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ANALYZING CAUSALITY AND COINTEGRATION OF MACROECONOMICS AND ENERGY-RELATED FACTORS OF NORDIC AND SEE EUROPEAN COUNTRIES

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Abstract. Discrepancies between several South-Eastern European (SEE) countries and Nordic countries are investigated in this paper using an econometric analysis. Its aim is to examine the relationship between CO_2 emissions, GDP per capita, urban population (URB) and electricity production from Renewable Energy Sources (RES) – EPREN, excluding hydroelectric for the two groups of EU countries located in the North and S-E of Europe. The data covers a period from 1990 to 2022, providing a comprehensive view over three decades. The relationship between the four variables is determined by various causality and cointegration tests. We check the unit root tests and conclude that the analyzed time series are stationary at first difference. Further, we estimate two models: Fully Modified and Dynamic Ordinary Least Squares and study causality and cointegration between variables. The results show that CO_2 emissions are impacted by GDP, URB and EPREN for both regions. Testing causality, for SEE and Nordic countries, the bidirectional and causalities do exist.

Keywords: FMOLS and DOLS, macroeconomics, greenhouse gases, renewables, fossil fuels, energy-related factors.

JEL Classification: C23, O13, O44.

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1. Introduction

The European Union's (EU) efforts to combat climate change are significant as climate change is already impacting Europe in various ways, including biodiversity loss, reduced crop yields, forest fires, and rising temperatures (heatwaves) (Knez et al., 2022; Văduva et al., 2023). Our paper is grounded in the fundamental distinctions between the electricity systems of SEE countries and Nordic nations. These differences encompass several key aspects, including their sources of electricity generation, market structures (Bâra et al., 2023; Cancro et al., 2022), and grid integration (Grădinaru & Maricuț, 2022; Tchapchet-Tchouto et al., 2022).

In the SEE countries, electricity generation relies heavily on natural gas and coal, with nuclear power also playing a significant role (Popescu et al., 2022; Ozarisoy & Altan, 2021). In contrast, Nordic countries place a greater emphasis on RES, particularly hydroelectric power, wind energy, and biomass, in addition to utilizing nuclear power (Ranta et al., 2020). Notably, the adoption of RES in SEE countries lags behind that of the Nordic countries. This discrepancy can be attributed to limited investments in RES infrastructure and a lack of robust policy support for RES in the SEE region. Furthermore, the market structures in these two regions differ significantly. Historically, SEE countries have maintained more centralized and state-controlled energy markets. Market regulation and deregulation have progressed at a slower pace in these countries compared to the Nordics (Dagoumas, 2021; Sabău-Popa et al., 2014). In the Nordic countries, energy markets have been liberalized, enabling consumers to choose their electricity suppliers and benefit from transparent pricing. In contrast, SEE electricity prices may be influenced by factors such as the cost of fossil fuels and political considerations. Nordic countries experience higher electricity prices due to the costs associated with grid maintenance and investments in RES infrastructure. However, they excel in grid integration, which aids in balancing the supply and demand for electricity (Bozkaya et al., 2022; Wu et al., 2023; Nycander et al., 2020). In the SEE countries, difficulties may arise in integrating RES into the grid due to outdated infrastructure. Thus, there are substantial disparities between SEE and Nordic electricity systems, encompassing generation sources, market structures, readiness to disclose data for enhancing energy efficiency and integrating with the grid (Reyes, 2022; Carlsen & Bruggemann, 2021).

Particularly in the current paper, the relationship between CO_2 emissions, urbanization (URB), Gross Domestic Product (GDP) and electricity generation from RES (EPREN) is investigated for the two groups of countries using several statistical tests such as: unit root tests, FMOLS, DOLS, causality and cointegration. Further, we focus on the following two research questions: **RQ1:** Are CO_2 emissions impacted by URB, GDP and EPREN in the long run? The following three hypotheses are asserted in the framework of RQ1. Hypothesis HY1: GDP per capita impacts positively CO_2 emissions. Hypothesis HY2: EPREN impacts negatively CO_2 emissions. Hypothesis HY3: URB impacts negatively CO_2 emissions. **RQ2:** What kind of causality relationships exist between CO_2 emissions, urbanization level, GDP and generation from RES for the two groups of countries?

This paper has a specific focus and set of objectives centered on a comparative analysis of several South-Eastern European and Nordic countries. The geographical scope is confined to these two distinct regions within the EU. The study investigates the relationship between four main variables: CO_2 emissions, GDP per capita, URB and EPREN. Methodologically, the research employs econometric analysis using various statistical tests such as unit root tests, Fully Modified and Dynamic Ordinary Least Squares (FMOLS, DOLS), causality, and cointegration tests to analyze the relationships and causal links between the variables. The primary objective of the study is to explore the relationship and causality between CO_2, GDP per capita, URB and EPREN, determining how these variables interact with each other in both Nordic and SEE countries. The paper aims to test three specific hypotheses within its first research question. Another key objective is to understand if the influences of URB, GDP, and EPREN on CO_2 emissions are sustained in the long run. Additionally, the study seeks to determine the nature of causality relationships between CO_2 emissions, URB level, GDP and EPREN, analyzing whether these relationships are unidirectional or bidirectional, and how they differ between the two groups of countries. Overall, the current paper aims to provide a detailed and comparative understanding of the environmental-economic dynamics in Nordic and SEE countries, using advanced econometric techniques to uncover deeper insights into the causality and long-term relationships among key variables affecting CO_2 emissions.

This paper makes several important contributions such as: (a) Comparative analysis between different EU regions: By focusing on Nordic and SEE countries, the paper contributes to understanding regional disparities within the EU. This comparative analysis helps to highlight how different economic and environmental conditions can influence the relationship between key variables; (b) In-depth econometric analysis: The use of various econometric tools such as unit root tests, FMOLS, DOLS causality, and cointegration tests provides a robust analytical framework; (c) Focus on long-term relationships and causalities: By examining long-run influences and causal relationships among CO_2 emissions, urbanization, GDP and RES generation, the paper contributes insights into the dynamics of environmental and economic factors over time; (d) Testing specific hypotheses: The paper's approach to addressing specific hypotheses related to the impact of GDP, renewable energy production, and urbanization on CO_2 emissions adds a structured and focused contribution to the debate on environmental policy; (e) Filling knowledge gaps: By exploring the relationship between these variables in the context of both Nordic and SEE countries, the paper fills a gap in the existing literature, which previously focused more on either one of these regions or on different variables. Therefore, this paper addresses a notable research gap by providing a recent detailed, comparative and methodologically advanced analysis of the relationships between key environmental and economic variables across Nordic and SEE countries.

