Center for
Economic Theories and Policies
Sofia University St. Kliment Ohridski
Faculty of Economics and Business Administration

ISSN: 2367-7082

Bulgarian Economic Papers

Governance, Clean Energy, and FDI: Pathways to Sustainability in CEE

Mihaela Simionescu
Monica Răileanu Szeles
Beata Gavurova
Urszula Mentel

BEP 04-2026
Publication: September 2026

Governance, Clean Energy, and FDI: Pathways to Sustainability in CEE

Mihaela Simionescu
Faculty of Business and Administration, University of Bucharest, Bucharest, Romania
Institute for Economic Forecasting, Bucharest, Romania
E-mail: mihaela.simionescu@faa.unibuc.ro, mihaela.simionescu@ipe.ro

Monica Răileanu Szeles
Faculty of Economic Sciences and Business Administration, Transilvania University of Brasov
Institute for Economic Forecasting, Bucharest, Romania
E-mail: monica.szeles@unitbv.ro

Beata Gavurova
Technical University of Košice
Faculty of Mining, Ecology, Process Control and Geotechnologies
e-mail: beata.gavurova@tuke.sk

Urszula Mentel
Department of Projects Management and Security Policy
Faculty of Management
Rzeszow University of Technology
e-mail: u.mentel@prz.edu.pl

Abstract. In light of the European Green Deal, contemporary Environmental Kuznets Curve (EKC) literature emphasizes non-income mechanisms for mitigating environmental degradation. In particular, the decarbonization potential of renewable energy relies heavily on institutional frameworks that facilitate or impede green initiatives. This study examines the Renewable Kuznets Curve across 10 Central and Eastern European (CEE) economies from 2006 to 2025. Alongside standard economic controls- economic freedom, foreign direct investment, private sector domestic credit, and labor productivity- the empirical framework incorporates institutional metrics from the Worldwide Governance Indicators alongside language-specific Google Trends data on corruption-related search volume. Employing Panel Dynamic OLS (PDOLS) and Pooled Mean Group (PMG-ARDL) estimation techniques, the findings reveal that government effectiveness curbs emissions across both short- and long-term horizons, whereas rule of law and corruption control yield substantial long-term ecological benefits. Furthermore, search-based corruption queries serve as a viable real-time proxy for institutional performance, offering practical value for environmental nowcasting.

Key-words: renewable Kuznets curve, Google Trends, pollution, corruption

JEL codes: C33, Q28, Q53, Q56

Highlights

- Worldwide Governance Indicators have significant impact on pollution
- Government effectivesness reduces GHG emissions in the short and long-run
- Google searches on corruption improve the pollution nowcasts

Introduction

Fully engaged on the road to become the world's first climate-neutral continent by 2050, the EU has set up an ambitious set of measures designed to facilitate the accomplishment of the climate action initiatives under the European Green Deal, as part of the Sustainable Development Goals. The decrease of net greenhouse gas emissions by at least 55% by 2030 and the complete climate neutrality by 2050 will result into a zero-pollution environment and a new clean, circular economy. However, many reinforcing areas for action at all policy levels are needed to facilitate the achievement of the economic, social and environmental objectives of the European Green Deal, since only launching and implementing a set of initiatives might not be enough. A deep transformation of the EU economy to a climate-neutral and circular economy requests the understanding of the specific mechanisms and processes which are at the core of the economy-environment relationship.

Recent decades have witnessed an increasing interest for environmental studies, with a focus on the Environmental Kuznets Curve (EKC) and the dynamic relationship between economic growth and environmental quality, under the influence of various predictors and covariates. The European Green Deal and the EU's strategic goal to become the world's first "climate-neutral block" by 2050 have urged the emergence of EKC research studies, slightly moving the analysis and discussion from the area of EKC hypothesis and the macroeconomic determinants to the role of institutional quality and its implications on EKC in the new challenging context. The quality of governance, in particular the environment governance, has become a key-issue in the successfully achievement of the Green Deal objectives.

The topic presents interest for scientific community that has to propose the better policies to improve quality of governance in order to achieve sustainable development in the light of the 2030 Agenda. By ensuring the quality of governance, the social and economic development are supported through well-being, social equity, health, quality education, better and more jobs, inclusive economic growth, innovation. Moreover, environmental policies and strategies could be successful implemented under high quality governance. In this context, the efficiency of the institutions is promoted by the 2030 Agenda for Sustainable Development as a condition for achieving sustainable development goals.

The European Green Deal can be seen as an unprecedented opportunity to modernize the European economy and to ensure long-term sustainable development, emerging when the rapid economic development and accelerated economic growth rates over the past decades have

increased the environmental degradation in both developed and emerging economies. The U-shaped relationship between ecosystem degradation and income has extensively been examined in empirical studies, with various results and model specifications. Overall, they provide a solid basis for the necessity to make a change and to foster green growth and the climate-friendly prosperity. Despite the mixed results and findings, there is a consensus about the insufficiency of economic growth, in the absence of effective environmental policies and governance, to preserve the natural ecosystems (Agras and Chapman, 1999; Kahuthu, 2006). As economic growth and climate neutrality are in the present supreme goals of all EU countries, restructuring and refining policy measures accelerating economic growth and economic development on the challenging path of reaching "net-zero greenhouse gas emissions" are strongly required.

Our paper is intended to add new empirical evidence over the existing strand of literature, by underlying the impact of the quality of governance on sustainable development from environmental point of view. Therefore, the impact of quality of governance and various economic variables on pollution is analyzed from a different perspective. Beside the worldwide governance indicators provided by the World Bank, we use the Google Trends index associated to the keyword *corruption* in each country of our analysis, as a proxy for the quality of governance. This new approach introduces the use of microdata as an alternative to macroeconomic data reflecting the quality of governance. This is the first study using Google searches to assess the governance and to explain the GHG emissions. The COVID-19 pandemic accelerated the recent tendency to combine the official statistics with Internet data. The Google Trends has been used to collect data to reflect various aspects of social life, but the quality of governance was never assessed. The social issues targeted by Google data refer to unemployment (Simionescu, 2020), well-being (Brodeur et al., 2021), COVID-19 pandemic (Mavragani and Gkillas, 2020), psychological moods, tourism flows, consumer behaviour and various behaviour patterns in financial markets (Brodeur et al., 2020).

This topic is actual and supported by a) policy-makers, b) economists and c) the EU citizens for post-pandemic period.

a) "The quality of public institution has a major impact on social and economic development at regional level" (EU Parliament Research Service, 2018). The United Nations Environment Programme (UNEP) mission is to support environmental governance and laws in order to ensure "a health planet and healthy people".

b) In her presentation for Frontiers Forum Speaker Series ("Good economics for harder times"), Esther Duflo that was awarded the Nobel Prize in Economic Sciences in 2019 identified three opportunities for the post-pandemic period that are in line with our research topic: more support to population by "breaking down the usual political impasse", "stepping up the environmental action and renewal the international cooperation".

c) As international cooperation is vital to surpass the actual issues, Conference on the Future of Europe was built as a citizen-led series of debates and discussions that will enable people from across Europe to share their ideas and help shape their common future.

There are sections in the conference assigned to climate change and environment, health, education and stronger economy, social justice, jobs, values and rights, rule of law and security, European democracy. The aim of the debates on these topics is to provide solutions to ensure the green transition by reducing pollution and keeping a good quality economic and social environment. The webinar called "Social Economy Solutions towards Zero Pollution" in the Future of Europe conference provides solutions for this green transition.

The EU citizens consider compulsory the respect of rule of law within the European community. Measures to diminish public corruptions are required by more citizens gathering initiatives from fines to higher transparency to economic actions. It seems that corruption and rule of law are the most significant issues identified by the EU citizens in the Conference on the Future of Europe and our proposed solutions could reach their expectations.

Therefore, we can conclude that the importance of our research is supported by policy-makers, academic and scientific environment and society represented by the voice of the EU citizens.

The paper is structured in fifth sections, of which the first is Introduction, the second is the Literature review, the third introduces the methods and data, the fourth presents the results and discussion, and the last one concludes and formulates policy recommendations.

Literature review

Green economy can refer to principles, topics, policies or sectors. There are more definitions of green economy, but a generally agreed one does not exist yet. A critical analysis of green economy concept will be made starting from the definitions in literature. Among the different definitions of the green economy (Loiseau et al. 2016), the mostly one used is that of UNEP (2011)

as it highlights improvement in social equity and well-being in the context of less environmental risks and ecological scarcities. Starting from this definition, we will propose a definition that links green economy with governance: green economy promotes economic growth that ensures functional ecosystems under governance that supports sustainable development. The green economy is measured using indicators in three sustainability dimensions (economic, ecological and social dimensions). Each of the indicators fulfils one of the green economy paradigms: social equity, ecosystem resilience and resource efficiency. There are many classifications of indicators used to describe green economy, some of them being aggregated in a green economy index (Timonen et al., 2021). However, these indicators could be improved by considering sub-components that are correlated with quality of governance and supports our definition for green economy. The economic complexity plays a major role in environmental quality by providing new solutions to climate challenges (Shahzad et al., 2021). Other factors like urban agglomerations might affect the relationship between pollution and economic development (Akram et al., 2020).

