1 THE ROLE OF THE EUROPEAN DIRECTIVE ON RENEWABLE ENERGY CONSUMPTION IN REDUCING POLLUTION IN CEE COUNTRIES FROM THE EUROPEAN UNION

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Abstract

Pollution is a major challenge for the Central and Eastern European (CEE) countries that joined the EU. In this context, the main aim of this paper is to check if renewable energy consumption reduced the CO2 emissions in the region due to EU directives. According to method of moments quantile regression (MMG) and mean group (MG) estimators, the renewable energy consumption reduced the CO2 emissions in 11 CEE countries from the EU in the period 2007-2021. Moreover, the synthetic control method based on a donor pool composed by Russian Federation and Montenegro suggests that Renewable Energy Directive launched in 2009 reduced pollution in the 11 CEE states, but the reduction is larger compared to CEE countries outside the EU since 2019 given the new targets proposed in the Revised Renewable Energy Directive in 2018. In the complex EU policy framework, gender pay gap should be considered and it seems it reduces CO2 emissions in the CEE countries from the EU. These findings support the policy recommendations in the EU countries from Central-Eastern region of Europe.

Keywords: renewable energy consumption; CO2 emissions; pollution; gender pay gap; synthetic control method; panel data model

JEL Classification Codes: Q2, Q4, C51, C53

1. Introduction

Despite the constant efforts to improve the environmental quality to ensure human development, pollution remains the largest environmental health risk in the European Union (EU) (less healthy life expectancy, respiratory and cardiovascular diseases and even deaths). According to European Environment Agency, CEE countries and Italy registered the highest concentration in the Europe in 2022 for particles resulted from solid fuels burning used to cover heating in industry and households (EEA, 2023), which has negative consequences on health and well-being. Around 47.000 deaths each year are attributed to pollution in Poland that is the country in the CEE zone with the highest level of pollution.

Many experts claim that renewable energy consumption reduces pollution, but the empirical findings do not support this hypothesis in all the cases (for any sample of countries and in any

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period) (Simionescu, 2021 a). The measures to reduce pollution in CEE countries from the EU are strongly related to directives coming from the European Commissions for the member states. One European Directive launched in 2009 set up some targets to be reached by 2020 for all the EU Member States. After the waves of entrance in 2004 and 2007 for most of the CEE countries and in 2013 for Croatia, this directive was successfully implemented. However, its effect should be assessed in terms of pollution reduction.

Given this framework, the main goal of this paper is to assess the impact of renewable energy consumption on CO2 emissions as proxy for pollution in the CEE countries from the EU in the period 2007-2021, when all the states except Croatia were already members of the European Community. Moreover, the analysis is deepened in another direction that has never been studied in any other paper related to pollution-renewable energy nexus. Specifically, a counterfactual analysis is conducted to check if the European Directive on Renewable Energy determined a significant decrease in CO2 emissions compared to the other CEE states that have not joined the EU yet. In this sense, the synthetic control method is employed to conclude that the European Directive significantly reduced CO2 emissions in CEE countries that joined the EU compared with the case in which the directive would have not been applied. The entire paper is constructed around these two hypotheses (the renewable energy consumption reduced CO2 emissions in CEE countries from the EU and The Renewable Energy Directive from 2009 significantly reduced pollution in these countries compared to other CEE states outside the EU). The novelty of this study is given by the empirical evidence to support these hypotheses that have not been previously formulated in the literature. The CEE countries were selected in the analysis since pollution is a critical issue in the zone as previously argued. The paper continues with short review on literature, methodology description, results, discussion and conclusions.

2. Literature review

Pollution is a complex phenomenon that is affected by a variety of factors, from economic, environmental and social determinants to policy factors. The evaluation on empirical data might generate contradictory results or inconclusive findings depending on method, sample of countries or period. However, some policy tools proved to be effective in the fight against pollution and almost all the studies revealed the beneficial effect of renewable energy consumption on environment despite some inconclusive results.

This paper deals with a specific region- CEE countries belonging to the EU- that have a common history due to European directives on energy policy and de-carbonization. However, none of the previous study assessed if the European directive on renewable energy first launched in 2009 reduced the pollution more than in states outside of the EU that did not fix so challenging targets. Therefore, one of the research questions of this paper to cover this gap is: Did the European directive on renewable energy make a significant progress in CEE countries in the EU compared to other CEE countries outside the European Community that did not implement it?

Renewable energy consumption remains the most important EU solution to pollution. The Renewable Energy Directive launched in 2009 established as target 20% renewables by 2020 for the EU and specific national targets for member states. This directive was subject to revision in 2018 when new targets were set by 2030.

Besides the desired benefits for the environment, renewable energy use promotion has economic benefits in terms of the jobs creation or health impact by reducing the incidence of diseases caused by pollution. Despite the ambitious goals, biomass burning enhances air pollution and it is necessary to check on empirical data if the renewable energy consumption does reduce CO2 emissions. Many studies assessed the impact of renewable energy use on pollution even in CEE region (Simionescu, 2021 b). In the CEE, Majewska and Gierałtowska (2022) and Simionescu (2021a) concluded that renewable energy use has the capacity to reduce pollution. Therefore, the second research question is related to this hypothesis: Did the renewable energy consumption reduce CO2 emissions in the CEE countries from the EU?