The organization of the remaining sections of this paper is outlined as follows: Section 2 provides a succinct review of relevant literature, specifically focusing on studies that have been conducted within similar regional or group contexts. Section 3 covers the input data, detailing the sources and variables employed in our analysis. In Section 4, we present the research methodology proposed in this study. Section 5 shows the findings, highlighting the results obtained from our analysis of the panel data across the two groups of countries. Finally, Section 6 offers conclusions drawn from our investigation of these distinct regions.

2. Literature review

In this section, we present a brief overview of several recent studies that explore the connection between CO_2 emissions and economic growth factors such as GDP, urbanization, and renewable energy sources (RES). The primary objectives outlined in Kleanthis et al. (2022) were to compare and gather knowledge from various stakeholders to pinpoint the critical issues associated with the transition to climate neutrality in Greece, the Nordic region, and continental EU member countries. The authors identified substantial disparities in the progress of energy transition among these EU nations. The results highlighted that stakeholders' viewpoints regarding the energy transition are influenced by contextual factors, emphasizing the necessity for policies and strategies (measures) that are sensitive to the unique transition challenges faced by various European regions. Furthermore, the research reveals several issues and challenges across the mentioned case studies, suggesting opportunities for enhancing cooperation to advance the energy transition and obtain climate neutrality by 2050.

Some studies focused on countries or small regions whereas others focused on comparison between continents or significant regions (such as: Europe, Asia, America). The authors examined the roles of natural resources, financing RES, green energy and GDP in Nordic countries between 1990 and 2018 (Yang et al., 2023). The findings of this analysis (quantile regression) indicate that natural resources and GDP have a significantly positive impact on the ecological footprint, while financing RES and green energy are negatively related to the ecological footprint. This suggested that financing RES and green energy play a crucial role as solutions, while natural resources and GDP are drivers of environmental negative impact. Furthermore, an investigation was conducted in the context of the Nordic countries, focusing on biomass and its prospective utilization, as well as the exploration of alternative energy sources to meet heating needs in the region (Jåstad & Bolkesjø, 2023). The researchers engaged in modeling emissions and assessing the impact on land utilization resulting from biomass usage projections spanning from 2030 to 2050. The findings underscored the significance of biomass in heating systems within the Nordic countries, particularly through the year 2050 under optimal conditions. In scenarios with reduced biomass utilization, there would be a heightened reliance on fossil fuels and wind power by 2030, and by 2050, photovoltaic (PV) systems would also become more essential as an alternative energy source. Furthermore, diminished biomass usage would lead to an expansion in the land area required for the installation of wind and PV systems. Moreover, (Georgescu & Kinnunen, 2023) studied the determinants of Finland's carbon emissions for the period 2000–2020 and found that, in the long term, consumption of energy has a positive impact on CO_2 emissions, whereas urbanization and labor productivity have a negative impact.

The researchers found for Romania by means of an AutoRegressive Distributed Lag (ARDL) model that GHG have a long-run negative influence on GDP, while consumption-based RES has a long-run positive influence on GDP during 2000–2021 (Androniceanu et al., 2023). In Hatmanu et al. (2022), an analytical approach was proposed to investigate the connections between CO_2 emissions and their underlying factors in Bulgaria and Romania. They suggested that both Romania and Bulgaria are still on the journey toward achieving sustainable development. As a result, the findings from Hatmanu et al. (2022) may offer valuable insights and guidance for policymakers as they consider actions and policies aimed at fostering sustainable development in these countries. Other studies have also delved into the dynamics of the transition process from school to the labor market in Romania, Bulgaria, and Italy, with a comparative approach (Caroleo et al., 2022). These analyses take into consideration the level of urbanization within these countries. Through a series of comprehensive analyses, these studies have provided valuable insights into the Not in Education, Employment or Training (NEET) phenomenon and its determining factors in these regions. The findings from these investigations underscore the importance of tailoring support actions to the specific characteristics of NEET individuals. It is worth noting that the degree of urbanization has a notable influence on the NEET status in both Romania and Bulgaria. In contrast, Italy exhibits a distinct regional divide, with significant differences between the North and South regions.

Research (Destek et al., 2016) explored the interconnections among pollution, energy consumption, GDP, urbanization and trade within Central and Eastern European Countries (CEE) including Bulgaria, Hungary, Romania. It spanned the period from 1991 to 2011. The study's findings supported the EKC hypothesis for these countries. Furthermore, the study employed FMOLS and determined that a 1% increase in energy consumption led to a 1.09% increase in CO_2 emissions. By using both the Vector Error Correction (VEC) Model and Granger causality analysis, the researchers established bidirectional causal relationships. Specifically, they demonstrated causation between CO_2 emissions and GDP, as well as between energy consumption and GDP. The causal relationship between CO_2 emissions, GDP, available energy, and employment in the SEE countries was analyzed in Mitić et al. (2023) over the period from 1995 to 2019. The researchers employed a range of statistical techniques, including panel unit root tests, panel cointegration methods, and panel causality tests to conduct their analysis. Their findings unveiled several causal relationships.

The comparative analysis highlights the originality of our research, particularly in the context of comparing SEE and Nordic countries using the selected variables and extending the analysis up to the present date. This approach fills a gap in the existing body of research and contributes to a deeper understanding of the dynamics in these regions regarding urbanization, GDP, RES generation, and CO_2 emissions.

3. Input data

The input data was downloaded from the World Bank website[1]. GDP per capita, Renewable energy consumption (REN), EPREN, Fossil fuel energy consumption (FF), CO_2 emissions and URB. The data covers a period from 1990 to 2022, providing a comprehensive view over three decades. The period between 2020 and 2022 was marked by extraordinary circumstances, primarily due to the COVID-19 and the conflict in the Black Sea region. Despite the challenges and anomalies presented during these years, it is crucial to include them in our analysis. These years, being immediately preceding our current times, hold significant relevance as their aftermath and ongoing impacts are likely to shape the future trajectories of the two groups of countries under study. Regarding energy, the Nordic countries (Denmark, Sweden, Finland) exhibit a relatively low dependence on fossil fuels and imports, establishing a reputation for their high level of energy self-sufficiency. Conversely, SEE countries (Romania, Bulgaria, Hungary) exhibit a higher degree of dependency on fossil fuels, specifically natural gas and coal, in their energy mix. This heavy reliance on fossil fuels can give rise to concerns regarding energy security (Zlateva et al., 2020). The evolution of REN, FF and GDP over the last three decades for the two groups of countries is presented in Figure 1 and Figure 2. The trends are similar for the two groups of countries, Nordic countries having an early start in consuming from RES. Moreover, there are significant difference in the GDP levels. On average, the GDP level in Nordic countries is 5 times higher.