The EKC hypothesis, formulated by Grossman and Krueger (1991), states the U-shaped relationship between economic growth and environmental degradation, resulting from the country's moving across different stages of economic development. Many critics have been formulated against the EKC hypothesis, mostly advancing econometric weaknesses (Perman & Stern, 2003; Stern, 2004), but despite them, numerous subsequent studies examined the hypothesis validity, under different econometric models, data and timespans. The results are mixed, with empirical findings confirming either the EKC validation (e.g. Apergis and Ozturk, 2015; Beak and Kim, 2013; Tamazian and Rao, 2010), or its invalidation (e.g. Kang et al., 2016; Pal and Mitra, 2017). It has been shown that the relationship between economic growth and environmental quality could take various forms, such as an N-shaped or an inverted N-shaped curve, upon the specific country's development pattern (Churchill et al., 2018).

Beside the empirical validation of EKC hypothesis, most empirical studies also look at macroeconomic determinants and their influence on the quality of environment. Among them, foreign direct investment (FDI), trade openness, renewable energy consumption, domestic credit to private sector, technological change, institutional quality and corruption are among the most significant predictors. In general the results are mixed, which is not surprising since there is no policy fitting all countries. As Allard et al. (2018) concludes after conducting a quantile regressions, the relationship between income and environment widely differs across quantiles, as well as the impact of covariates, so that there is no model fitting all data.

As a consequence of the European energy policies (enhanced by the 2009 Renewable Energy Directive) and technological progress, the consumption of renewable energy has increased over the past decades in the EU, with significant differences between Member States. The growth in renewable energy has reduced the fossil fuel energy use, especially in energy-intensive industrial sector. However, the effect of renewable energy on pollution is rather mixed, because the biomass burning can negatively impact the environment. The empirical findings confirm the positive effects of the renewable energy consumption on pollution (Shahnazi and Shabani, 2021; Assi et al., 2021; Destek and Aslan, 2020). Sharif et al. (2020) also analyze the relationship between renewable energy utilization and environmental degradation on a dataset comprising the top 10-polluted countries, and finds a bidirectional causal link between renewable energy consumption and environmental degradation in most countries, excepting India, Indonesia and China where the relationship is inconclusive.

The role of the institutional quality has been underlined in the EKC literature, but in general the results are different for developed, developing and low income countries. Lau et al. (2018) find that the control of corruption plays an important role in reducing CO_2 emissions, but only in high income countries, while rule of law has a positive effect on environment in all countries, but not in low income ones. Godil et al. (2020) applies the quantile autoregressive distributed lag estimator for Pakistan data running from 1995 to 2018 and finds that the institutional quality and GDP contribute to environmental degradation in the long term. The same negative effect of the institutional quality on environment is underlined by Abid (2016) in the case of 25 Sub-Sahara African economies, and Zakaria and Bibi (2019) in South-Asia. In turn, in cross-country studies applied to a set of emerging economies (Le and Ozturk, 2020) and EU countries (Usman et al., 2019) the GDP and institutional quality are found to generate positive effects on environment. Usman and Jahanger (2021) investigate the dynamic linkages of remittances and institutional quality on ecological footprint by using a global sample of 93 counties covering data from 1990 to 2016. They find that the ecological footprint is positive and statistically significant when associated with institutional quality, and suggest a set of policy measures such as the development of lending channels financing only eco-friendly industries.

The index of economic freedom, created by the Heritage foundation and the Wall Street journal, measures the influence of liberty and free market by four areas of policy control: Rule of Law, (property rights, freedom from corruption) Government size (fiscal freedom, government spending), Regulatory efficiency (business freedom, labor freedom, monetary freedom) and Market

openness (trade freedom, investment freedom, financial freedom). Since economic freedom is the fuel for economic progress, the impact of economic freedom on the environment quality might reveal interesting findings. This topic has been examined in the literature either by considering the aggregated levels of economic freedom, or upon each component in part, and the results indicate a positive association. For instance, as highlighted by Fan and Zhao (2019) as well as by Raine and Pluchon (2019), an effective environmental governance could ensure the pollution control by rule of law. Ashfaq and Sharma (2012) extend the space of governance indicators beyond the rule of law, by also including the fight against corruption, regulatory standards, the effectiveness of government, and also find a positive effect. In general, economic freedom is positively associated to the quality of environment, when economic freedom is operationalized by the trade freedom index, business freedom index and financial freedom index (Adesina and Mwamba, 2019), by the government subsidies on carbon pollutants (Moltke, 2012), by environmental policies such as financial and tax policies (Li et al, 2016), when using the economic freedom index (Lazăr et al., 2019) etc. Despite the abundant body of papers indicating the positive relationship between economic freedom and the environment quality, there also have been reported few inconclusive (Joshi and Beck (2018), negative results (Saint Akadırı et al., 2021) or an U-shaped relationship (Shahnazi and Shabani, 2021).

Another body of literature on EKC aims to test the EKC hypothesis when also considering the impact of FDI and trade. The effect of FDI on CO_2 emissions is contrasting in rich and developing countries. In advanced economies the FDI inflows contribute to CO_2 reduction, while in developing and low income countries the effect is rather negative (Lau et al, 2018; Marques and Caetano, 2020). When analysing a panel of Sub-Saharan Africa countries, Twerefou, Danson-Mensah, and Bokpin (2017) concluded that the expansion of globalisation will result in the deterioration of environmental quality. The empirical evidence from Asian countries is rather mixed. FDI is found to contribute to pollution enhancement in India from 1983 to 2014 (Adamu and Shafiw, 2019) and in China from 2013 to 2017 (Zhu et al., 2019). However, cross-country studies based on Asian countries identify the positive effect of FDI on pollution (Huynh and Hoang, 2019; Zhu et al., 2016). When studying a panel of OECD countries, Ganda (2019) find that FDI is positive and significantly linked to carbon emissions but not significantly related to greenhouse gases.

The quality of environment has also been studied in the literature in relation with financial development, and the results are mixed again. Financial development has the potential to support

the environment-friendly projects and investment in clean and new technologies (Zhang, 2011; Zhang and Zhang, 2018), but equally to accelerate the environment degradation by providing credit facilities for the acquisition of machines, plants, houses by increasing the carbon emissions (Zhang and Zhang, 2018). Financial development was generally operationalized by a set of variables like domestic credit to private sector, domestic credit by the banking sector, and domestic credit by the financial sector. Given the broad area of empirical findings, this kind of variables could bring additional insights when being included in any EKC study.

Variables, data and methodology

This paper employs panel data for ten countries in the Central and Eastern Europe (Romania, Poland, Bulgaria, Hungary, Czech Republic, Slovenia, Slovakia, Estonia, Lithuania, Latvia) in the period 2006-2025, according to data availability for Google Trends indexes. The main hypotheses of this study refer to:

H1: The quality of governance significantly influences the level of pollution.

H2: More searches on Google for *corruption* indicating a weaker quality of governance might affect the level of pollution.

GHG emissions (in thousand tonnes CO2 equivalent provided by Eurostat) are used as a proxy for the level of pollution. The renewable energy Kuznets Curve (RKC) explains GHG emissions based on renewable energy consumption as Yao et al. (2019) stated:

$$GHG_{it} = \beta_{0i} + \beta_1 \cdot GDP_{it} + \beta_2 \cdot GDP_{it}^2 + \beta_3 \cdot REC_{it} + \varepsilon_{it} \quad (1)$$

REC- renewable energy consumption
GDP- real gross domestic product per capita
GHG- greenhouse gas emissions
X- control variables (vector)
β_{0i}- country-fixed effects
$\beta_1, \beta_2, \beta_3, \gamma$- parameters
e_{it}- errors
i- country index, t- time index

The data for real GDP per capita (in PPP, constant 2017 international $) and renewable energy consumption (REC) (percent of total final energy consumption) are provided by World Bank.

This equation could be extended by adding various control variables:

$$GHG_{it} = \beta_{0i} + \beta_1 \cdot GDP_{it} + \beta_2 \cdot GDP_{it}^2 + \beta_3 \cdot REC_{it} + \gamma \cdot X_{it} + \varepsilon_{it} \quad (2)$$

The variables in this model are considered in natural logarithmic forms:

$$ln\ GHG_{it} = \beta'_{0i} + \beta'_1 \cdot ln\ GDP_{it} + \beta'_2 \cdot ln^2\ GDP_{it} + \beta'_3 \cdot ln\ REC_{it} + \gamma' \cdot ln\ X_{it} + \varepsilon'_{it} \quad (3)$$

where $\beta'_2 < 0$,

The optimal real GDP per capita level is computed as exp ($-\beta'_1/2\beta'_2$). The signs for β'_1 and β'_2 should be positive and negative, respectively, since the growth of GDP will increase GHG emissions in the initial stage and, then, it will decrease them after a maximum level. A negative value for β'_3 is expected since REC implies less pollution.

The role of REC in reducing pollution is proved by previous empirical studies. For example, Assi et al.(2021) showed that REC reduced pollution in ASEAN+3 countries in the period 1998-2018. Saint Akadiri et al.(2019) showed that REC reduced carbon emissions in the long-run in the EU-28 countries in the period 1995-2015. Moreover, wind power determined a significant decrease in GHG emissions in G7 countries in the period 1991-2004, while water energy consumption reduced the pollution in the UK, Italy and US (Destek and Aslan, 2020).

The other control variables in the vector X are represented by the following indicators in natural logarithmic forms:

- Index of economic freedom (IEF) provided by Heritage taking values from 0 (lack of economic freedom) to 100 (maximum economic freedom);

The economic liberalization might reduce pollution in the long-run in these countries since during the transition process from planned economy to a functional market one heavy industries are replaced by more environmental-friendly ones. This hypothesis was checked for

the ten CEE countries in our sample by Lazăr et al. (2019) in the period 1996-2015. However, in our sample the first phase of transition is not taken into account.