The research is constructed around the Environmental Kuznets Curve (EKC) that links pollution to economic growth. According to this theory, the carbon dioxide emissions increase in the first phase with the economic growth, and after a maximum level, the emissions decrease while growth continues. This connection described inverted U pattern, but the data analysis might indicate the opposite pattern when EKC is invalidated. If the third order polynomial is considered, then an N pattern confirms EKC. The studies related to CEE countries bring mixed evidence. Most of the papers validate the EKC under inverted U pattern for various periods: 1980-2016 in 16 CEE countries (Chen et al., 2019), 1980-2016 in Poland, Croatia, Serbia, Slovakia and Ukraine (Saud et al., 2019), 1990-1999 for ten CEE states (Archibald et al., 2004), 1991-2011 for ten CEE countries (Destek et al., 2016), 1993-2004 for all the ex-communist countries (Tamazian and Rao, 2010), 1995-2014 for ten CEE states (Christoforidis and Katrakilidis, 2021), 1995-2015 in 11 CEE states (Destek and Okumus, 2019), 1990-2018 in Poland, Hungary, Slovakia, Czechia (Leitão et al., 2023). On the other hand, Simionescu (2021 b) identified U pattern and inverted N pattern for a sample composed by Hungary, Romania, Czechia, Slovenia, Slovakia and Bulgaria in the period 1990-2019 and an inverted U shape and N shape only for Poland in the same period for GHG emissions.

More control variables are considered in the panel data models. For example, index of economic freedom might explain pollution in the CEE states. The economic freedom creates the premises for concurrence and the extension of economic activities, which might be harmful for environment if clean technology is not promoted. For 10 CEE countries, Simionescu (2021 a) showed that economic freedom enhances GHG emissions only in the short-run in the period 2006-2019, while the correlation is negative in the long-run. The post-communist period also encouraged FDI in these states and the effect of this investment on pollution might be neutral, positive or negative. The results are mixed in the case of CEE countries. For example, no significant effect of FDI on CO2 emissions was reported by Archibald *et al.* (2004) for 10 CEE states in a short period of transition from planned economy to functional market economy (1990-1999). The harmful effect of FDI on environment is supported by Leitão et al. (2023) for V4 states in the period 1990-2018 and by Christoforidis and Katrakilidis (2021) for 10 CEE states in the period 1995-2014. For the same sample of 10 CEE countries, negative impact of FDI on pollution is documented by Simionescu (2021 a) in the period 1990-2019 and by Jambor and Leitao's (2017) in the period 1995-2017.

Human development is strongly correlated with pollution. For ten CEE countries, Simionescu (2021) suggested that human capital index reduced GHG emissions in the period 1990-2019, while in the study of Apostu et al. (2022) no significant relationship between pollution and CO2 is figured out for these states. Labour productivity growth might involve more economic activities that are harmful for the environment. Labour productivity enhanced pollution in ten CEE states in the period 2006-2019 as Simionescu et al. (2021) indicated.

As highlighted before, pollution is a major actual challenge for which more renewable energy consumption is an immediate solution. However, the actual debate on gender pay gap is closely related to pollution despite unexpected association due to differences in green consumption caused by the differences in salaries. Gender pay gap remains a measure of income inequality. The connection between income and demand conditions the effect of income inequality on CO2 emissions. If the income is linearly connected with environmental quality, then income inequality has no effect on environment. On the other hand, if there is a convex relationship between pollution and income, then less income inequality will determine more concern on environmental protection and, consequently, less pollution.

Income inequality might enhance pollution since poor individuals could try to overexploit the available natural resources, which is harmful for the environment (Grunewald et al., 2017). On the other hand, the income inequality might raise the number of working hours that could enhance pollution (Bowles and Park, 2005). Evidence from CEE countries lacks, this paper being the first one that explain CO2 emissions in this region using gender pay gap as measure of income inequality. Even if Gini index is the most popular indicator to quantify income inequality, gender pay gap was used in this study due to Europe directive to reduce gender discrimination in terms of wage differences. For 47 emerging countries, Yang et al. (2020) showed that income inequality contributed to reduction in pollution in the period 1980-2016.

3. Data and methodology

Starting from the research questions stated in the literature review section, two hypotheses are formulated in this study:

H1: The renewable energy consumption reduced the CO2 emissions in the CEE countries from the EU in the period 2007-2021.

H2: The Renewable Energy Directive launched in 2009 accelerated the decline in pollution in the 11 CEE countries from the EU compared to the CEE states outside the European Community.

For checking H1, this study uses panel data for the period 2007-2021 corresponding to 11 CEE countries located in the EU: Bulgaria, Hungary, Czech Republic, Croatia, Lithuania, Estonia, Romania, Latvia, Poland, Slovakia and Slovenia. The models start from the theoretical background given by the EKC under the polynomial form of order two to evidence a non-linear relationship between CO2 emissions and economic growth. The dependent variable is a proxy for pollution (CO2 emissions), while the rest of the indicators in Table 1 are used as explanatory variables in the model.

Table 1. The variables employed in the panel data models

Variable	Notation	Unit of measurement	Data source	Minimum value	Maximum value
Carbon dioxide emissions	CO_2	Kilo tonnes (kt)	World Bank Statista	7119.999 (Latvia, 2017)	313739.990 (Poland, 2007)
Gross domestic product per capita	GDP	constant 2015 US $/cap	World Bank	6048.696 (Bulgaria, 2007)	24744.841 (Slovenia, 2021)
Index of economic freedom	IEF	Index	The Heritage Foundation	53.4 (Croatia, 2007)	79.057 (Estonia, 2017)
Human development index	HDI	Index	United Nations Development Programme (UNDP)	0.774 (Bulgaria, 2007)	0.921 (Slovenia, 2019)
Foreign direct investment	FDI	% of GDP stock	World Bank	21.538 (Slovenia, 2008)	112.591 (Estonia, 2020)
Variable	**Notation**	**Unit of measurement**	**Data source**	**Minimum value**	**Maximum value**

Variable	Notation	Unit of measurement	Data source	Minimum value	Maximum value
Renewable energy consumption	REC	% of total final energy consumption	World Bank	7.28 (Poland, 2007)	42.6 (Latvia, 2017)
Labour productivity	LP	Output per worker (GDP constant 2015 US $)	International Labour Office (ILO)	45369 (Bulgaria, 2014)	71860 (Czech Republic, 2008)