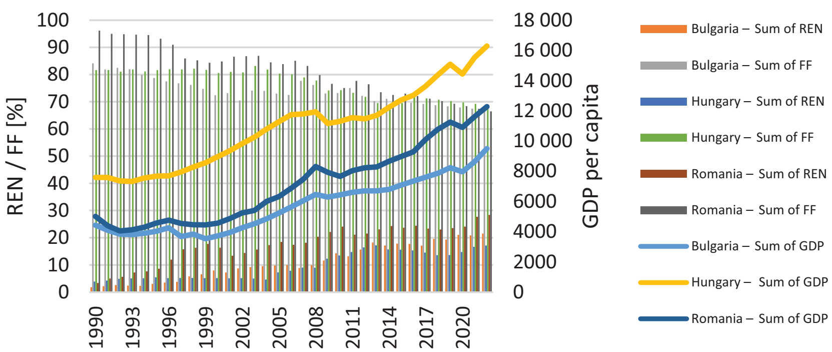

Figure 1. REN, FF and GDP long-run evolution for SEE countries

Nordic countries' urban areas provide high living standards, featuring well-developed infrastructure and public services (Nycander et al., 2020). In contrast, SEE countries face urban planning challenges that encompass transportation issues, pollution concerns, and urban sprawl. These countries tend to experience higher urban population concentrations, with a significant proportion of their inhabitants living in cities (Rowe et al., 2019). The evolution of urbanization level and CO_2 over the last three decades for the two groups of countries is presented in Figure 3 and Figure 4. For both groups of countries, CO_2 emissions have decreased (more abruptly for Nordic countries), while urbanization level tends to increase over time.

When it comes to CO_2 emissions, Nordic countries maintain relatively low per capita emissions compared to the global average (Scarlat et al., 2022; Xiao et al., 2022). These nations

[1] https://data.worldbank.org/

have also established ambitious climate goals, with Denmark, for instance, aiming to achieve carbon neutrality by 2050 (Drysdale et al., 2019; X. C. Wang et al., 2020). On the other hand, SEE countries (Romania, Bulgaria, Hungary) generally exhibit higher per capita CO_2 emissions compared to their Nordic counterparts. The evolution of EPREN and CO_2 over the last three decades for the two groups of countries is presented in Figure 5 and Figure 6. As expected, the generation from RES is much higher in the Nordic countries.