- ❖ Foreign direct investment (FDI) as net inflows (percent of GDP) from World Bank database;

Previous studies bring mixed evidence regarding the impact of FDI on pollution: positive effect of FDI on pollution and negative one. Marques and Caetano (2020) showed that FDI reduces pollution only in developed countries, while in less developed ones FDI enhances environmental degradation. For example, Adamu and Shafiw (2019) showed that FDI contributes to pollution enhancement in India from 1983 to 2014, while Zhu et al. (2019) obtained the same result for Chinese towns in the period 2013–2017. For 19 developing Asian countries in the period 2002-2015, Huynh and Hoang (2019) showed the positive impact of FDI on pollution, but this influence becomes lower when the quality of institutions improves. On the other hand, in ASEAN-5 countries, Zhu et al. (2016) indicated that FDI reduced CO2 emissions in the period 1981-2011.

- ❖ Domestic credit to private sector (percent of GDP) provided by World Bank;

Acheampong (2019) indicated that domestic credit to private sector enhances pollution in 46 sub-Saharan Africa countries during 2000–2015. The same influence was observed by Ganda (2019) in the case of OECD countries in the period 2001-2012 using static and dynamic panel data models to explain CO2 and GHG emissions.

- ❖ Labour productivity as output per worker in GDP constant 2011 international dollar in PPP from International Labour Organization;

Simionescu et al. (2021) indicated the positive effect of labour productivity on GHG emissions in the EU-28 countries during 2007-2019. The same influence was observed in the US in the period spanning from 2007 and 2013 and the working time reduction is recommended for emissions mitigation.

- ❖ Indicators showing the quality of governance:

the Worldwide Governance Indicators:

- government effectiveness reflecting the quality of policy and of public and civil services;
- political stability and absence of violence as an indicator measuring chances of political instability;
- voice and accountability reflecting citizens' freedoms;

- control of corruption showing the use of public power in personal purposes;
- regulatory quality refers to policies supporting private sector;
- rule of law shows confidence in rules of society.

The impact of quality of governance on CO2 emissions was evaluated by Gill et al. (2019) in the case of 19 countries from South-Eastern Asia from 2002 to 2016, but only five of the governance dimensions above have been found to have a significant impact on pollution. Baloch and Wang (2019) showed that good governance reduced CO2 emissions in BRICS countries during 1996-2007. Most of the studies focused on control of corruption or perceived corruption. The role of corruption in enhancing pollution was supported for 16 OECD countries in the period of 1995–2016 (Balsalobre-Lorente et al., 2019). The corruption of public sector in BRICS and next 11 states contributed to environmental degradation in the period 1990-2017 (Sinha et al., 2019).

Google Trends index associated to the keyword *corruption* in each country: корупция (Bulgaria), korupce (Czech Republic), korupcia (Slovakia), korrupció (Hungary), korupcja (Poland), corupție (Romania), korruptsioon (Estonia), korupcija (Latvia), korupcija (Lithuania). The Google Trends index in this study is computed as geometric mean of the Google Trends indexes associated to searches for this keyword at certain moments in each year. The use of microdata based on Google Trends tool to measure quality of governance and the assessment of the impact of Google Trends indexes on pollution represent a novelty for literature in this field. From mathematical point of view, if the number of searches for a query q is n(q,l,t) where l is the location (country) and t is the period, the relative popularity of the query is:

$$RP(q,l,t) = \frac{n(q,l,t)}{\sum_{q \in Q(l,t)} n(q,l,t)} \cdot D_{(n(q,l,t)>\tau)}$$

Q(l,t)- set of all queries made during t from the area l, $D_{(n(q,l,t)>\tau)}$ is a dummy variable with value 1 for enough popular query $(n(q,l,t) > \tau)$ and else it is 0. The resulted values are scaled on a range from 0 to 100 based on the proportion of that topic in the total number of search topics. The GTI is calculated as:

$$GTI(q,l,t) = \frac{RP(q,l,t)}{\max\{RP(q,l,t)_{t \in 1,2,\dots,T}\}} \cdot 100$$

, GTI takes the value zero for queries with low search volume. The searches made repeatedly from the same machine in a short period are not considered and queries with apostrophes and special characters are filtered. The GTI are available since the first of January up to 36 hours prior the search.

According to descriptive statistics in Table 1, the highest level of real GDP per capita is 40862.21 in PPP, constant 2017 international $. It was observed in Czech Republic in 2019, while Bulgaria registered the lowest values of this indicator. The performance of Czech economy is explained by high levels of occupation and intensive export, while in Bulgaria the risk of poverty, unemployment and social exclusion is higher compared to other countries in the sample.

Table 1. Descriptive statistics

Variable	Mean	Standard deviation	Minimum	Maximum
GHG emissions	81334.31	104223.6	6990.58	381407.2
real GDP per capita	27840.88	5659.66	15437.52	40862.21
REC	18.92892	8.573276	5.364129	40.36562
IEF	67.99143	4.706103	58.1	79.1
labour productivity	50669.9	14745.21	26113.6	80539.48
domestic credit to private sector	52.05994	15.40396	24.716	100.8176
Google Trends index	27.7857	10.13006	5.354671	52.86301
rule of law	0.6853703	0.3997196	0.1178744	1.372891
voice and accountability	0.8361897	0.2476588	0.22	1.213275
control of corruption	0.4005777	0.4178217	-0.2672882	1.542329
government effectiveness	0.6763513	0.4157565	-0.3597497	1.191938
political stability and absence of violence	0.681332	0.2945087	0.02	1.147953
regulatory quality	0.9481896	0.2907747	0.4262204	1.698142

Source: own computations in Stata 15

Poland is the country that registered the highest level of GHG emissions in the period 2006-2025 with a maximum reached in 2007. Since the integration in the EU, the level of pollution started to decrease in Poland due to environmental policies at community level. However, the progress in terms of pollution reduction is not enough since Poland is the fifth European country as level of GHG emissions. Fossil fuel combustion in Poland determines more than 40,000 deaths per year. The minimum value GHG emissions was reached by Latvia in 2008, but the indicator is situated on an ascending trend in this country.

Few tests are applied before the selection of the suitable model to explain GHG emissions in the ten CEE countries: cross-sectional tests, unit root tests, and cointegration tests. Moreover, heterogeneity is confirmed since there are differences between countries in the sample related to climate, geographical position, speed of economic development etc. The cross-sectional dependence is explained by the fact that the level of pollution in one country might depend on the pollution of another country in the sample. This correlation was empirically proved by Shahnazi and Shabani (2021) for the EU countries in the period 2000-2017 using a spatial dynamic panel data model. The authors show that the CO2 level in a contry depndens on the CO2 emissions in the neighbooring countries. CD Pesaran (2004) test was selected to check for this hypothesis, since it is not affected by the small size of the analyzed sample.

$$H_0: \rho_{ij} = \rho_{ji} = cor(e_{it}, e_{jt}) = 0, \;\; i \neq j \;\; (\text{cross} - \text{sectional independence})$$

$$H_1: \rho_{ij} = \rho_{ji} \neq 0, \qquad for\ some\ i \neq j$$

ρ_{ij}- pair-wise coefficient of correlation associated to errors

$$\rho_{ij} = \rho_{ji} = \frac{\sum_{t=1}^{T} e_{it} \cdot e_{jt}}{\sqrt{\sum_{t=1}^{T} e_{it}^2} \cdot \sqrt{\sum_{t=1}^{T} e_{jt}^2}}$$

For balanced panels, the statistic of CD Pesaran (2004) test is computed as:

$$CD = \sqrt{\frac{2}{N(N-1)}} \cdot \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}$$

T_{ij}- number of common observations for two states in the sample *i* and *j*

$$\hat{\rho}_{ij} = \hat{\rho}_{ji} = \frac{\sum_{t \in T_i \cap T_j} (\hat{e}_{it} - \bar{e}_i)(\hat{e}_{jt} - \bar{e}_j)}{\sqrt{\sum_{t \in T_i \cap T_j} (\hat{e}_{it} - \bar{e}_i)^2} \cdot \sqrt{\sum_{t \in T_i \cap T_j} (\hat{e}_{jt} - \bar{e}_j)^2}}$$

$$\bar{e}_i = \frac{\sum_{t \in T_i \cap T_j} (\hat{e}_{it})}{\#(T_i \cap T_j)}$$

If the cross-section dependence is confirmed, the presence of unit root is checked by using Breitung test for balanced panels. For integrated data series, the cointegration is studied using specific tests like Kao, Pedroni or Westerlund tests.