Source: own synthesis

Since the data series are not stationary in level, the calculation of average of the indicators is not relevant (Box and Tiao, 1965). According to Table 1, Poland reached the maximum level of pollution in 2007, but it made little progress since then and the CO2 emissions decreased by around 2% in 2021 compared to 2007. Poland represents the third larger CO2 emitter in the entire EU in 2021 being surpassed only by Germany and Italy. The level of CO2 emissions in Latvia in 2021 is below the EU-27 average. On the other hand, Poland has the lowest share of renewable energy consumption in total energy use in the year with the highest level of pollution, while Latvia reached the highest share in 2017. The low labour productivity in Bulgaria is associated with low human development index and low GDP per capita. Estonia presents high values for index of economic freedom with a maximum level reached in 2017, which is associated with high FDI inflows. Slovenia is the leader in the sample in terms of GDP per capita and human development.

The data series associated to all the variables are taken in the natural logarithm in the models to alleviate the potential multi-collinearity and ensure interpretations of coefficients based on elasticities. The basic form EKC model using the second order polynomial function links CO2 emissions to economic growth in natural logarithm:

$$CO_{2it} = \alpha + \beta_1 \cdot GDP_{it} + \beta_2 \cdot GDP_{it}^2 + \beta_3 \cdot X_{it} + e_{it} \quad (1)$$

X-vector including control variables in the model

α -country-fixed effects

$\beta_1, \beta_2, \beta_3$- parameters

e_{it}- errors

i-index for cross-section (state), t-index for time (year)

Preliminary tests are run before the construction of the panel data models. The tests refer to cross-sectional dependence, normality, slope heterogeneity, panel unit root. Under the hypothesis of no normal distribution for data series, method of moments quantile (MMQ) regressions are run.

Let us start from a basic MMQ model for EKC:

$$CO_{2it} = f(GDP_{it}, GDP_{it}^2, REC_{it}) \quad (2)$$

The model in (2) is extended to include additional control variables and has the advantage of including distributional and country heterogeneity.

If we consider α_i as unobserved country effects, the equation (2) is rewritten in the following form:

$$E[CO_{2it}|(GDP_{it}, GDP_{it}^2, REC_{it}), \alpha_i] = ({GDP^T}_{it}, {GDP_{it}^2}^T, REC_{it}^T)\beta + \alpha_i \quad (3)$$

$$Q_{CO_{2it}}[\tau|(GDP_{it}, GDP_{it}^2, REC_{it}), \alpha_i] = \beta_{1\tau} GDP_{it} + \beta_{2\tau} GDP_{it}^2 + \beta_{3\tau} REC_{it} + \alpha_i \quad (4)$$

As Koenker and Hallock (2001) suggested, $\hat{\beta}(\tau)$ is computed as the τ^{th} quantile level. For τ we consider different values associated with conditional quantile functions (0.25, 0.5, 0.75, 0.95).

$$\hat{\beta}(\tau) = argmin_{\beta \in R^k}\left[\sum_{i \in \{i: y_i \geq x_i\beta\}} \tau|y_i - x_i\beta| + \sum_{i \in \{i: y_i < x_i\beta\}} (1-\tau)|y_i - x_i\beta|\right] \quad (5)$$

τ is the parameter size in the interval [0,1] to have the minimum of the weighted sum of deviation in the absolute value. The conditional quantile associated with CO2 emissions for different explanatory variables x_i is:

$$Q_{CO2}(\tau|GDP_{it}, GDP_{it}^2, REC_{it}) = (GDP_{it}, GDP_{it}^2, REC_{it})\beta_\tau \quad (6)$$

Mean group (MG) estimators are proposed for robustness check under the hypothesis of no cointegration. This allows us to make decisions on the utility of the renewable energy promotion.

For checking H2, synthetic control method is applied. The dependent variable is represented by CO2 emissions, while renewable energy consumption and GDP per capita play the role of predictors. The synthetic CEE-EU has to indicate predictor values of average CO2 emissions in the CEE countries from EU before the Directive on Renewable Energy from 2009.

To assess the impact of the European Directive on Renewable Energy on CO2 emissions under the hypothesis that pollution is influenced by GDP and renewable energy consumption, the comparison uses two types of countries: the 11 CEE countries from the EU that are considered on average as the unit exposed to policy intervention and the other type is represented by the other CEE countries that are not EU member countries.

Let's consider *J+1* countries. If CEE countries from the EU are considered a single unit exposed to policy intervention, the J countries that remain are known as donor pool from matching perspective. Moreover, it fulfilles the hypothesis that CEE countries from the EU are uninterruptedly exposed to this directive since 2009.

The result observed in any state *i* at time *t* without any policy intervention is given by the CO2 emissions: CO_{2it}^N , when i is the index for state (i=1, 2, …, J+1) and t is the time index (t=1, 2, …, T).

There are T_0 periods before the implementation of the European Directive in 2009, where $1 \leq T_0 \leq T$. The CO2 emissions that would be registered for unit *i* at time *t* if unit *i* is subject to intervention in the next periods (from $T_0 + 1$ to T) is CO_{2it}^I. The directive has no effect on pollution before intervention. Consequently, $CO_{2it}^I = CO_{2it}^T$, for i=1, 2, …, N and t= 1, 2, …, T_0. The research deals with the hypothesis that CO2 emissions in CEE countries outside the EU are not influenced by the European Directive on Renewable Energy.

