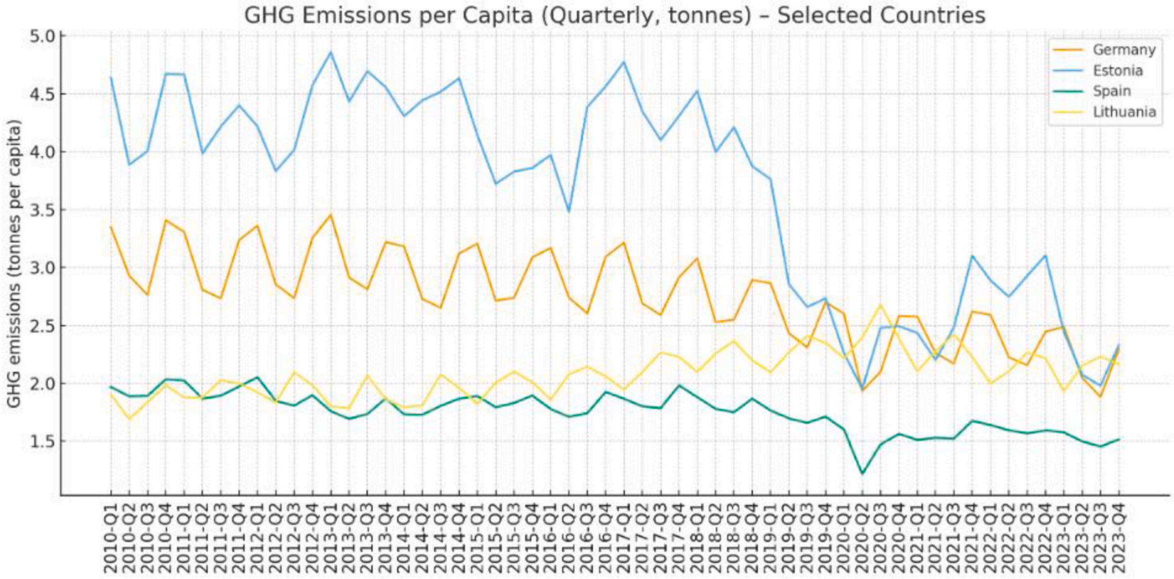

Fig. 3. Time-series of GHG emissions per capita for selected countries

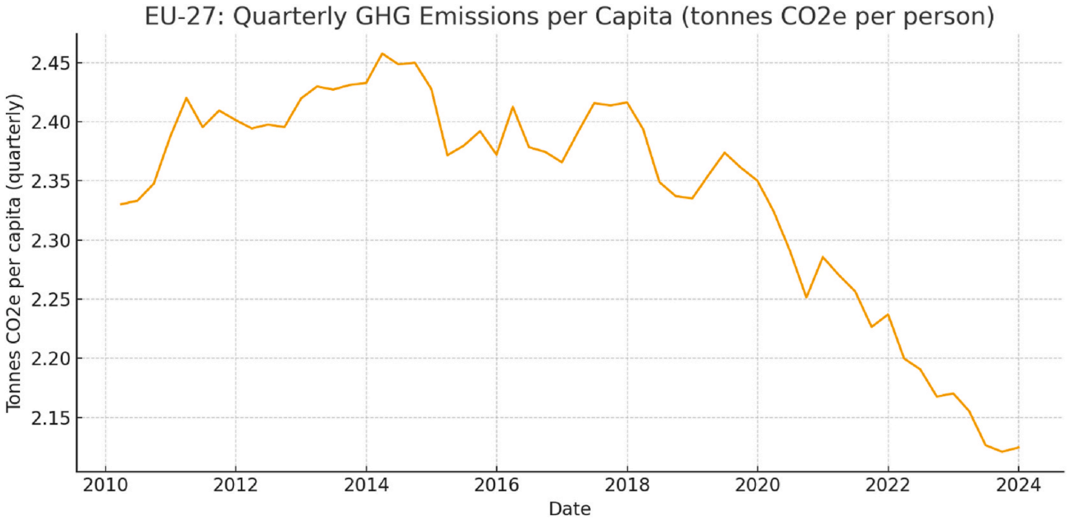

Fig. 4. Time-series of EU-27 GHG emissions per capita

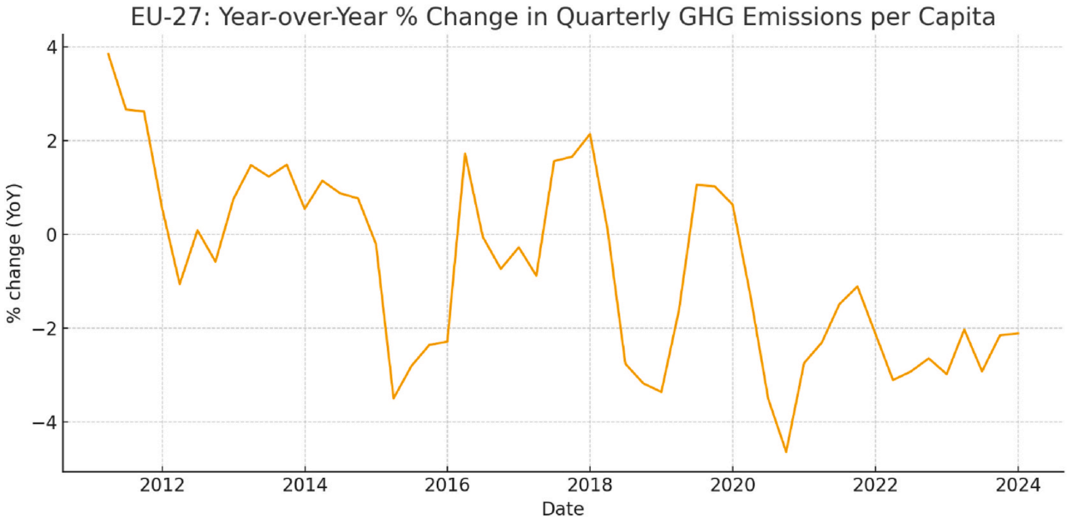

Fig. 5. Time-series of EU-27 Year-over-year change in GHG emissions per capita

Data availability

Data will be made available on request.

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