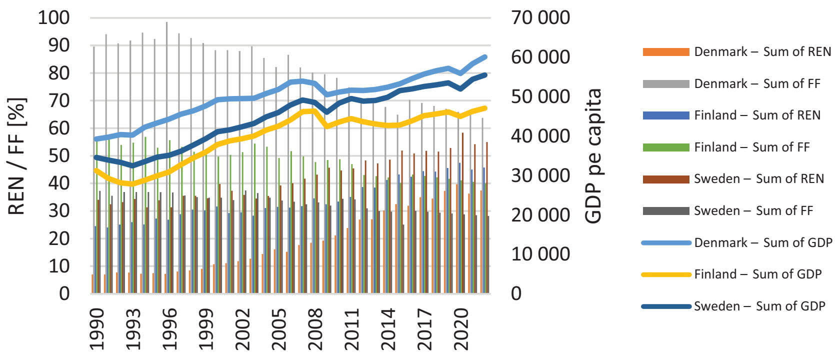

Figure 2. REN, FF and GDP long-run evolution for Nordic countries

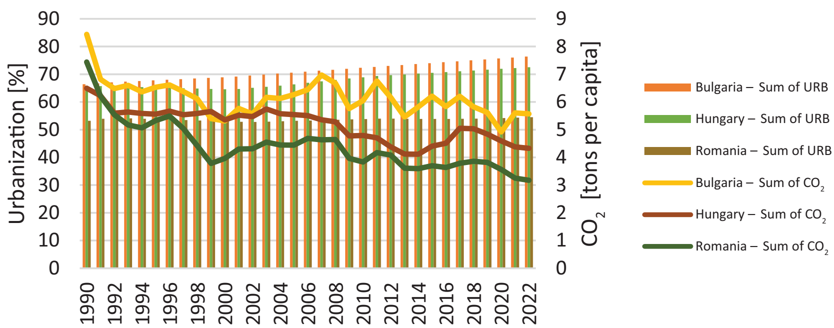

Figure 3. Urbanization and CO_2 long-run evolution for SEE countries

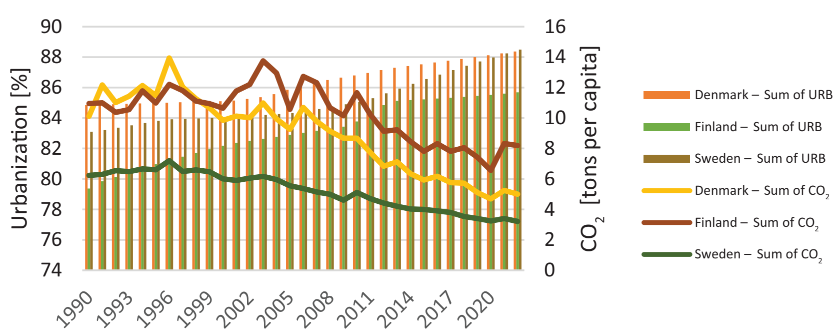

Figure 4. Urbanization and CO_2 long-run evolution for Nordic countries

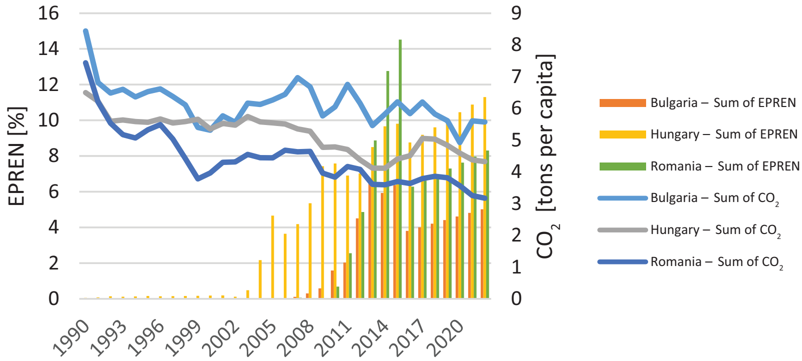

Figure 5. EPREN and CO_2 long-run evolution for SEE countries

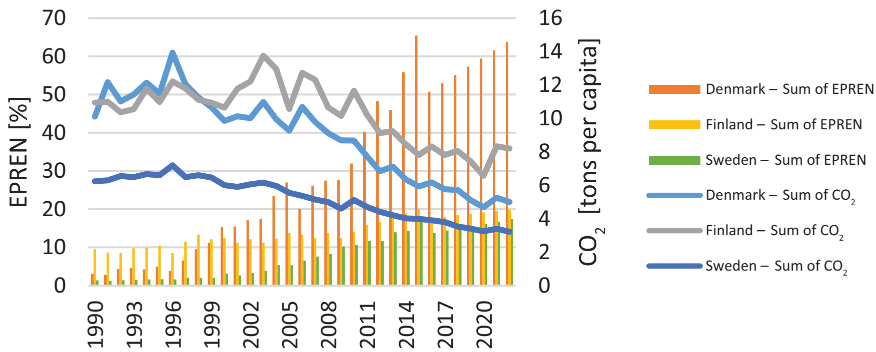

Figure 6. EPREN and CO_2 long-run evolution for Nordic countries

Nordic countries are known for their robust and diversified economies, often reflected in their high GDP per capita. In contrast, SEE countries like Romania, Bulgaria, and Hungary generally report significantly lower GDP per capita compared to their Nordic counterparts. Economic disparities are evident both within these countries and across the region (Ciucu-Durnoi et al., 2023). It is worth noting that over time, the population levels in SEE countries have exhibited a more abrupt decrease (especially in Romania and Bulgaria) (Parr, 2023), while they have been on the rise in the Nordic countries (see Figures 7 and 8).

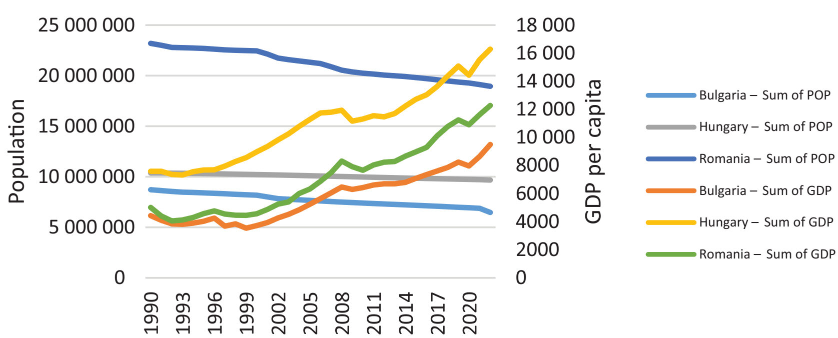

Figure 7. Population and GDP long-run evolution for SEE countries

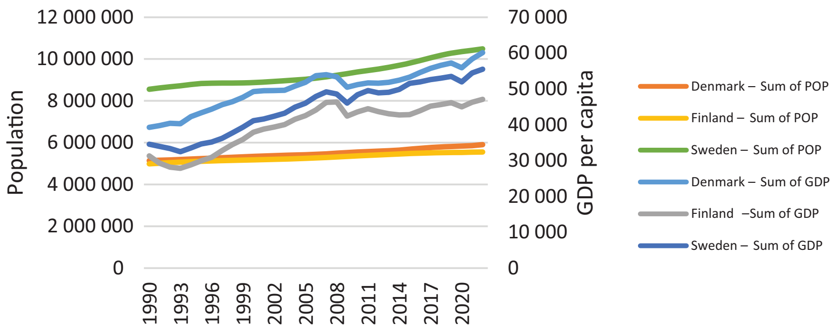

Figure 8. Population and GDP long-run evolution for Nordic countries

The disparities between Nordic and SEE European countries regarding CO_2 emissions, GDP, and various other aspects can be attributed to a complex interplay of historical, geographical, economic, and policy factors (Kolluru & Semenenko, 2021; Cota et al., 2023; Duarte et al., 2021).

4. Research methodology

In this section, we briefly describe each step of the econometrical analysis performed in this paper.

4.1. Panel unit root tests

We begin the econometric analysis by apply some first-generation unit root tests: Levin, Lin and Chu (2002) – (LLC) (Levin et al., 2002), Im, Pesaran and Shin (2003) – (IPS) (Im et al., 2003) and the Augmented Dickey-Fuller (ADF) test by Maddala and Wu (1999). The AR(1) process for panel data has the form as in Eq. (1):

$$y_{i,t} = \rho_i y_{i,t-1} + \delta_i X_{i,t} + \varepsilon_{i,t}. \quad (1)$$

In Eq. (1), i = 1, ..., N cross-sectional observations, t = 1, ..., T periods, $X_{i,t}$ represent the independent variables, $\varepsilon_{i,t}$ is the error term. ρ_i represent autoregressive coefficients. We say that y_i is weakly stationary if $|\rho_i| < 1$. If $|\rho_i| = 1$ then y_i has a unit root. The panel unit root tests used in this paper have two approaches: 1) LLC panel unit root test assumes common unit root processes, where $\rho_i = \rho$ is constant, $\forall i - 1, ..., N$; 2) the ADF and IPS panel unit root tests assume individual unit root processes, where ρ_i is different with respect to cross sections. Following Baltagi (2021), we briefly discuss the theoretical framework of the three panel unit root tests applied to our data panel.

4.2. Levin, Lin and Chu panel unit root test

The null hypothesis says that there is a unit root, while the alternative hypothesis says the time series is stationary. For each cross-section, the ADF specification is written as in Eq. (2):

$$\Delta y_{i,t} = \rho_i y_{i,t-1} + \sum_{L=1}^{p_i} \theta_{iL} \Delta y_{i,t-L} + \alpha_{m.i} d_{m,t} + \varepsilon_{i,t}. \quad (2)$$

Two regressions are performed: 1) $\Delta y_{i,t}$ on $\Delta y_{i,t-L}$ and $d_{m,t}$ such that the residuals $\hat{e}_{i,t}$ are obtained; 2) $y_{i,t-1}$ on $\Delta y_{i,t-L}$ and $d_{m,t}$ such that the residuals $\hat{v}_{i,t-1}$ are obtained. The residuals are standardized according to Eqs (3) and (4):

$$\tilde{e}_{i,t} = \frac{\hat{e}_{i,t}}{\hat{\sigma}_{\varepsilon_i}}; \quad (3)$$

$$\tilde{\nu}_{i,t} = \frac{\hat{\nu}_{i,t}}{\hat{\sigma}_{\varepsilon_i}}, \quad (4)$$

where $\hat{\sigma}_{\varepsilon_i}$ is the standard error of each ADF. The pooled OLS regression is performed:

$$\tilde{e}_{i,t} = \rho\tilde{\nu}_{i,t-1} + \hat{\varepsilon}_{i,t}. \quad (5)$$

The null hypothesis says that there is a unit root $(\rho = 0)$, while the alternative hypothesis says the time series is stationary. The disadvantage of the LLC test is that it is too restrictive, in the sense that the null hypothesis posits that all cross-sections have a unit root.