The impact of the directive on country *i* at time *t* is written as $\alpha_{it} = CO_{2it}^I - CO_{2it}^N$. One dummy variable shows if a state is subject to the directive at a certain time: $D_{it} = 1$, if state *i* is exposed to the directive at time *t* and $D_{it} = 0$, else. The observed CO2 emissions for state *i* at time *t* are computed as follows: as:

$$CO_{2it} = CO_{2it}^N + \alpha_{it}D_{it} \quad (7)$$

Since only the 11 CEE from EU taken as a single unit are exposed to the directive after period T_0, with $1 \leq T_0 \leq T$, then, the dummy variable is described as: $D_{it} = 1$, if i=1 and $t > T_0$ and $D_{it} = 0$, otherwise.

The aim is the estimation of the components of the vector $(\alpha_{1T_0+1}, \ldots, \alpha_{1T})$. If $t > T_0$, then $\alpha_{1t} = CO_{21t}^I - CO_{21t}^N = CO_{21t} - CO_{21t}^N$. In this case, CO_{21t}^I is known and CO_{21t}^N has to be computed. A factor model is taken into account to calculate CO_{21t}^N:

$$CO_{21t}^N = \delta_t + \theta_t Z_i + \lambda_t \mu_i + \varepsilon_{it} \quad (8)$$

δ_t- unknown common factor with constant factor loadings across states

θ_t- vector of coefficients (1 x r)

μ_i- vector of unknown factor loadings (F x 1)

λ_t- vector of unobserved common factors (1 x F)

Z_i- vector for observed covariates (r x 1) not affected by the directive

ε_{it}- transitory shocks of null mean, that are not observed at the country level

Equation (8) generalizes the basic difference-in-differences model by considering constant λ_t at time t. The factor model is the one that supports the change in time for confounding unobserved characteristics.

If W is the vector of weights (J x 1), where $W = (w_2, \dots, w_{J+1})'$, $w_j \geq 0$, for j=2, 3, …, J+1 and $w_2 + w_3 + \cdots + w_{J+1} = 1$, any component of it is a potential synthetic control calculated as a weighted mean of control units. The value of CO2 emissions for each synthetic control supports the indexation according to W:

$$\sum_{j=2}^{J+1} w_j u_{jt} = \delta_t + \theta_t \sum_{j=2}^{J+1} w_j Z_j + \lambda_t \sum_{j=2}^{J+1} w_j \mu_j + \sum_{j=2}^{J+1} w_j \varepsilon_{jt} \qquad (9)$$

Let's consider $(w_j^*, \dots, w_{J+1}^*)$, with

$$\sum_{j=2}^{J+1} w_j^* u_{j1} = u_{11}$$

$$\sum_{j=2}^{J+1} w_j^* u_{j2} = u_{12}$$

$$\dots\dots\dots\dots\dots$$

$$\sum_{j=2}^{J+1} w_j^* u_{jT_0} = u_{1T_0}$$

$$\sum_{j=2}^{J+1} w_j^* Z_j = Z_1$$

$\sum_{t=1}^{T_0} \lambda_t' \lambda_t$ is non-singular

$$u_{1t}^N - \sum_{j=2}^{J+1} w_j^* u_{jt} = \sum_{j=2}^{J+1} w_j^* \sum_{s=1}^{T_0} \lambda_t \left(\sum_{n=1}^{T_0} \lambda_n' \lambda_n\right)^{-1} \lambda_s' \left(\varepsilon_{js} - \varepsilon_{1s}\right) - \sum_{j=2}^{J+1} w_j^* (\varepsilon_{jt} - \varepsilon_{1t}) \qquad (10)$$

In (10), the mean corresponding to the right-hand side is zero for many pre-intervention periods with respect to the scale related to transitory shocks. We may compute the estimator associated with α_{1t} as:

$$\hat{\alpha}_{1t} = u_{1t} - \sum_{j=2}^{J+1} w_j^* u_{jt}, \text{ if } t > T_0 \qquad (11)$$

The equation (8) is built when $(u_{11}, \dots, u_{1T_0}, Z_1')$ belongs to the convex hull of $\{(u_{21}, \dots, u_{2T_0}, Z_2'), \dots, (u_{J+1\,1}, \dots, u_{J+1\,T_0}, Z_{J+1}')\}$.

Let us describe the implementation of the method on our dataset. Weights higher than one in absolute value are also used to make extrapolation. The CO2 emissions in CEE countries from the EU at time t is CO_{21t}, while this variable in the states from donor pool at the time t is CO_{2jt} , j=2,…, J+1. We define the vector K (T_0 x 1) as $K = (k_1, \dots, k_{T_0})'$ and the linear combination of values before the European Directive on Renewable Energy: $\overline{CO}_{2i}^K = \sum_{s=1}^{T_0} k_s CO_{2is}$.

For M linear combination using the vectors K_1, ..., K_M, for the CEE countries that joined EU, the vector of characteristics before the European Directive (k x 1): $X_1 = (Z_1', \overline{CO}_{21}^{K_1}, \dots, \overline{CO}_{21}^{K_M})'$, where k= r +M.

X_0 is a matrix (k x J) with indicator corresponding to states in the donor pool. The j-th column of X_0 is $(Z_j', \overline{CO}_{2j}^{K_1}, \dots, \overline{CO}_{2j}^{K_M})'$. The vector W* is chosen with the scope to minimize the distance between X_1 and X_0W, $\|X_1 - X_0W\|$. In this case, the weights are at least zero and their sum is one.

The distance is calculated using the positive semi-definite and symmetric matrix V (k x k): $\|X_1 - X_0W\|_V = \sqrt{(X_1 - X_0W)'V(X_1 - X_0W)}$. The selection of V is made to ensure the minimization of the root mean squared prediction error (RMSPE) of the CO2 emissions in the period before the implementation of the European Directive on Renewable Energy.

Given the description of the methods used to check the two hypotheses, the next section presents the results that will support our assumptions. The results will allow us to formulate policy recommendations.