Under the hypothesis of cointegration, the panel data models are estimated using the PDOLS method ((panel dynamic OLS model)) of Pedroni (2001). The advantages of PDOLS estimator are related to the alleviation of endogeneity and errors auto-correlation by including instruments given by leads and lags of differenced endogenous variables. The PDOLS approach associated to basic model for RKC is:

$$ln\ GHG_{it} = \beta_{0i} + \beta_{1i} \cdot ln\ GDP_{it} + \beta_{2i} ln^2\ GDP_{it} \cdot + \beta_{3i} \cdot REC_{it} + \sum_{k=-k_i}^{k_i} \alpha_{ik} \Delta \ln GDP_{i,t-k} +$$

$$+ \sum_{k=-k_i}^{k_i} \tau_{ik} \Delta \ln^2 GDP_{i,t-k} + \sum_{k=-k_i}^{k_i} \varphi_{ik} \Delta \ln REC_{i,t-k} + \varepsilon_{it} \qquad (4)$$

$-K_i$ and K_i refer to leads and lags associated to differenced endogenous variables in the model

The heterogeneity of the parameters between dimensions is another advantage of the model proposed by Pedroni (2001). The group mean associated to PDOLS estimator is computed as an average of each parameter between dimensions:

$$\hat{\beta}_{GD} = \frac{1}{N} \sum_{i=1}^{N} \hat{\beta}_{D,i}$$

$\hat{\beta}_{D,i}$- DOLS estimator for country *i*

Under the hypothesis of no cointegration, the panel Autoregressive Distributed Lag model (panel ARDL) is used with the following representation for basic model:

$$GHG_{it} = \alpha_i + \sum_{l=1}^{p} \beta_0\ GHG_{it-l} + \sum_{l=0}^{q} \beta_1 GDP_{it-l} + \sum_{l=0}^{q} \beta_2 \mathrm{GDP}^2{}_{it-l} + \sum_{l=0}^{q} \beta_3 REC_{it-l} + e_{it}$$

After parameterization, the equation in logarithmic form becomes:

$$\Delta \ln\ \mathrm{GHG}_{it} = \alpha_i + \Phi_i(\ln \mathrm{GHG}_{it-l} - \theta_1 \ln GDP_{it-l} - \theta_2 \ln^2 GDP_{it-l} + \theta_3 \ln REC_{it-l})$$
$$+ \sum_{l=1}^{p-1} \lambda_{il} \Delta \ln \mathrm{GHG}_{it-l}$$
$$+ \sum_{l=0}^{q-1} \lambda_{il}^{'} \Delta \ln \mathrm{GDP}_{it-l} + \sum_{l=0}^{q-1} \lambda_{il}^{''} \Delta ln^2 GDP_{\ it-l} + \sum_{l=0}^{q-1} \lambda_{il}^{'''} \Delta \ln REC_{\ it-l} + e_{it}$$

$\lambda, \lambda', \lambda'', \lambda'''$ represent short-run parameters for lagged endogenous variable and for regressors. θ type parameters are long-run coefficients for regressors. The speeds of adjustment is represented by Φ_i

The PMG estimator is based on homogenous long-run equilibrium between countries in the sample and heterogeneous short-run equilibrium due to countries gaps. Alternative methods that could be used in this study are represented by non-linear panel ARDL models or other types of linear panel ARDL models (two-way fixed effect estimator (2FE) and mean group estimator (MG)). The MG estimator considers both short and long term heterogeneous nexus, but it is not recommended for small samples like in our study. 2FE estimator considers both long and short-run homogeneous connection, but it is not suitable for this case since there are differences between countries related to initial level of pollution. Non-linear panel ARDL would be a suitable method for robustness check, but this will be the subject of a future study.

The PMG estimator is recommended in this case, since it is based on homogenous long-run equilibrium across countries and heterogeneous short-run nexus. These hypotheses could be justified from economic point of view. The analyzed countries present significant short-run effects of economic development on GHG emissions, but in the long-run the convergence to a steady state is achieved due to common policies supported by European Commission through European Green Deal. All these countries should apply common measures as EU member states to manage climate changes by pollution reduction: more investment in green technology, more energy efficiency, and promotion of renewable energy consumption. Therefore, the short-run difference between countries related to level of pollution should disappear in the long-run because net-zero GHG emissions should be achieved for all the countries by 2050 as a target for European Green Deal.

Results

The results of CD Pesaran's test indicate the cross-sections dependence in case of GDP, GHG emissions, REC, labour productivity, FDI, domestic credit to private sector and index of economic freedom index at 5% level of significance. Cross-sectional independence was observed for Worldwide Governance indicators and Google Trends indexes and it is explained by the fact that the government instability is determined by specific issues in each country.

Table 2. The CD Pesaran's test –results (2006-2025)

Variables	Statistics	p-values
ln(GDP)	22.19	<0.05
ln(GHG)	5.54	<0.05
ln(REC)	22.20	<0.05
ln(index of economic freedom)	5.08	<0.05
ln (FDI)	8.96	<0.05
ln (labour productivity)	20.17	<0.05
ln (domestic credit to private sector)	5.92	<0.05
ln (Google Trends index)	-0.87	0.382
ln (voice and accountability)	0.16	0.870
ln (control of corruption)	1.53	0.127
ln (political stability and absence of violence)	1.75	0.079
ln (rule of law)	0.75	0.452
ln (government effectiveness)	-0.95	0.344
ln (regulatory quality)	0.16	0.870

Source: own calculations in Stata 15

According to Breitung test for balanced panel, the data for all the variables are non-stationary in level. The Im-Pesaran-Shin test for unbalanced panel indicates stationary data in the first difference at 5% level of significance. Therefore, the data are integrated of order 1 and the cointegration will be checked.

Since the data for all variables present the same order of integration, the cointegration relationship is verified using Pedroni, Kao, and Westerlund tests. The dependent variable is represented by GHG emissions. The common regressors are represented by the logarithmic values of real GDP per capita, FDI, labour productivity, domestic credit to private sector, index of economic freedom. An additional regressor related to quality of governance is added to check the cointegration relationship.

Table 3. The results of Breitung and Im-Pesaran-Shin tests for unit root (p-values in brackets)

Test	Breitung test		Im-Pesaran-Shin test	
Variable	**Statistic (constant & trend) (no lag) data in level**	**Statistic (constant & trend) (one lag) data in level**	**Statistic (no trend) for data in the first difference**	**Statistic (trend) for data in the first difference**
ln(GDP)	-0.0822 (0.4673)	0.5010 (0.6918)	-4.0028 (0.000)	-4.8356 (0.0000)
ln(GHG)	-0.1404 (0.4442)	-0.5671 (0.2853)	-4.3866 (0.0000)	-5.2039 (0.0000)
ln(REC)	2.3285 (0.9901)	1.1449 (0.8739)	-3.3789 (0.0004)	-5.3368 (0.0000)
ln(index of economic freedom)	0.2273 (0.5899)	1.3682 (0.9144)	-4.9608 (0.000)	-4.9570 (0.0000)
ln (FDI)	-0.0733 (0.4456)	0.5230 (0.7023)	-4.5523 (0.000)	-4.9978 (0.000)
ln (labour productivity)	-0.3089 (0.3787)	0.9517 (0.8294)	-4.8258 (0.000)	-5.2342 (0.0000)
ln (domestic credit to private sector)	-0.0837 (0.4722)	0.6022 (0.6778)	-4.5653 (0.000)	-4.4620 (0.000)
ln (Google Trends index)	-2.9533 (0.0016)	-1.6144 (0.0532)	-6.2719 (0.000)	-6.2855 (0.0000)
ln (control of corruption)	1.1137 (0.8673)	0.2134 (0.5845)	-4.5377 (0.000)	-4.6411 (0.000)
ln (voice and accountability)	0.6933 (0.7559)	0.2860 (0.6126)	-4.5662 (0.000)	-4.8781 (0.0000)
ln (political stability and absence of violence)	-1.1316 (0.1289)	-2.4267 (0.0076)	-5.3786 (0.000)	-5.2554 (0.0000)
ln (rule of law)	-0.9858 (0.1621)	-0.9733 (0.1652)	-5.1409 (0.000)	-5.4272 (0.0000)
ln (government effectiveness)	-0.8642 (0.1937)	0.7457 (0.7721)	-5.5269 (0.000)	-5.8927 (0.0000)
ln (regulatory quality)	0.8219 (0.7944)	0.5506 (0.7090)	-4.0766 (0.000)	-4.0727 (0.0000)

Source: own calculations in Stata 15

According to Table 4, the evidence of cointegration is mixed, some tests indicating lack of cointegration and some of them cointegration for the same set of variables. Thereforefore, the estimations will be made under two hypotheses: cointegration (panel DOLS models) and no cointegration (pooled mean group estimator (PMG)).