4.3. Im, Pesaran and Shin panel unit root test

IPS panel unit root test is less restrictive than LLC panel unit root test, since the coefficients may be heterogeneous. The null hypothesis says that all individuals have unit roots: H0: $\rho_i = 0, \forall i.$ The alternative hypothesis says that some individuals have unit roots: H1: $\rho_i < 0, i = 1,...,N;$ $\rho_i = 0, i = N_1 + 1,...,N.$ t_{ρ_i} represents the individual t-statistic associated with H0. $\bar{t}$ is the average of the individual t-statistics t_{ρ_i} : $\bar{t} = \frac{1}{N}\sum_{i=1}^{N} t_{\rho_i}.$ When dealing with small sample sizes, IPS test outperforms LLC test according to Monte Carlo simulations.

4.4. Fisher-type panel unit root tests

The Fisher-type tests incorporate p-values from unit root tests conducted on individual cross-sections. If G_i stands for the test statistic associated with the null hypothesis for cross-section i and $F(.)$ is the cumulative distribution function of the asymptotic distribution for $T \to \infty$, the p-value has the following expression: $p_i = F(G_i).$ By Maddala and Wu (1999) and Choi (2001), it results:

$$P = -2\sum_{i=1}^{N} \ln p_i. \quad (6)$$

An advantage of the test is its capability to deal with unbalanced panels. Additionally, it allows for varying lag lengths in the ADF test for each individual case. However, a limitation of the test is that p-values are obtained through Monte Carlo simulations.

4.5. Panel cointegration tests

To verify the existence of cointegration, Pedroni panel cointegration test is applied under the hypothesis of heterogeneous panels (Pedroni, 1999). Pedroni (1999) introduced two tests. The first test uses the within-dimension approach and deals with four statistics: panel v-statistics, panel rho-statistics, panel-PP statistics and panel-ADF statistics. The second test uses the between-dimension approach and comprises three statistics: group p-statistics, group

PP-statistics and group ADF-statistics. If the number of statistics with p-values less than a significance level is dominant, then one rejects the null hypothesis of no cointegration.

The second panel cointegration test that we used belongs to Kao (1999) and enforces homogeneity among the panel members. Pedroni and Kao tests are based on Engle-Granger (1987) two-step (residual-based) cointegration tests (Engle & Granger, 1987). Pedroni test has the advantage over Kao test that it incorporates heterogeneity across cross-sections.

4.6. Panel FMOLS and DOLS estimators

When cointegration exists, the cointegration parameters are estimated by means of FMOLS by Pedroni (2001, 2000) and the DOLS by Pedroni (2001, 2004). By Monte Carlo simulations, Kao and Chiang (2000) compared the performances of OLS, FMOLS and DOLS, concluding that DOLS is the best estimator for heterogeneous panels (Kao & Chiang, 2000). Mark and Sul (1999) compare the weighted and unweighted panel DOLS estimators and find that the unweighted panel DOLS estimates better then weighted panel DOLS. Lee (2007) asserts that alternative methods, including FMOLS and DOLS are employed because the OLS procedure is known to yield invalid standard errors due to second-order asymptotic bias. According to Narayan and Smith (2007), the DOLS method is asserted to yield reliable coefficient estimates for explanatory variables, especially in small sample sizes, as it takes into account potential issues related to endogeneity and serial correlation (Narayan & Smyth, 2007). The FMOLS model consists of Eqs (7) and (8):

$$y_{it} = \alpha_i + \beta_i X_{it} + e_{it}; \tag{7}$$

$$X_{it} = X_{it-1} + \varepsilon_{it}. \tag{8}$$

The panel FMOLS estimator has the expression as in Eq. (9):

$$\hat{\beta}^*_{FM} = \frac{1}{N}\sum_{i=1}^{N} \hat{\beta}^*_{FM_i}. \tag{9}$$

In Eq. (9), $\hat{\beta}^*_{FM_i}$ denotes the FMOLS estimator computed for the i-th cross section. The t-statistic associated with panel FMOLS estimator is:

$$t_{\hat{\beta}^* FM} = \frac{1}{N}\sum_{i=1}^{N} t_{\hat{\beta}^*_{FM,i}}. \tag{10}$$

The panel DOLS model has the form as in Eq. (11):

$$y_{it} = \alpha_i + \beta_i X_{it} + \sum_{K=-P_i}^{P_i} \gamma_{ik} \Delta X_{it-k} + \varepsilon_{it}. \tag{11}$$

In Eq. (11), P_i and $-P_i$ are lagged and lead values. The DOLS estimator has the form:

$$\hat{\beta}^*_D = \frac{1}{N}\sum_{i=1}^{N} \hat{\beta}^*_{D_i}. \tag{12}$$

The t-statistic associated with panel DOLS estimator is given in Eq. (13):

$$t_{\hat{\beta}^* D} = \frac{1}{N}\sum_{i=1}^{N} t_{\hat{\beta}^*_{D,i}}. \tag{13}$$

4.7. Dumitrescu-Hurlin panel causality test

In 2012, Dumitrescu and Hurlin proposed a linear heterogenous model as a Granger causality test for panel data (Dumitrescu & Hurlin, 2012), as follows:

$$y_{i,t} = \alpha_i + \sum_{k=1}^{K} \gamma_i^{(k)} y_{i,t-k} + \sum_{k=1}^{K} \beta_i^{(k)} x_{i,t-k} + \varepsilon_{i,t}. \quad (14)$$

In Eq. (14), $i = 1,\dots,N$, $\beta_i = \left(\beta_i^{(1)},\dots,\beta_i^{(K)}\right)$, α_i is the constant, $\gamma_i^{(k)}$ is the autoregressive parameter, $\beta_i^{(k)}$ is the regression coefficient slope. K is the lag order, constant for all cross sections. $\gamma_i^{(k)}$ and $\beta_i^{(k)}$ differ for the cross-sections of the panel. N is the dimension of the panel. The null hypothesis is provided in Eq. (15):

$$\text{H0: } \beta_i = 0,\ i = 1,\dots,N. \quad (15)$$

The null hypothesis posits that there is no causal relationship present among any of the cross-sections within the panel. Eq. (15) is called the Homogeneous Non-Causality hypothesis (HNC). The alternative hypothesis is: H1: $\begin{cases} \beta_i = 0,\ \forall i = 1,\dots,N_1 \\ \beta_i \neq 0,\ \forall i = N_1+1,\dots,N \end{cases}$. If $N_1 = N$, we are in the case of H0 of no causality (HNC). If $N_1 = 0$, there is causality for all cross sections; in this case, we have Homogeneous Causality Hypothesis (HCH). If $N_1 > 0$, then we have a heterogeneous causality.