4. Results and discussion

Preliminary tests are applied before the proposal of specific panel data models. First, the hypothesis that renewable energy consumption reduces pollution is checked for the CEE countries in the EU in the period 2007-2021. According to Table 2, cross-sectional independence hypothesis is rejected for all data series at 1% significance level, while heterogeneity is supported only in the cases of FDI and LP at 5% significance level and for REC at 10% significance level.

Table 2. Pesaran (2004) CD test and slope homogeneity test

Indicator	$\bar{\Delta}_{adj}$	Pesaran CD test
CO2	-1.158 (0.247)	19.16*** (<0.01)
GDP	-0.694 (0.488)	25.84*** (<0.01)
FDI	-2.492** (0.013)	14.00*** (<0.01)
IEF	-0.449 (0.653)	8.45*** (<0.01)
GPG	-0.377 (0.706)	3.97*** (<0.01)
HDI	0.152 (0.879)	26.73*** (<0.01)
REC	1.955* (0.051)	19.79*** (<0.01)
LP	-2.000** (0.045)	24.44*** (<0.01)

*Source: own calculations in Stata 15; p-values in brackets; Note: ***p-value<0.01, **p-value<0.05, *p-value<0.1.*

The second-generation panel unit root tests like the Breitung test, are used under cross-sectional dependence. Two cases are considered when a lag is added or not to the equation. The results in Table 3 suggest that all the data series are stationary in the first difference.

Table 3. The results of Breitung test

Variable	Data in level		Data in the first difference	
	no lag	one lag	no lag	one lag
CO2	0.8206 (0.7941)	0.0954 (0.5380	-6.0785*** (0.0000)	-1.3862* (0.0828)

Variable	Data in level		Data in the first difference	
	no lag	one lag	no lag	one lag
GDP	3.8197 (0.9999)	2.7356 (0.9969)	-5.7141*** (0.0000)	-1.7222* (0.0514)
FDI	-2.4939*** (0.0063)	1.4362 (0.9245)	-4.6885*** (0.0000)	-1.3884* (0.0825)
IEF	1.7921 (0.9634)	1.5371 (0.9379)	-6.0203*** (0.0000)	-2.9921*** (0.0014)
GPG	0.8334 (0.7756)	0.0984 (0.5465)	-5.3473*** (0.0000)	-5.4464*** (0.0000)
HDI	3.2964 (0.9995)	0.1252 (0.5498)	-1.8651** (0.0311)	-2.6748*** (0.0037)
REC	2.9853 (0.9986)	0.7448 (0.7718)	-4.5684*** (0.0000)	-1.5000* (0.0668)
LP	4.5134 (0.9999)	4.0358 (0.9999)	-5.1272*** (0.0000)	-2.5991*** (0.0027)

*Source: own calculations in Stata; Note: ***p-value<0.01, **p-value<0.05, *p-value<0.1.*

According to the correlation matrix for variables in the natural logarithm (coefficients of correlation in brackets), there is a strong correlation between GDP and labour productivity (0.9423) and between GDP and human capital index (0.9042), between FDI and gender pay gap (0.6282), labour productivity and human capital index (0.8639), the index of economic freedom and gender pay gap (0.4191) (see Appendix).

According to the Shapiro-Wilk and Shapiro-Francia tests, the normal distribution is supported only for a few data series at the 5% significance level: GDP, IEF and HDI (see Table 4). Therefore, the MMQ regressions could be considered.

Table 4. The results of Shapiro Wilk W test and Shapiro Francia W test for normal data

Variable (series in ln)	Shapiro Wilk W test		Shapiro Francia W test	
	Stat.	p-value	Stat.	p-value
CO2	4.394	0.00001	3.931	0.00004
GDP	1.512	0.06532	1.069	0.14256
FDI	2.027	0.02133	1.722	0.04254
IEF	1.271	0.10192	1.137	0.12772
GPG	6.077	0.00000	5.615	0.00001
HDI	0.495	0.31033	-0.007	0.50281
Variable (series in ln)	**Shapiro Wilk W test**		**Shapiro Francia W test**	
	Stat.	p-value	Stat.	p-value
REC	3.661	0.00013	3.364	0.00038
LP	3.655	0.00013	3.359	0.00039

Source: own calculations in Stata 15.

The results in Table 5 suggest a U-pattern in the growth-pollution nexus in most of the cases. Gender pay gap and renewables consumption had a negative impact on CO2 emissions. The indirect effect of IEF on pollution is significant only for the 25th, 50th and 75th quantiles. FDI has a positive impact on CO2 at 25th and 50th quantiles and a negative one at the 95th quantile. These empirical findings suggest that FDI is friendly-environmental only in the lung-run. Economic freedom enhanced the economic activities, but in a manner that was favourable to the environment.

Table 5. MMQ regression models based on EKC to explain CO2 emissions in CEE countries (2007-2021)