Table 4. The results of cointegration tests (p-values in brackets)

Test	**Statistics**						
Additional regressor	ln(Google Trends index)	ln (control of corruption)	ln (voice and accountability)	ln (political stability and absence of violence)	ln (rule of law)	ln (government effectiveness)	ln (regulatory quality)
Kao test							
Modified Dickey	-0.1640 (0.4349)	-1.7646 (0.0388)	-1.1843 (0.1181)	-0.7889 (0.2151)	-1.5691 (0.0583)	-1.1165 (0.1321)	-1.1870 (0.1176)
Dickey	-1.6914 (0.0454)	-2.9700 (0.0015)	-2.4051 (0.0081)	-2.1184 (0.0171)	-3.1279 (0.0009)	-2.3049 (0.0106)	-2.6310 (0.0043)
Augmented Dickey	-0.9771 (0.1643)	-2.0515 (0.0201)	-1.4413 (0.0748)	-1.0696 (0.1424)	-1.0723 (0.1418)	-1.1380 (0.1276)	-1.4855 (0.0687)
Unadjusted modified Dickey	-2.5635 (0.0052)	-3.0494 (0.0011)	-2.5700 (0.0051)	-2.5079 (0.0061)	-3.3819 (0.0004)	-2.8831 (0.0020)	-2.6724 (0.0038)
Unadjusted Dickey	-3.1459 (0.0008)	-3.5323 (0.0002)	-3.0892 (0.0010)	-3.0381 (0.0012)	-3.9505 (0.0000)	-3.1881 (0.0007)	-3.3604 (0.0004)
Pedroni test							
Modified Phillips	4.0213 (0.0000)	3.5241 (0.0002)	4.0047 (0.0000)	4.1295 (0.0000)	4.1205 (0.0000)	3.9397 (0.0000)	3.5057 (0.0002)
Phillips	-0.0435 (0.4826)	-2.6424 (0.0041)	-1.5180 (0.0645)	-10.4856 (0.0000)	-0.7518 (0.2261)	-1.3614 (0.0867)	-1.9787 (0.0239)
Augmented Dickey	-0.2378 (0.4060)	-2.8730 (0.0020)	-1.7692 (0.0384)	-3.0878 (0.0010)	1.4782 (0.0697)	-1.7086 (0.0438)	-2.0848 (0.0185)
Westerlund test							
Variance ratio	8.7303 (0.0000)	8.2114 (0.0000)	5.3516 (0.0000)	4.9359 (0.0000)	8.7411 (0.0000)	1.3230 (0.0929)	11.3954 (0.0000)

Source: own calculations in Stata 15

The estimations in Table 5 for panel DOLS models suggest a bell shape relationship between pollution and economic growth. Renewable energy consumption contributes to the reduction of GHG emissions. In most of the models, FDI have a significant and negative impact on pollution. Domestic credit to private sector reduced the environment degradation, while economic freedom enhanced the GHG emissions.

Google Trends index used as a proxy for government instability was directly correlated with the level of pollution. The second hypothesis stating that more searches on Google for *corruption* indicates that the tensions related to corruption might encourage a behaviour that is not friendly

environmental. This result could help us in nowcasting GHG emissions knowing the searches on Google for *corruption* in times of political instabilities. The causality between searches on corruption and GHG emissions is checked in terms of predictability using Dumitrescu-Hurlin test. W-statistic is 5.22 (p-value less than 0.05), indicating causality from Google Index for corruption to GHG emissions.

Table 5. Panel DOLS models to explain GHG emissions in the ten CEE countries (2006-2025)

Variable	**Coefficients**						
	M1	M2	M3	M4	M5	M6	M7
ln(GDP)	79.851*	102.830*	99.919*	87.671*	97.924*	108.792*	105.516*
ln^2(GDP)	-4.052*	-5.167*	-5.071*	-4.441*	-4.978*	-5.469*	-5.374*
ln(REC)	-3.207*	-2.404*	-2.326*	-3.030*	-2.792*	-2.947*	-2.245*
ln(FDI)	-0.069*	-0.053*	-0.013	-0.099*	-0.024	-0.057*	-0.029
ln(index of economic freedom)	6.090*	5.907*	6.750*	5.899*	5.884*	6.156*	6.193*
ln(domestic credit to private sector)	-1.406*	-1.882*	-1.716*	-1.914*	-1.454*	-1.441*	-1.719*
ln(Google Trends index)	0.429*	-	-	-	-	-	-
ln (control of corruption)	-	-0.349*	-	-	-	-	-
ln (voice and accountability)		-	0.770*	-	-	-	-
ln (political stability and absence of violence)	-	-	-	-0.109*	-	-	-
ln (rule of law)	-	-	-	-	-0.151*	-	-
ln (government effectiveness)	-	-	-	-	-	-0.067*	-
ln (regulatory quality)	-	-	-	-	-	-	1.335*

Note: * means significant coefficient at 5% level of significance.

Source: own calculations in Stata 15

The six dimensions of quality of governance are also significantly correlated with GHG emissions. As expected, more control of corruption, more confidence in society rules, better public policies and more political stability contribute to pollution reduction. On the other hand, more citizens freedoms and more policies supporting private sector are associated with higher pollution. Therefore, more education of citizens related to environmental protection is required to make them

understand that they have freedoms, but also responsibilities to keep the environment clean. The private sector should be sustained, but government should support stronger environmental policies to encourage companies to make profit while respecting the laws that prevent environment degradation. More investment in green technologies is necessary in these countries and governments could support companies to implement these new technologies through subsidies. A stable policy environment with less corruption and confidence in societal rules is a desirable goal for governments in the fight against pollution and climate challenges.

The estimations based on PMG in Table 6 confirm the bell shape relationship between pollution and economic growth only in the short-run. In the long-run, when Google Trends index, control of corruption and regulatory quality are considered in the models, the economic growth-pollution nexus becomes U-shaped. There is a strong evidence of the contribution of REC to pollution reduction only in the short-run. Only government effectiveness has a both long and short-term influence on environmental degradation. The impact of other dimensions of governance quality is observed only in the long-run: control of corruption, rule of law and regulatory quality. Voice and accountability and political stability and absence of violence present a significant influence on GHG emissions based on PMG estimators only in the short-run. As in the previous model, less corruption, government effectiveness, stronger policies and better political stability are the key dimensions of government quality in achieving the goal of a cleaner environment. More freedoms for citizens and support for companies do not encourage the concern for environmental protection. Government effectiveness is the most important factor since its improvement could determine immediate and long-run effects in terms of pollution reduction.

Table 6. PMG estimators to explain GHG emissions in the ten CEE countries (2006-2025)

	Variable	**Coefficients**						
Long-run relationship	ln(GDP)	-111.086*	-20.762*	449.774*	5.442	309.124*	47.239*	-16.281
	$\ln^2$(GDP)	5.459*	1.038*	-20.775*	0.065	-14.355*	-2.259*	0.852
	ln(REC)	0.617*	0.050	-1.159	-2.886*	-0.229	-0.155*	-0.355*
	ln(index of economic freedom)	-3.157*	-1.466*	16.944	3.907*	-	-	-
	ln(labour productivity)	-	-	-	-	-	-	-
	ln(Google Trends index)	0.046*	-	-	-	-	-	-

	ln (control of corruption)	-	-0.293*	-	-	-	-	-
	ln (voice and accountability)	-		2.467	-	-	-	-
	ln (political stability and absence of violence)	-	-	-	-0.204	-	-	-
	ln (rule of law)	-	-	-	-	-1.948*	-	-
	ln (government effectiveness)	-	-	-	-	-	-0.252* -	-
	ln (regulatory quality)	-	-	-	-	-	-	1.370*
Error correction term		-0.279*	-0.412*	-0.003	-0.037	-0.022	-0.420*	-0.271**
Short-run relationship	ln(GDP)	32.440	45.679	44.934	71.575	56.231	28.366	65.015
	ln^2(GDP)	-1.374	-2.156	-1.977	-3.382	-2.670	-1.356	-3.117
	ln(REC)	-0.360	-0.273*	-0.354*	-0.409*	-0.345*	-0.348	-0.325*
	ln(index of economic freedom)	1.703*	1.017	0.787*	1.131	-	-	-
	ln(labour productivity)	-	-	-	-	-	-	-
	Ln(Google Trends index)	0.023	-	-	-	-	-	-
	ln (control of corruption)	-	0.012	-	-	-	-	-
	ln (voice and accountability)	-	-	0.109*	-	-	-	-
	ln (political stability and absence of violence)	-	-	-	-0.041*	-	-	-
	ln (rule of law)	-	-	-	-	0.094	-	-
	ln (government effectiveness)	-	-	-	-	-	0.298*	-
	ln (regulatory quality)	-	-	-	-	-	-	0.254
	Constant	163.963*	49.763*	-7.973	-2.321	-37.094	-99.028*	23.880
Errors		I(0)	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)

Note: * means significant coefficient at 5% level of significance and ** means significant at 10% level of significance.

Source: own calculations in Stata 15

The robustness check based on adding of labour productivity in the models in Table 7 suggests a positive impact of labour productivity on GHG emissions in the ten CEE countries in the period 2006-2025. When this variable is introduced in the models, some governance dimensions become irrelevant in explaining the pollution in the analyzed countries: political stability and absence of violence and voice and accountability

Table 7. Robustness check (additional variable: labour productivity) Panel DOLS models to explain GHG emissions in the ten CEE countries (2006-2025)

Variable	**Coefficients**						
	M1	M2	M3	M4	M5	M6	M7
ln(GDP)	89.613*	90.756*	97.415*	102.536*	97.101*	102.809*	106.668*
ln^2(GDP)	-4.712*	-4.777*	-5.119*	-5.342*	-5.083*	-5.334*	-5.586*
ln(REC)	-0.610*	1.227*	-0.027	-0.786*	-0.477*	-0.725*	0.102
ln(FDI)	0.012	-0.012	-0.020	-0.062*	-0.004	-0.047*	-0.035
ln(index of economic freedom)	-6.093*	-9.021*	-6.079*	-5.001*	-6.510*	-4.024*	-6.230*
ln(domestic credit to private sector)	0.894*	0.845*	0.618	0.385*	0.712*	0.392*	0.925*
ln(labour productivity)	9.213*	11.324*	9.561*	8.609*	9.282*	7.926*	9.847*
ln(Google Trends index)	0.334*	-	-	-	-	-	-
ln (control of corruption)	-	-0.620*	-	-	-	-	-
ln (voice and accountability)		-	0.434	-	-	-	-
ln (political stability and absence of violence)	-	-	-	-0.033	-	-	-
ln (rule of law)	-	-	-	-	-0.07*	-	-
ln (government effectiveness)	-	-	-	-	-	0.04*	-
ln (regulatory quality)	-	-	-	-	-	-	0.510*

Note: * means significant coefficient at 5% level of significance.