To assess the null hypothesis of no causality, Dumitrescu and Hurlin (2012) proposed employing the average of individual Wald statistic corresponding to H0 (Dumitrescu & Hurlin, 2012). The average Wald statistic has the form as in Eq. (16):

$$W_{N,T} = \frac{1}{N} \sum_{i=1}^{N} W_{i,T}, \quad (16)$$

where $W_{i,T}$ is the Wald statistic for the cross-section i and the null hypothesis H0: $\beta_i = 0$, i = 1, ..., N.

For small samples, $W_{i,T}$ does not follow the chi-square distribution. Dumitrescu and Hurlin (2012) pointed out other two statistics which follow a normal distribution: the asymptotic standardized statistic Z_N and the approximated standardized statistic $\tilde{Z}_N$. Z_N has the form as in Eq. (17), whereas $\tilde{Z}_N$ has the form as in Eq. (18).

$$Z_N = \frac{\sqrt{N}[W_{N,T} - N^{-1}\sum_{i=1}^{N} E\left(W_{i,T}\right)]}{\sqrt{N^{-1}\sum_{i=1}^{N} Var\left(W_{i,T}\right)}} \in N(0,1); \quad (17)$$

$$\tilde{Z}_N = \frac{\sqrt{N}\left[W_{N,T} - E\left(W_{i,T}\right)\right]}{\sqrt{Var\left(W_{i,T}\right)}} \in N(0,1). \quad (18)$$

If Z_N or $\tilde{Z}_N$ exceeds the critical value for a given threshold of significance, then HNC is rejected. In this case, for at least one cross-section causality exists. If one accepts HNC, then for all N cross-sections, there is no pairwise causality and the method stops (Ndoricimpa, 2014).

5. Empirical results and discussion

This case study uses the following functional form as in Eq. (19):

$$CO_2 = f\left(GDP, EPREN, URB\right). \quad (19)$$

The variables were chosen based on their significance level, considering the reliable theoretical or empirical justification that may lead to a good fitting and interpretability. We have converted all the variables into their natural logarithms to mitigate the presence of heteroscedasticity (Rahman et al., 2021). Additionally, the estimated coefficients of these variables will be interpreted as elasticities. Eq. (20) is expressed as a long-run relationship among these variables:

$$CO_{2it} = \alpha + \beta_1 GDP_{it} + \beta_2 EPREN_{it} + \beta_3 URB_{it} + \varepsilon_{it}, \quad (20)$$

β_i, $i = 1,\ldots,3$ are the long-run elasticities of CO_2 with respect to GDP, EPREN and URB. i denotes the country and t denotes the time.

We intend to study the impact of EPREN, URB and GDP on CO_2 for two groups of EU countries: Romania, Hungary and Bulgaria on one hand, and Finland, Sweden and Denmark on the other hand. This study is based on a panel data approach. According to Hsiao (2007), there are some advantages that include enhanced parameter stability, control of unobservable factors, minimized estimation bias, modelling of individual and group behaviour and comprehensive information coverage. Thus, panel data analysis offers a powerful tool to explore complex phenomena, control for unobservable factors and offer more reliable estimates.

The descriptive statistics of the dataset for SEE and Nordic countries are shown in Tables 1 and 2.

Table 1. Basic statistics for SEE countries

Variable	Count	Mean	Std Dev	Min	25th Percentile	Median	75th Percentile	Max
GDP	99	7876.14	3187.13	3540.32	4863.52	7589.90	10180.81	16288.99
EPREN	99	3.07	3.88	0.00	0.004566	0.18	6.33	14.52
CO2	99	5.24	1.01	3.18	4.43	5.46	5.83	8.44
URB	99	64.17%	7.95%	52.78%	53.97%	66.38%	70.54%	76.36%

The data covers a period from 1990 to 2022, providing a comprehensive view over three decades. GDP shows significant variability (std dev: 3187.13) with a range from 3540.32 to 16288.99, indicating diverse economic conditions across different years and countries. EPREN, indicating electricity production from renewable sources (excluding hydroelectric), varies widely (std dev: 3.88) and has increased over time, as evidenced by the median being much lower than the mean. CO_2 emissions also show variability (std dev: 1.01) and a range from 3.18 to 8.44, suggesting differences in environmental impact across different countries and years. URB ranges from 52.78% to 76.36%, with a standard deviation of 7.95%, reflecting different levels of urbanization.

The mean GDP is significantly higher in the Nordic dataset (44,757.45) compared to the SEE countries, with a wide range of values indicating economic diversity among these countries. EPREN (excluding hydroelectric) shows a higher mean (17.00) in Nordic countries

Table 2. Basic statistics for Nordic countries

Variable	Count	Mean	Std Dev	Min	25th Percentile	Median	75th Percentile	Max
GDP	99	44,757.45	7,698.60	27,833.70	39,891.96	45,570.08	50,982.73	60,113.09
EPREN	99	17.00	15.77	1.27	7.07	13.33	18.59	65.44
CO2	99	8.16	2.90	3.21	5.92	8.05	10.68	13.94
URB	99	84.83%	2.07%	79.37%	83.72%	85.01%	86.17%	88.49%

compared to SEE countries, reflecting a potentially stronger emphasis on RES in the Nordic region. CO_2 emissions have a higher mean (8.16) and standard deviation (2.90) in the Nordic dataset, suggesting larger variability and generally higher emissions compared to the SEE countries. URB is significantly higher on average (84.83%) in Nordic countries, indicating a more urbanized population compared to SEE countries. These statistics suggest that Nordic countries, on average, have higher GDP, greater EPREN, higher CO_2 emissions and a more urbanized population compared to the SEE countries.

In order to check the order of integration of selected variables, we used various panel unit root tests: Levin et al. (2002), Im et al. (2003) and ADF-Fisher Chi-square (Maddala & Wu, 1999) briefly described in Section 4. The panel unit root tests results for the group of SEE countries and Nordic countries are reported in Tables 3 and 4. All variables are stationary at first difference.

Table 3. Panel Unit Root tests results – group of SEE countries

At levels				
	CO_2	GDP	EPREN	URB
Unit root (Common Unit Root Process)				
Levin, Lin & Chu	–0.71 (0.232)	1.24 (0.851)	–1.53 (0.062)*	1.35 (0.912)
Unit root (Individual Unit Root Process)				
Im, Pesaran & Shin	–0.81 (0.208)	3.15 (0.999)	–0.96 (0.167)	1.86 (0.968)
ADF-Fisher Chi-square	7.22 (0.300)	0.26 (0.999)	9.75 (0.135)	2.52 (0.866)
At first difference				
Unit root (Common Unit Root Process)				
Levin, Lin & Chu	–4.59 (0.000)***	–3.92 (0.000)***	–3.12 (0.000)***	–1.255 (0.10)*
Unit root (Individual Unit Root Process)				
Im, Pesaran & Shin	–5.50 (0.000)***	–3.91 (0.000)***	–2.95 (0.001)***	–2.05 (0.020)**
ADF-Fisher Chi-square	38.86 (0.000)***	26.81 (0.000)***	20.82 (0.002)***	14.41 (0.025)**

Note: *, **, *** denote significant at 10 %, 5% and 1% level, respectively.