Variable (series in ln)	Quantiles for M1				Quantiles for M2				Quantiles for M3			
	0.25	0.5	0.75	0.95	0.25	0.5	0.75	0.95	0.25	0.5	0.75	0.95
GDP	-2.93 (0.003)	-2.51 (0.012)	-1.37 (0.172)	-0.44 (0.657)	-66.36 (0.102)	-69.72 (0.049)	-76.16 (0.047)	-82.58 (0.127)	-63.95 (0.161)	-71.01 (0.061)	-80.71 (0.04)	-88.47 (0.075)
GDP^2	2.91 (0.004)	2.51 (0.012)	1.37 (0.169)	0.46 (0.645)	3.29 (0.099)	3.45 (0.047)	3.76 (0.045)	4.07 (0.126)	3.09 (0.168)	3.47 (0.062)	4.01 (0.038)	4.43 (0.069)
RC	-2.25 (0.024)	-4.08 (0.000)	-4.90 (0.000)	-5.33 (0.000)	-0.48 (0.012)	-0.66 (0.000)	-0.99 (0.000)	-1.32 (0.000)	-0.38 (0.042)	-0.70 (0.000)	-1.13 (0.000)	-1.48 (0.000)
IEF	-	-	-	-	-5.20 (0.001)	-4.44 (0.002)	-2.96 (0.054)	-1.49 (0.485)	-		-	-
FDI	-	-	-	-	0.92 (0.015)	0.41 (0.0259)	-0.57 (0.154)	-1.55 (0.002)	-		-	-
GPG	-	-	-	-	-	-	-	-	-0.30 (0.095)	-0.46 (0.003)	-0.68 (0.000)	-0.86 (0.000)
Constant	3.01 (0.003)	2.59 (0.010)	1.41 (0.157)	0.47 (0.639)	362.89 (0.080)	379.62 (0.036)	411.82 (0.035)	443.83 (0.109)	341.27 (0.141)	374.40 (0.052)	419.97 (0.036)	456.35 (0.070)

*Source: authors' computations in Stata 15 with p-values in brackets; *, **, *** show p-value less than 10%, 5%, and 1% respectively.*

The results in Table 6 suggest that labour productivity measured as output per worker reduces pollution for inferior quantiles (0.25 and 0.5) and increases it for the superior quantile (0.95). The human development index has a negative impact on CO2 for the first two quantiles considered in this study and a positive one for the last two. Renewable energy consumption and the gender pay gap reduce CO2 emissions for all quantiles.

Table 6. MMQ regression models to explain the non-linear relationship between HDI and CO2 emissions in CEE countries (2007-2021)

Variable (series in ln)	Quantiles for M4				Quantiles for M5			
	0.25	0.5	0.75	0.95	0.25	0.5	0.75	0.95
HDI	-	-	-	-	-6.470** (0.032)	-1.683* (0.052)	6.984**(0.011)	11.744**(0.027)
LP	-0.934* (0.088)	-0.264* (0.097)	0.821 (0.11)	1.946*** (0.001)	-	-	-	-
REC	-0.431** (0.018)	-0.656*** (<0.01)	-1.022*** (<0.01)	-1.420*** (<0.01)	-0.336* (0.09)	-0.634*** (0.001)	-1.174*** (<0.01)	-1.471*** (<0.01)

Variable (series in ln)	Quantiles for M4				Quantiles for M5			
	0.25	0.5	0.75	0.95	0.25	0.5	0.75	0.95
GPG	-0.389*** (0.009)	-0.462*** (0.001)	-0.580*** (<0.01)	-0.702 (<0.01)	-0.335* (0.089)	-0.449*** (0.009)	-0.654*** (0.001)	-0.767*** (0.002)
Constant	21.558*** (<0.01)	14.994*** (0.003)	4.347 (0.433)	-6.684 (0.309)	9.967*** (<0.01)	11.745***(<0.01)	14.964*** (<0.01)	16.732*** (<0.01)

*Source: own calculations in Stata 15; p-values in brackets; Note: ***p-value<0.01, **p-value<0.05, *p-value<0.1.*

For robustness, Pesaran and Smith (1995) Mean Group estimators are considered and the results in Table 7 confirm the U pattern in the growth-pollution nexus and the negative impact of renewables consumption and the gender pay gap. On the other hand, FDI and HDI enhance pollution, while IEF reduces it.

Table 7. Pesaran and Smith (1995) Mean Group estimators

Variable	M6	M7
GDP	-130.876***(<0.001)	-
GDP^2	6.413***(<0.001)	-
GPG	-0.485***(<0.001)	-
HDI	-	4.028***(0.01)
REC	-0.931***(<0.001)	-1.078***(<0.001)
IEF	-	-5.819***(<0.001)
FDI	-	0.144* (0.064)
Constant	680.153***(<0.001)	35.997***(<0.001)

*Source: own calculations in Stata 15; p-values in brackets; Note: ***p-value<0.01, **p-value<0.05, *p-value<0.1.*

A non-linear relationship was not valid between pollution and FDI or pollution and HDI, which creates the premises of a stable connection for which policy proposals are necessary. These results are subject to discussion and policy proposals.

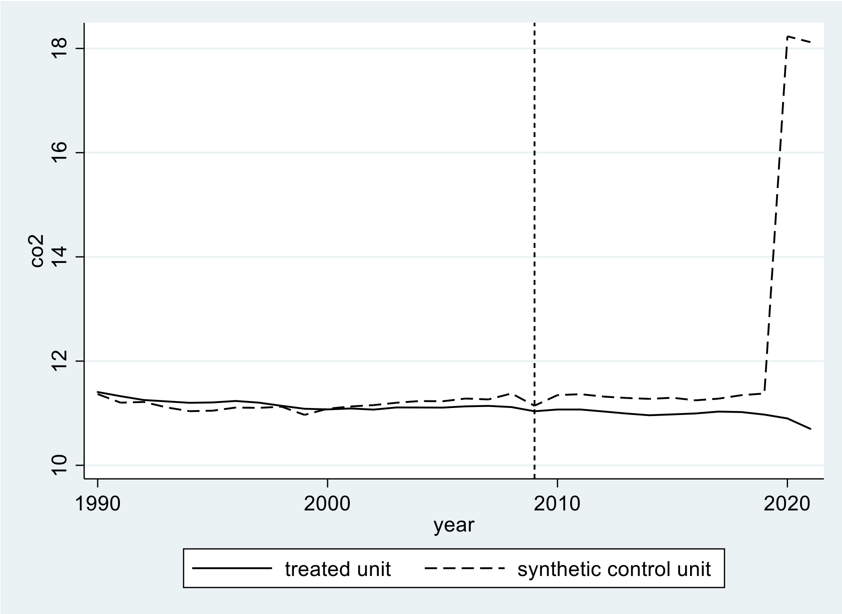
The second hypothesis related to the effect of the European Directive on Renewable Energy on CO2 emissions in the CEE countries from the community is checked by making comparisons with CEE countries outside the EU. Since the synthetic control method allows the use of only one treatment unit, the average values of the indicators are calculated for CEE countries in the EU in the period 1990-2021.