Source: own calculations in Stata 15

When labour productivity is introduced in the models, the GDP-GHG emissions nexus becomes unstable as Table 8 shows. In most of the cases, labour productivity enhances pollution in the long-run. When labour productivity is added in the model, rule of law, control of

corruption, government effectiveness reduce pollution. Regulatory quality continues to enhance pollution in the long-run. Government effectiveness influences pollution in the long and in the short-run and contributes to its reduction.

When labour productivity is added in the model, the impact of rule of law on GHG emissions becomes significant and negative in the short-run, not only in the long-run. More productive people that trust in rules of society tend to have a more ecological behaviour. The regulatory quality in the short-run enhances pollution when labour productivity is considered as control variable. This result might be explained by the extension of economic activities with more productive labour force that negatively affect the quality of environment. Control of corruption might reduce the GHG emissions only in the long-run. Google searches for corruption have significant effects on pollution in the long-term.

Table 8. Robustness check (additional variable: labour productivity) PMG estimators to explain GHG emissions in the ten CEE countries (2006-2025)

	Variable	Coefficients				
Long-run relationship	ln(GDP)	-48.673*	45.009*	87.422*	35.462*	24.150*
	$\ln^2$(GDP)	2.314*	-2.281*	-4.201*	-1.790*	-1.035*
	ln(REC)	-0.127*	-0.678*	-0.238*	-0.616*	0.074
	ln(index of economic freedom)	-2.131*	-	-	-	-
	ln(labour productivity)	1.707*	2.148*	-0.789*	1.733*	-1.547*
	ln(Google Trends index)	0.018*	-	-	-	-
	ln (control of corruption)	-	-0.042*	-	-	-
	ln (rule of law)	-	-	-0.259*	-	-
	ln (government effectiveness)	-	-	-	-0.058*	-
	ln (regulatory quality)	-	-	-		-1.101*
Error correction term		-0.352**	-0.359*	-0.357*	-0.298	-0.255*
Short-run relationship	ln(GDP)	-2.450	-49.136	6.145*	43.323	107.581**

	$\ln^2$(GDP)	0.290	2.419	-0.349*	-2.096	-5.233**
	ln(REC)	-0.507*	-0.381*	-0.672*	-0.503*	-0.482*
	ln(index of economic freedom)	1.799*	-	-	-	-
	ln(labour productivity)	-0.117	-0.356	0.481*	-0.265	0.562
	ln(Google Trends index)	0.01	-	-	-	-
	ln (control of corruption)	-	-0.127	-	-	-
	ln (rule of law)	-	-	-0.247*	-	-
	ln (government effectiveness)			-	-0.165*	-
	ln (regulatory quality)	-	-	-	-	0.291**
	Constant	90.567**	-83.572	-11.298	-54.194	-28.856*
Errors		I(0)	I(0)	I(0)	I(0)	I(0)

Note: * means significant coefficient at 5% level of significance and ** means significant at 10% level of significance.

Source: own calculations in Stata 15

All in all, this study confirms the role of quality of governance in explaining the pollution in the ten CEE countries in the period 2006-2025. Moreover, more searches on Google for *corruption* indicating a weaker quality of governance enhance the level of pollution. The results vary with the method, but few conclusions are supported by both methodological approaches:

- there is a bell-shape relationship between economic growth and pollution in the short-run, but the connection might become unstable in the long-run;
- REC ensures environmental protection in the short-run, but more efforts should be made to ensure a stable long-run relationship;
- economic freedom enhances pollution in the short-term, but there are premises to ensure a reduction in GHG emissions in the long-run;
- labour productivity contributes to increase in GHG emissions in the short-run;

- there is a stable and positive relationship between Google searches for *corruption* and pollution;
- control of corruption, rule of law and government effectiveness have a significant long-run impact on GHG emissions by reducing pollution.

It is esential to analyze the connection between GHG emissions and quality of governance in terms of causality. In this case, Granger causality is analyzed to identify a possible predictive power of governance indicators in explaining and forecasting pollution. Dumitrescu-Hurlin test for causality in panel is used on stationary data (all the series in the first difference) and on balanced panels. The results are presented in Table 9.

Table 9. Dumitrescu & Hurlin Granger non-causality test results

Null hypothesis	Computed statistic	Conclusion
Changes in regulatory quality do not Granger cause changes in GHG emissions	2.1549 (p-value = 0.0312)	Changes in regulatory quality are cause for changes in GHG emissions
Changes in voice and accountability do nt Granger cause changes in GHG emissions	1.4930 (p-value = 0.1354)	Changes in voice and accountability do nt Granger cause changes in GHG emissions
Changes in political stability do not Granger cause changes in GHG emissions	4.7725 (p-value = 0.0000)	Changes in political stability do Granger cause changes in GHG emissions
Changes in rule of law do not Granger cause changes in GHG emissions	6.8283 (p-value = 0.0000)	Changes in rule of law do Granger cause changes in GHG emissions
Changes in government effectiveness do not Granger cause changes in GHG emissions	1.9467 (p-value = 0.0516)	Changes in government effectiveness do Granger cause changes in GHG at 10% level of significance
Changes in control of corruption do not Granger cause changes in GHG emissions	5.223 (p-value=0.0000)	Changes in control of corruption do Granger cause changes in GHG emissions
Changes in Google Trends index for corruption do not Granger cause changes in GHG emissions	6.778 (p-value=0.0000)	Changes in Google Trends index for corruption do Granger cause changes in GHG emissions

Source: own calculations in Stata 1

Excepting changes in voice and accountability, all the other variables were causes for pollution. These results confirm the predictive power of quality of governance in explaining GHG emissions. Google Trends indexes that reflect the people's concerns on corruption showed that the perception on corruption in society influences the behavior of individuals on environmental protection.

Discussion

Akram et al. (2020) suggested that policymakers should take into account the asymmetric behavior of the renewable energy, energy efficiency, and economic growth when various policies are considered in terms of energy, environmental protection, and economic growth.

Renewable energy consumption has the capacity to reduce GHG emissions in the analyzed CEE countries, but in the long-run the role of this type of energy in reducing pollution might diminish its importance. This result supports the development of policies that enhance the use of renewable energy in line with the European Green Deal targets.

The utility of REC in promoting sustainability through the reduction in pollution proved in this study was supported by other studies from literature. For example, Shahnazi and Shabani (2021) showed that renewable energy consumption reduced the level of pollution in the EU countries in the period 2000-2017 reducing the environmental degradation. The environmental sustainability improved in ASEAN +3 countries due to renewable energy consumption in the period 1998–2018 (Assi et al., 2021). A particular type of renewable energy like wind energy diminished the GHG emissions in the G7 countries over 1991-2004 (Destek and Aslan, 2020).

Economic freedom is positively correlated with GHG emissions in the short-run in our sample which suggests that the transition to functional market economy was made with the price of environmental degradation. However, in the long-run the economic freedom might ensure sustainable development if it is associated with renewable energy consumption and energy efficiency. This objective could be achieved if suitable measures and policies are implemented in these CEE countries: regulations against pollution-havens, cooperation between countries in order to ensure European Green Deal targets, externalities internalization, growth based on low-carbon. Saint Akadırı et al. (2021) also obtained a negative impact of economic freedom on pollution only in the long-run in BRICS countries in the period 1995-2018. For eleven CEE countries, Lazăr et al. (2019) also showed that economic freedom reduced pollution in the long-run, but Joshi and Beck (2018) included the influence of political freedom while assessing the impact of economic freedom

on CO2 emissions. The authors showed that for partially free non-OECD countries in transition the effect of economic freedom is not statistically significant. For all the EU countries, Shahnazi and Shabani (2021) found a U-shape relationship between CO2 and economic freedom using a spatial dynamic panel data model in the period 2000-2017.

Labour productivity impact on pollution was mostly analyzed for developed countries suggesting a similar result: the contribution of productivity to environmental degradation. The positive effect of labour productivity on pollution was previously supported by Mazzanti and Zoboli (2009) for Italian sectors in the period 1991–2001. For Italian agriculture, the impact of labour productivity on GHG emissions is significant under the sustainability hypothesis in the period 1980-2008 (Coderoni and Esposti, 2014). Cui et al. (2017) showed that higher labour productivity in Scotland enhances export and inter-regional migration with direct effects on environmental degradation. Compared to developed countries, in the CEE states, the effect of labour productivity on pollution is explained by the low technological progress in industry. The study of Simionescu et al. (2021) for all the EU countries supported the hypothesis that labour productivity should be reduced to achieve sustainable development in the long-run.

Google Trends could be succesfully used to capture the political instability that serves in nowcasting the GHG emissions in the ten CEE countries in the sample. This approach has the advantage of providing real-time data compared to macroeconomic indicators that are released late. Compared to Worldwide Governance Indicators, Google Trends index establishes a stable relationship with the level of pollution. From this point of view, the use of microdata based on Google Trends is recommended as a better indicator for quality of governance that influences GHG emissions. These findings are a novelty for literature review analyzing EKC. Actually this study is the first one that uses data based on Google Trends in the model for EKC. This type of microdata was successfully used to predict macroeconomic indicators like unemployment rate (Simionescu, 2020), private consumption (Vosen and Schmidt, 2011), tourism arrivals (Dergiades et al., 2018), and bitcoins (Arratia and López-Barrantes, 2021).