Table 4. Panel Unit Root tests results – group of Nordic countries

At levels				
	CO_2	GDP	EPREN	URB
Unit root (Common Unit Root Process)				
Levin, Lin & Chu	1.70 (0.959)	–0.55 (0.290)	1.35 (0.912)	–0.04 (0.483)
Unit root (Individual Unit Root Process)				
Im, Pesaran & Shin	2.59 (0.995)	1.29 (0.903)	1.10 (0.865)	1.85 (0.968)
ADF-Fisher Chi-square	1.13 (0.579)	1.65 (0.948)	5.08 (0.532)	0.99 (0.985)
At first difference				
Unit root (Common Unit Root Process)				
Levin, Lin & Chu	–9.05 (0.000)***	–6.05 (0.000)***	–3.59 (0.000)***	–1.56 (0.058)*
Unit root (Individual Unit Root Process)				
Im, Pesaran & Shin	–10.71 (0.000)***	–5.67 (0.000)***	–5.20 (0.000)***	–1.40 (0.080)*
ADF-Fisher Chi-square	79.59 (0.000)***	39.37 (0.000)***	34.16 (0.000)***	11.30 (0.079)*

Note: *, **, *** denote significant at 10 %, 5% and 1% level, respectively.

Further, we apply Pedroni (1999) and Kao (1999) panel co-integration tests. The first type of tests contains four statistics: panel v-statistics, panel rho-statistics, panel PP-statistics and panel ADF-statistics. The second type of tests contains three statistics: group rho-statistics, group PP-statistics and group ADF-statistics (Tables 5 and 6). In the Pedroni cointegration test, the null hypothesis assumes there is no cointegration among variables, while the alternative hypothesis assumes the existence of cointegration. Out of 11 outcomes (8 for within-dimension test and 3 for between-dimension test), 6 are significant (the corresponding probabilities are less than 10%) both for the SEE and the Nordic countries groups. Therefore, one can reject the null hypothesis, accepting the alternative hypothesis that the five variables are cointegrated at 10% significance level. Then, we applied Kao homogeneous panel cointegration test. Since the p-value of the ADF statistics is less than 0.05, one accepts the alternative hypothesis and conclude that the four variables are cointegrated.

Table 5. Pedroni Cointegration Tests results – group of SEE countries

Common AR Coefficients Within-Dimension		
	Statistics (Prob.)	Weighted Statistics (Prob.)
v-statistics	0.94 (0.173)	–0.82 (0.794)
rho-statistics	0.53 (0.705)	0.94 (0.827)
PP-statistics	–1.35 (0.088)*	–2.23(0.082)*
ADF-statistics	–1.95(0.025)**	–2.56(0.005)***

End of Table 5

Individual AR Coefficients Between-Dimension		
rho-statistics	1.18 (0.881)	
PP-statistics	–2.39 (0.008)***	
ADF-statistics	–1.75 (0.039)**	
Kao's Cointegration Test		
	t-statistics	Probability
ADF	–3.79	0.000***

Note: *, **, *** denote significant at 10 %, 5% and 1% level, respectively.

Table 6. Pedroni Cointegration Tests results – group of Nordic countries

Common AR Coefficients Within-Dimension		
	Statistics (Prob.)	Weighted Statistics (Prob.)
v-statistics	0.41 (0.661)	–2.58 (0.602)
rho-statistics	0.20 (0.419)	–0.13 (0.448)
PP-statistics	2.15 (0.015)**	–2.51 (0.006)***
ADF-statistics	–2.68 (0.003)***	–3.10 (0.000)***
Individual AR Coefficients Between-Dimension		
rho-statistics	0.59 (0.723)	
PP-statistics	–3.06 (0.001)***	
ADF-statistics	3.31 (0.000)***	
Kao's Cointegration Test		
	t-statistics	Probability
ADF	–3.6	0.000***

Note: *, **, *** denote significant at 10 %, 5% and 1% level, respectively.

The FMOLS and DOLS results are presented in Tables 7 and 8. From Table 7, one can see that for SEE countries, in the FMOLS model, URB and GDP do not exert a statistical significance on CO_2, while in the DOLS model, all predictors have a significant impact on CO_2. The DOLS model for SEE countries shows that EPREN and URB have a negative impact on CO_2, while GDP impacts positively CO_2. 1% increase in GDP leads to 0.51% increase in CO_2, validating hypothesis HY1. As economies grow, they often rely heavily on carbon-intensive activities, consuming more energy and resulting in more CO_2 emissions. Hypothesis HY1 from RQ1 is also confirmed in other studies, such as Onofrei et al. (2022), Mitić et al. (2023) or invalidated by Kasperowicz (2015), Dogan et al. (2015). Furthermore, one can see that GDP changes the signs between FMOLS and DOLS in Table 6, but the negative impact on GDP on CO_2 is not statistically significant, therefore the interpretation is not necessary. Moreover, 1% increase in EPREN causes a 0.062% decrease in CO_2, confirming hypothesis HY2 from RQ1. 1% increase in URB causes a 2.71% decrease in CO_2, validating hypothesis HY3 from RQ1.

One can see from Tables 7 and 8 that the DOLS for SEE countries and both the FMOLS and DOLS for Nordic countries validate the three hypotheses. The difference between the two groups of countries is that for the Nordic countries, the estimated coefficients are higher in absolute value. The differential impact of GDP, EPREN and URB on CO_2 emissions between the two groups of countries can be attributed to a combination of geographical factors, economic development, urban planning and international collaboration. Nordic countries have the advantage of abundant access to RES, facilitating the generation of electricity from RES and releasing less CO_2. Higher income levels of the Nordic countries facilitate investments in RES and technologies. The Nordics have a tradition of urban planning, with an emphasis on green spaces and cycling. The accentuated urban-rural divide in SEE countries makes them more dependable on conventional energy sources. The Nordics have close collaborations on environmental strategies and a stronger environmental consciousness than the SEE countries.

Table 7. FMOLS and DOLS results – group of SEE countries

	Panel FMOLS		
	Coef.	t-stat.	Prob.
GDP	–0.146	–1.70	0.902
EPREN	–0.018	–2.38	0.020**
URB	–0.779	–1.61	0.110
	Panel DOLS		
	Coef.	t-stat.	Prob.
GDP	0.516	2.27	0.029**
EPREN	–0.062	–2.71	0.010**
URB	–2.716	–3.75	0.000***

Note: *, **, *** significant at 10 %, 5% and 1% level, respectively.