The synthetic CEE from the EU (CEE-EU) is considered a synthetic control unit and its computation is based on the weighted mean corresponding to potential control countries. The weights are selected to result the synthetic CEE-EU that optimally reproduces the values of predictors on CO2 emissions in the CEE from EU before the European Directive on Renewable Energy was released in 2009. The synthetic CEE-EU has to reproduce the level of pollution that would have been registered if the CEE states from EU had not implemented this directive in 2009.

The initial donor pool is represented by the CEE countries outside the EU: North Macedonia, Russia, Ukraine, Serbia, Bosnia and Herzegovina, Albania, Armenia, Georgia, Azerbaijan, Moldova, Montenegro, and Belarus (12 countries). After the application of the method, only two countries were selected in the final control group: Montenegro with the weight 0.458 and Russian Federation with weight 0.542.

The control group is suitable for the CEE countries in the EU in terms of renewable energy consumption and GDP per capita. In the case of GDP per capita in natural logarithm for the treated unit we have the value 9.049, and for the synthetic unit the value 8.615. However, the difference is lower in the case of renewable energy consumption in the natural logarithm: 2.546 (treated) and 2.428 (synthetic).

Figure 1. Treated and synthetic control unit in the period 1990-2021 for CO2 emissions in CEE from EU



Source: own graph in Stata 15.

Figure 1 suggests that after the application on the European Directive of Renewable Energy in 2009, the CO2 emissions were lower compared with the case when this directive would not have been implemented. This difference is higher compared to previous period, but it is still not very high. However, a huge difference has been observed since 2019, and this might be explained by at least three arguments. First, the revised directive implemented in 2018 strengthened the necessity of continuing the progress in consuming more renewable energy in the EU. Second, the CEE countries in the EU struggled more to exceed the targets set up for 2020 in the directive from 2009. Third, the COVID-19 pandemic reduced the level of air pollution, but enhanced plastic pollution as Benson et al. (2021) suggested. The conclusion shows that the European Directive on Renewable Energy reduced the pollution in the long run more than in the short run compared to CEE states outside the European Community.

An U-pattern is observed in the EKC for the 11 CEE countries that are among the EU countries, which is similar to the result of Christoforidis and Katrakilidis (2021) for the interval 1995–2014 and contrary to the conclusion of Simionescu (2023), who highlighted the beneficial impact of economic development on environment in these countries using another method (DOLS/FMOLS estimators). The U pattern is confirmed by Majewska and Gierałtowska (2022) for more CEE countries during 2000-2019 and by Simionescu (2021 b) for the same sample, but in the period 1990-2019. The empirical findings of this paper suggest that CEE states might make more efforts to enhance green growth with a positive effect on environmental quality. Moreover, these countries need more national regulations and restrictive directives to manage climate change by promoting sustainable economic growth.

Renewables consumption reduces pollution in the states that were analysed in this paper. The role of renewable energy use in mitigating pollution based on GHG emissions in the long-run in 10 CEE states is previously demonstrated by Simionescu *et al.* (2022) in the period 2002-2019 and by Chen *et al.* (2019) for the period 1991-2014. Moreover, for the 11 CEE states, Simionescu et al. (2023) showed using the DOLS/FMOLS approach and CCEMG estimations that renewable energy consumption reduces CO2 emissions in the period 2007-2021. Renewable energy consumption is promoted by the European Green Deal and the investment in this type of energy and reduction in costs of the technologies based on it had the expected results in terms of pollution reduction. However, more efforts are necessary for all the EU states to achieve zero-net greenhouse emissions by 2050 and make Europe the first neutral climate continent. Besides the beneficial effects of this renewable energy for the environment, the competitive position of the markets associated with this type of energy needs to improve.

FDI enhances pollution in the analysed sample. The pollution haven hypothesis is supported by Martínez-Zarzoso et al. (2013) for CEE countries in the period 1999-2013 for some dirty industries. Usually, foreign investors from developed countries prefer these emerging economies due to lax pollution regulations. Their profit seems to be more important than environmental protection, which supports the U pattern in the EKC framework in this case. Therefore, CEE countries should implement stricter rules for foreign investors to reduce the negative impact of their economic activities on the environment. On the other hand, Spatareanu (2007) showed that more stringent regulations for a cleaner environment in the origin country determine foreign investors' willingness to extend their activity abroad. If host countries were stricter, then FDI would be discouraged.

Economic freedom reduces CO2 emissions in the 11 CEE countries. The result is in line with Simionescu et al. (2021 a) for 10 CEE states in the period 2006-2019 and with Saint Akadiri et al. (2019) for the EU-28 countries in the period 1995-2015. The role of economic freedom in reducing pollution might be explained by its association with more renewable energy consumption and energy efficiency.

The gender pay gap reduces CO2 emissions in the 11 CEE states. A similar finding was previously obtained by Yang et al. (2020) for 47 developing states during 1980-2016 and for a few less developed states. This characteristic is specific to emerging countries, while in developed countries the gender pay gap enhances pollution.

Human development and labour productivity enhance pollution in the long-run, but the effect is beneficial for the environment in the short-run. The results are in line with Simionescu *et al.* (2022) who showed the direct influence of labour productivity on pollution measured by GHG emissions in ten CEE countries from the EU in the period 2002-2019. Cui *et al.* (2017) showed that increased labour productivity in Scotland simulated export with a negative impact on the environment. Moreover, Majewska and Gierałtowska (2022) showed for more CEE countries during 2000-2019 that human development is a real threat to environmental quality.