The results indicate that less corruption and a good legislative framework are important pillars for reducing GHG emissions in the short and long-run in the analyzed CEE countries. This study showed that less control of corruption enhances the GHG emissions. The result is in line with previous studies. For example, less control of **corruption** enhanced the pollution in various regions: 16 OECD countries in the period 1995-2016 (Balsalobre-Lorente et al., 2019), and BRICS countries in the period 1990-2017 (Sinha et al., 2019). For APEC countries, Zhang et al. (2016) showed that

corruption positively influences CO2 emissions through its effect on economic growth, while in countries with low level of pollution corruption improves the environmental quality. A similar result was observed by Cole (2007) for developed countries in the period 1987-2000 where corruption reduces environmetal issues while in developing countries pollution is enhanced by corruption. In our study, the control of corruption to reduce it contributes to less pollution. **Environmental regulations** have the capacity to reduce the pollution in the short-run and long-run, as previous studies showed for energy regulations. Since air pollution will not stop when economic growth increases, policy measures should be implemented to ensure a strong legislative framework in the field. Environmental regulations determine a cleaner transformation in the economic system based on a better utilization of natural resources. Energy regulation reduces the GHG emissions in 28 OECD countries due to R&D in energy efficiency (Alvarez-Herranz and Balsalobre-Lorente, 2015). For 17 OECD countries from 1990 to 2012, Lorente and Álvarez-Herranz (2016) showed that energy regulation initiatives are necessary to reduce long-run pollution.

In our study, **rule of law** had the capacity to reduce GHG emissions for analyzed CEE countries. This finding is in line with the result of Lau et al. (2018) that proved the role of rue of law in reducing pollution for both developed and developing countries.

The role of **control of corruption, rule of law and government effectiveness** in the fight against pollution in the long-run is confirmed by Gani and Scrimgeour (2014) for water pollution across all industrial activities in the OECD countries. Moreover, Dadgara and Nazari (2017) showed the significant impact of government effectiveness, control of corruption and rule of law on pollution in the South West Asian Countries in the period 2002-2015.

Conclusions

Beside easy access to Internet data that are well economical and digitally organized, microdata based on Google Trends allows the observation of behavioral trends in countries with rather high Internet penetration rate. The goal of the European Green Deal is to achieve sustainable economy by eliminating GHG emissions by 2050 in the context of digital transformation. These two pillars of the EU framework, green economy and digital transformation could be achieved by using the benefits of digitalization in designing effective environmental policies. One example could be the motorization of quality of governance using Google Trends under the hypothesis that corruption influences the environmental quality.

Besides the traditional approach of assessing the quality of governance using worldwide indicators, this paper introduces Google Trends as a tool to collect data reflecting the quality of institutions. The results of this study based on EKC show the superiority of this tool in explaining and nowcasting the GHG emissions. In a more digitalized economy due to EU policies and to COVID-19 pandemic, the GHG emissions forecasting is a necessity for evaluating the degree of filling the target for 2050. The use of official statistics provides late results and less reliable compared to Google Trends approach. Therefore, this research recommends the use of this tool in the green and digital economy to observe the progress in achieving the goal for 2050 and in the elaboration of the most suitable environmental policies to support this goal.

The main limitation of this study is given by the dependence of results by Internet penetration rate, but this issue has been alleviated in the context of COVID-19 pandemic and the EU investment to support the digital economies. Our Google Trends index refers only to corruption as key-word, but in a future study more key-words related to corruption will be considered since this issue is actual and relevant for the ten CEE countries in the EU.

Another limit of this research is related to the fact that the conclusions are drawn for the entire sample of countries, but differences between countries might exist. Therefore, in a future study a cross-country analysis will be made to check the impact of governance and economic indicators on pollution in each country of the sample. The short period for data availability did not allow us to consider a separate analysis in this paper.

Author contributions

M.S. designed the research, collected data, processed data in Stata 15 and analyzed data, wrote sections: Introduction, Variables, data and methodology, Results, Discussion, M.R.S., B.G. and U.M. wrote Introduction, Literature review, Conclusions and review the paper.

Conflict of interest

The authors declare no conflict of interest or competing interests.

References

Abid, M. (2016). Impact of economic, financial, and institutional factors on CO2 emissions: evidence from Sub-Saharan Africa economies. *Util Policy*, 41, 85–94.

Acheampong, A. O. (2019). Modelling for insight: does financial development improve environmental quality?. *Energy Economics*, *83*, 156-179.

Adamu, T. M., & Shafiq, M. (2019). Analyzing the impact of energy, export variety, and FDI on environmental degradation in the context of environmental kuznets curve hypothesis: A case study of India. *Energies*, *12*(6), 1076.

Adesina, K.S., Mwamba, J.W.M. (2019). Does economic freedom matter for CO2 emissions? Lessons from Africa. *J Dev Areas*, 53(3), 155-167.

Agras, J. & Chapman, D. (1999). A Dynamic Approach to the Environmental Kuznets Curve Hypothesis. *Ecological Economics* 28, 267–77.

Ahmad, M., Li, H., Anser, M. K., Rehman, A., Fareed, Z., Yan, Q., & Jabeen, G. (2020). Are the intensity of energy use, land agglomeration, CO2 emissions, and economic progress dynamically interlinked across development levels?. *Energy & Environment*, 0958305X20949471.

Akram, R., Majeed, M. T., Fareed, Z., Khalid, F., & Ye, C. (2020). Asymmetric effects of energy efficiency and renewable energy on carbon emissions of BRICS economies: evidence from nonlinear panel autoregressive distributed lag model. *Environmental Science & Pollution Research*, *27*(15). https://doi.org/10.1007/s11356-020-08353-8

Allard, A., Takman, J., Uddin, G.S. et al. (2018). The N-shaped environmental Kuznets curve: an empirical evaluation using a panel quantile regression approach. *Environ Sci Pollut Res*, 25, 5848–5861 (2018).

Alvarez-Herranz, A., & Balsalobre-Lorente, D. (2015). Energy regulation in the EKC model with a dampening effect. *J Environ Anall Chem*, *2*(3), 1-10.

Apergis, N., & Ozturk, I. (2015). Testing Environmental Kuznets Curve hypothesis in Asian countries. *Ecological Indicators*, 52, 16-22.

Arratia, A., & López-Barrantes, A. X. (2021). Do google trends forecast bitcoins? stylized facts and statistical evidence. *Journal of Banking and Financial Technology*, 1-13.

Ashfaq, A., Sharma, P. (2012). Environmental effects of air pollution and application of engineered methods to combat the problem. *I Control Pollution*, 29(1).

Assi, A. F., Isiksal, A. Z., & Tursoy, T. (2021). Renewable energy consumption, financial development, environmental pollution, and innovations in the ASEAN+ 3 group: Evidence from (P-ARDL) model. *Renewable Energy*, *165*, 689-700. https://doi.org/10.1016/j.renene.2020.11.052.

Aşıcı, A. A., & Acar, S. (2018). How does environmental regulation affect production location of non-carbon ecological footprint?. Journal of Cleaner Production, 178, 927-936.

Baek, J., & Kim, H. S. (2013). Is economic growth good or bad for the environment? Empirical evidence from Korea. *Energy Economics*, 36, 744-749.

Balsalobre-Lorente, D., Shahbaz, M., Jabbour, C. J. C., & Driha, O. M. (2019). The role of energy innovation and corruption in carbon emissions: Evidence based on the EKC hypothesis. In *Energy and environmental strategies in the era of globalization* (pp. 271-304). Springer, Cham.

Brodeur, A., Clark, A. E., Fleche, S., & Powdthavee, N. (2020). Assessing the impact of the coronavirus lockdown on unhappiness, loneliness, and boredom using Google Trends. *arXiv preprint arXiv:2004.12129*.

Brodeur, A., Clark, A. E., Fleche, S., & Powdthavee, N. (2021). COVID-19, lockdowns and well-being: Evidence from Google Trends. *Journal of public economics*, *193*, 104346.

Churchill, S.A., Inekwe, J., Ivanovski, K., & Smyth, R. (2018). The Environmental Kuznets Curve in the OECD: 1870-2014. *Energy Economics*, 75, 389–399.

Coderoni, S., & Esposti, R. (2014). Is there a long-term relationship between agricultural GHG emissions and productivity growth? A dynamic panel data approach. *Environmental and Resource Economics*, *58*(2), 273-302.

Cole, M. A. (2007). Corruption, income and the environment: an empirical analysis. *Ecological Economics*, *62*(3-4), 637-647.

Cui, C. X., Hanley, N., McGregor, P., Swales, K., Turner, K., & Yin, Y. P. (2017). Impacts of regional productivity growth, decoupling and pollution leakage. *Regional Studies*, *51*(9), 1324-1335.

Dadgara, Y., & Nazari, R. (2017). The impact of good governance on environmental pollution in South West Asian Countries. *Iranian Journal of economic studies*, *5*(1), 49-63.

Dergiades, T., Mavragani, E., & Pan, B. (2018). Google Trends and tourists' arrivals: Emerging biases and proposed corrections. *Tourism Management*, *66*, 108-120.

Destek, M. A., & Aslan, A. (2020). Disaggregated renewable energy consumption and environmental pollution nexus in G-7 countries. *Renewable energy*, *151*, 1298-1306. https://doi.org/10.1016/j.renene.2019.11.138.

Fan, Z., Zhao, R. (2019). Does rule of law promote pollution control? Evidence from the establishment of the environmental court. *Econ Res J*, 54, 21–37.