Table 8. FMOLS and DOLS results – group of Nordic countries

	Panel FMOLS		
	Coef.	t-stat.	Prob.
GDP	1.093	5.46	0.000***
EPREN	–0.256	–8.91	0.000***
URB	–10.909	–7.30	0.000***
	Panel DOLS		
	Coef.	t-stat.	Prob.
GDP	1.284	6.39	0.000***
EPREN	–0.329	–9.61	0.000***
URB	–11.025	–6.42	0.000***

Note: *, **, *** significant at 10 %, 5% and 1% level, respectively.

After establishing the cointegration among the variables and reporting the long-term estimates, a Granger causality test is applied. This help uncover the causal relations between the four variables pairwise, by applying the Dumitrescu-Hurlin causality test (Dumitrescu and Hurlin, 2012). Unlike the standard Granger causality approach, the Dumitrescu-Hurlin causality test assume that all coefficients may vary across the cross sections. This test is suitable for relatively short spans of data, even when cross-sectional dependence exists (Dogan et al., 2015).

The null hypothesis H0 in Tables 9 and 10 asserts that variable X does not Granger-cause variable Y. If the p-value is less than 0.05, than we reject H0 and we have unidirectional causality from X to Y. Tables 9 and 10 provide the answer to RQ2.

Table 9. Dumitrescu-Hurlin Panel Causality Test – group of SEE countries

Null hypothesis (H0)	Z-bar stat	p-value	Causality
GDP does not Granger-cause CO2	1.78	0.073*	GDP→CO2
CO2 does not Granger-cause GDP	3.70	0.000***	CO2→GDP
EPREN does not Granger-cause CO2	2.90	0.003***	EPREN→CO2
CO2 does not Granger-cause EPREN	–1.05	0.291	–
URB does not Granger-cause CO2	2.53	0.001***	URB→CO2
CO2 does not Granger-cause URB	4.72	2E–06***	CO2→URB
EPREN does not Granger-cause GDP	0.69	0.418	–
GDP does not Granger-cause EPREN	1.61	0.105	–
URB does not Granger-cause GDP	2.64	0.008***	URB→GDP
GDP does not Granger-cause URB	19.25	0.000***	GDP→URB
URB does not Granger-cause EPREN	14.82	0.000***	URB→EPREN
EPREN does not Granger-cause URB	1.14	0.251	–

Note: *, **, *** denote significant at 10 %, 5% and 1% level, respectively.

URB can influence EPREN by the increased industrialization and the development of infrastructure, including energy infrastructure. RES technologies are integrated in urban areas, making RES production more efficient.

Table 10. Dumitrescu-Hurlin Panel Causality Test – group of Nordic countries

Null hypothesis (H0)	Z-bar stat	p-value	Causality
GDP does not Granger-cause CO_2	3.38	0.000***	GDP→CO2
CO2 does not Granger-cause GDP	0.06	0.947	–
EPREN does not Granger-cause CO2	2.06	0.039**	EPREN → CO2
CO2 does not Granger-cause EPREN	0.50	0.615	–
URB does not Granger-cause CO2	3.40	0.000***	URB→CO2
CO2 does not Granger-cause URB	2.47	0.013**	CO2→URB
EPREN does not Granger-cause GDP	–0.36	0.716	–
GDP does not Granger-cause EPREN	1.51	0.128	–
URB does not Granger-cause GDP	0.68	0.49	–
GDP does not Granger-cause URB	1.72	0.084*	GDP→URB
URB does not Granger-cause EPREN	4.85	1.E-06***	URB→EPREN
EPREN does not Granger-cause URB	3.71	0.000***	EPREN→URB

Note: *, **, *** denote significant at 10 %, 5% and 1% level, respectively.

In case of Nordic countries, the bidirectional causality URB↔CO_2 can be explained similar to the East-European countries. One can see in the Nordic case the presence of the bidirectional causality EPREN↔URB. As the Nordic countries have invested in renewable energy production, they experienced increased economic growth. In the urban regions more economic opportunities appeared, industries set up their operations to take advantage of renewable energy resources. The quality of life has improved, driving urbanization. One also remarks that GDP→URB; some potential explanations would be the economic development which drives urbanization, infrastructure investment, industrialization and job opportunities, rural-to-urban migration, consumer preferences and urban lifestyle.

6. Conclusions

This comparative analysis highlights the originality and significance of our research endeavor. By directly comparing SEE and Nordic countries while employing our unique combination of variables and extending the study's timeframe, we aim to contribute valuable insights to the existing body of research. Ultimately, our research seeks to enhance our understanding of the complex dynamics related to urbanization, EPREN, GDP and CO_2 emissions within SEE and Nordic countries.

By identifying how these variables interact differently in Nordic versus SEE countries, this paper fills an important gap by informing more region-specific policy recommendations. Understanding these dynamics can help policymakers in both regions develop more tailored strategies to manage CO_2 emissions, promote sustainable economic growth and encourage the adoption of renewable energy sources.

Variability in short-term dynamics due to heterogeneity can lead to significant fluctuations in estimations when using single equations cointegration vector models. As a consequence, these estimations can be highly responsive to both the specific period of the data and the individuals under study, introducing fragility in small samples. This sensitivity can arise despite the overall robustness of these estimators. In such scenarios, panel FMOLS and DOLS offer a more reliable option for obtaining precise estimates. For the two regions, the estimated long-term coefficients showed similar results. One remarks that the chosen model for the SEE countries is DOLS, while for the Nordic countries both FMOLS and DOLS lead to results of similar impacts and signs.

EPREN and URB negatively influence CO_2, while GDP positively impact CO_2, validating the three hypotheses asserted in RQ1. Summing up, with respect to RQ2, the bidirectional causalities URB↔GDP, URB↔CO2 and the unidirectional causalities EPREN→CO2, GDP→CO2, URB→EPREN for the SEE countries were obtained; whereas the bidirectional URB↔EPREN, URB↔CO2 and the unidirectional causalities EPREN→CO2, GDP→CO2 for the Nordic countries were obtained.

The main limitation of our approach is that we consider three countries on each group, although in the SEE countries, more countries could be included. Additionally, in the Nordic group, variables for Norway can be included. We plan to continue our research by including more countries in the analysis.

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Author contributions

IAG, SVO and AB conceived the study and were responsible for the design and development of the data analysis. IAG, SVO and AB were responsible for data collection and analysis. IAG, SVO and AB were responsible for data interpretation. SVO wrote the first draft of the article.

Conflict of interest

The authors have no competing interests to declare that are relevant to the content of this article.

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