Fitzgerald, J. B., Schor, J. B., & Jorgenson, A. K. (2018). Working hours and carbon dioxide emissions in the United States, 2007–2013. *Social Forces*, *96*(4), 1851-1874.

Ganda, F. (2019). The environmental impacts of financial development in OECD countries: a panel GMM approach. *Environmental Science and Pollution Research*, *26*(7), 6758-6772.

Gani, A., & Scrimgeour, F. (2014). Modeling governance and water pollution using the institutional ecological economic framework. *Economic modelling*, *42*, 363-372.

Godil, D.I., Sharif, A., Agha, H., & Jermsittiparsert, K. (2020). The dynamic nonlinear influence of ICT, financial development, and institutional quality on CO2 emission in Pakistan: new insights from QARDL approach. *Environ Sci Pollut Res*, 27, 24190–24200.

Grossman, G.,Krueger, A.B. (1991). Environmental Impacts of a North American Free Trade Agreement; *National Bureau of Economic Research working paper* 3914.

Huynh, C. M., & Hoang, H. H. (2019). Foreign direct investment and air pollution in Asian countries: does institutional quality matter? *Applied Economics Letters*, *26*(17), 1388-1392.

Joshi, P., & Beck, K. (2018). Democracy and carbon dioxide emissions: assessing the interactions of political and economic freedom and the environmental Kuznets curve. *Energy Research & Social Science*, *39*, 46-54.

Kahuthu, A. (2006). Economic Growth and Environmental Degradation in a Global Context. Environment. *Development and Sustainability*, 8, 55–68.

Kang, Y.Q., Zhao, T. & Yang, Y. (2016). Environmental Kuznets curve for CO2 emissions in China: A spatial panel data approach. *Ecological Indicators,* 63, 231–239.

Lau, L., Choong, C. & Ng, C. (2018). Role of Institutional Quality on Environmental Kuznets Curve: A Comparative Study in Developed and Developing Countries*, Advances in Pacific Basin Business, Economics and Finance* (Advances in Pacific Basin Business, Economics and Finance, Vol. 6), Emerald Publishing Limited, Bingley, 223-247.

Lazăr, D., Minea, A., & Purcel, A. A. (2019). Pollution and economic growth: Evidence from Central and Eastern European countries. *Energy Economics*, *81*, 1121-1131.

Le, H.P., Ozturk, I. (2020). The impacts of globalization, financial development, government expenditures, and institutional quality on CO2 emissions in the presence of environmental Kuznets curve. *Environ Sci Pollut Res*, 27, 22680–22697.

Li, B., Zhang, G., Ye, M., Du, J., Xiang, X., Quan, X. et al (2016). Network optimization and performance evaluation of the water-use system in China's straw pulp and paper industry: a case study. *Clean Techn Environ Policy*, 18(1), 257–268.

Loiseau, E., Saikku, L., Antikainen, R., Droste, N., Hansjürgens, B., Pitkänen, K., & Thomsen, M. (2016). Green economy and related concepts: An overview. *Journal of cleaner production*, *139*, 361-371.

Lorente, D. B., & Álvarez-Herranz, A. (2016). Economic growth and energy regulation in the environmental Kuznets curve. *Environmental Science and Pollution Research*, *23*(16), 16478-16494.

Marques, A. C., & Caetano, R. (2020). The impact of foreign direct investment on emission reduction targets: Evidence from high-and middle-income countries. *Structural Change and Economic Dynamics*, *55*, 107-118.

Mavragani, A., & Gkillas, K. (2020). COVID-19 predictability in the United States using Google Trends time series. *Scientific reports*, *10*(1), 1-12.

Mazzanti, M., & Zoboli, R. (2009). Environmental efficiency and labour productivity: Trade-off or joint dynamics? A theoretical investigation and empirical evidence from Italy using NAMEA. *Ecological Economics*, *68*(4), 1182-1194.

Pal, D., Mitra, S.K. (2017). The environmental Kuznets curve for carbon dioxide in India and China: Growth and pollution at crossroad. *J. Policy Modeling*, 39, 371–385.

Pedroni, P. (2001). Purchasing power parity tests in cointegrated panels. *Review of Economics and statistics*, *83*(4), 727-731.

Perman, R. & Stern, D. (2003). Evidence from panel unit root and cointegration tests that the environmental Kuznets curve does not exist. *Australian Journal of Agricultural and Resource Economics*, 47, 325–347.

Pesaran, M. H. (2004). General diagnostic tests for cross-sectional dependence in panels. *Empirical Economics*, 1-38.

Raine, A., Pluchon, E. (2019). UN environment—advancing the environmental rule of law in the Asia Pacific. *Chinese Journal of Environmental Law*, 3(1), 117–126.

Saint Akadiri, S., Alola, A. A., Akadiri, A. C., & Alola, U. V. (2019). Renewable energy consumption in EU-28 countries: policy toward pollution mitigation and economic sustainability. *Energy Policy*, *132*, 803-810. https://doi.org/10.1016/j.enpol.2019.06.040

Shahnazi, R., & Shabani, Z. D. (2021). The effects of renewable energy, spatial spillover of CO2 emissions and economic freedom on CO2 emissions in the EU. Renewable Energy, 169, 293-307.

Shahzad, U., Fareed, Z., Shahzad, F., & Shahzad, K. (2021). Investigating the nexus between economic complexity, energy consumption and ecological footprint for the United States: New insights from quantile methods. *Journal of Cleaner Production*, *279*, 123806. https://doi.org/10.1016/j.jclepro.2020.123806

Sharif, A. et al. (2020). The renewable energy consumption-environmental degradation nexus in Top-10 polluted countries: Fresh insights from quantile-on-quantile regression approach. *Renewable energy*, 150, 670-690.

Simionescu, M.(2020). Improving unemployment rate forecasts at regional level in Romania using Google Trends. *Technological Forecasting and Social Change*, *155*, 120026.

Simionescu, M.; Bilan, Y.; Zawadzki, P.; Wojciechowski, A.; Rabe, M. GHG Emissions Mitigation in the European Union Based on Labor Market Changes. *Energies* 2021, *14*, 465. https://doi.org/10.3390/en14020465

Sinha, A., Gupta, M., Shahbaz, M., & Sengupta, T. (2019). Impact of corruption in public sector on environmental quality: Implications for sustainability in BRICS and next 11 countries. *Journal of Cleaner Production*, *232*, 1379-1393.

Stern, D. (2004). The rise and fall of the Environmental Kuznets Curve. *World Development*, 32(8), 1419–1439.

Tamazian, A., & Rao, B. B. (2010). Do economic, financial and institutional developments matter for environmental degradation? Evidence from transitional economies. *Energy Economics*, 32(1), 137-145.

Timonen, K., Reinikainen, A., Kurppa, S., & Riipi, I. (2021). Key Indicators and Social Acceptance for Bioenergy Production Potential as Part of the Green Economy Transition Process in Local Areas of Lapland. *International Journal of Environmental Research and Public Health*, *18*(2), 527.

Twerefou, D. K., Danso-Mensah, K., & Bokpin, G. A. (2017). The environmental effects of economic growth and globalization in Sub-Saharan Africa: A panel general method of moments.

Usman, M., Jahanger, A. (2021). Heterogeneous effects of remittances and institutional quality in reducing environmental deficit in the presence of EKC hypothesis: A global study with the application of panel quantile regression. *Environmental Science and Pollution Research*, https://doi.org/10.1007/s11356-021-13216-x

Usman, O., Elsalih, O., Koshadh, O. (2019). Environmental performance and tourism development in EU-28 countries: the role of institutional quality. *Curr Issue Tour,* 23, 2103–2108.

United Nations Environmental Programme (UNEP), 2011, *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication*, [www.unep.org/greeneconomy]

von Moltke, K. (2012). *Globalisation and environmental policy design A Handbook of Globalisation and Environmental Policy*. Edward Elgar Publishing, Second Edition.

Vosen, S., & Schmidt, T. (2011). Forecasting private consumption: survey-based indicators vs. Google trends. *Journal of forecasting*, *30*(6), 565-578.

Yao, S., Zhang, S., & Zhang, X. (2019). Renewable energy, carbon emission and economic growth: A revised environmental Kuznets Curve perspective. *Journal of Cleaner Production*, *235*, 1338-1352.

Zakaria, M, & Bibi, S. (2019). Financial development and environment in South Asia: the role of institutional quality. *Environ Sci Pollut Res*, 26, 7926–7937.

Zhang, Y. J. (2011). The impact of financial development on carbon emissions: An empirical analysis in China. *Energy Policy*, 39(4), 2197-2203.

Zhang, Y. J., Jin, Y. L., Chevallier, J., & Shen, B. (2016). The effect of corruption on carbon dioxide emissions in APEC countries: a panel quantile regression analysis. *Technological Forecasting and Social Change*, *112*, 220-227.

Zhang, Y., & Zhang, S. (2018). The impacts of GDP, trade structure, exchange rate and FDI inflows on China's carbon emissions. *Energy Policy*, 120, 347-353.

Zhu, H., Duan, L., Guo, Y., & Yu, K. (2016). The effects of FDI, economic growth and energy consumption on carbon emissions in ASEAN-5: evidence from panel quantile regression. *Economic Modelling*, *58*, 237-248.

Zhu, L., Hao, Y., Lu, Z. N., Wu, H., & Ran, Q. (2019). Do economic activities cause air pollution? Evidence from China's major cities. *Sustainable Cities and Society*, *49*, 101593.