The application of the synthetic control method suggested that the European Directive on Renewable Energy significantly contributed to the reduction in CO2 emissions in the long-run. The decrease is more significant after 2018 when the revised directive was implemented and the countries were close to 2020 for which the initial targets were set up. These results suggest the efficiency of constant European initiatives to increase the share of renewable energy consumption in final energy use.

5. Conclusions and further works

This paper assesses the role of renewable energy consumption in reducing pollution in emerging economies like CEE countries in the EU in the period 2007-2021, when all of these states were already EU member states, except for Croatia that joined the EU in 2013. Moreover, the role of the European Directive on Renewable Energy in reducing pollution was tested using the synthetic control method. These hypotheses were stated in line with the previous findings in the literature for other countries. Indeed, renewable energy consumption reduced CO2 emissions due to the European Directive on Renewable Energy Use that was also assumed by these countries as part of the EU. On the other hand, more income inequality between males and females contributes to environmental protection, despite the acute debate related to gender discrimination.

These findings are subject to environmental and social policies. Governments should continue to invest in renewable energy sources, due to reduction in CO2 emissions. These might consist in subsidies assigned to green transportation and the development of social welfare programs to promote a sustainable lifestyle even in the case of low-income families. The differences in wages between males and females affect decisions related to green consumption.

Besides the utility of these results in designing sustainable policies to reduce pollution in CEE countries, this study is still subject to limitations. First, only few variables are considered in the model, neglecting aspects related to governance quality. Second, a short period was analysed when all the countries were EU member states, because the aim was to highlight the impact of the European Directive on renewable energy use on pollution. Therefore, more variables should be included in the models, like indicators related to the quality of governance variables (political stability, rule of law etc.). A longer period should be considered and a comparative analysis is necessary for the period before and after the EU integration in terms of the effective impact of renewable energy consumption on CO2 emissions using panel data models.

References

Apostu, S.A., Panait, M., and Vasile, V., 2022. The energy transition in Europe—a solution for net zero carbon?. *Environmental Science and Pollution Research*, *29*47, pp.71358-71379. https://doi.org/10.1007/s11356-022-20730-z.

Archibald, S.O., Banu, L.E., and Bochniarz, Z., 2004. Market liberalisation and sustainability in transition: Turning points and trends in central and Eastern Europe. *Environmental Politics*, *13*1, pp.266-289. https://doi.org/10.1080/09644010410001685236.

Benson, N.U., Bassey, D.E., and Palanisami, T., 2021. COVID pollution: impact of COVID-19 pandemic on global plastic waste footprint. *Heliyon*, *7*2, e06343. https://doi.org/10.1016/j.heliyon.2021.e06343.

Bowles, S. and Park, Y. 2005. Emulation, inequality, and work hours: Was Thorsten Veblen, right? *The Economic Journal*, *115*507, pp. F397-F412. https://doi.org/10.1111/1468-0297.00081.

Box, G.E., and Tiao, G.C., 1965. A change in level of a non-stationary time series. *Biometrika*, *52*1/2, pp. 181-192. https://doi.org/10.1093/biomet/52.1-2.181.

Chen, S., Saud, S., Saleem, N. and Bari, M.W., 2019. Nexus between financial development, energy consumption, income level, and ecological footprint in CEE countries: do human capital and biocapacity matter?. *Environmental Science and Pollution Research*, *26*, pp. 31856-31872. https://doi.org/10.1007/s11356-019-06343-z.

Christoforidis, T. and Katrakilidis, C., 2021. Does foreign direct investment matter for environmental degradation? Empirical Evidence from Central–Eastern

European Countries. *Journal of the Knowledge Economy*, pp.1-30. https://doi.org/10.1007/s13132-021-00820-y.

Cui, C.X., Hanley, N., McGregor, P., Swales, K., Turner, K. and Yin, Y.P., 2017. Impacts of Regional Productivity Growth, Decoupling and Pollution Leakage. Reg. Stud. 51 9, pp.1324–1335. doi:10.1080/00343404.2016.1167865.

Destek, M.A., and Okumus, I., 2019. Does pollution haven hypothesis hold in newly industrialized countries? Evidence from ecological footprint. *Environmental Science and Pollution Research*, *26*, pp.23689-23695. https://doi.org/10.1007/s11356-019-05614-z.

Destek, M.A., Balli, E. and Manga, M., 2016. The relationship between CO2 emission, energy consumption, urbanization and trade openness for selected CEECs. *Research in World Economy*, *7*1, pp.52-58. https://doi.org/10.5430/rwe.v7n1p52.

EEA, European Environment Agency 2023. Europe's air quality status 2023, https://www.eea.europa.eu/publications/europes-air-quality-status-2023 [Accessed 27 April 2024].

Grunewald, N., Klasen, S., Martínez-Zarzoso, I. and Muris, C., 2017. The trade-off between income inequality and carbon dioxide emissions. Ecological Economics, 142, pp.249-256. https://doi.org/10.1016/j.ecolecon.2017.07.017.

Jambor, A. and Leitao, N.C., 2017. Economic growth and sustainable development: evidence from Central and Eastern Europe. *International Journal of Energy Economics and Policy*, *7*5, pp.171-177. https://doi.org/10.18778/1508-2008.24.31.

Koenker, R. and Hallock, K.F., 2001. Quantile regression. Journal of economic perspectives, 154, pp.143-156. https://doi.org/10.1257/jep.15.4.143.

Leitão, N.C., Dos Santos Parente, C.C., Balsalobre-Lorente, D. and Cantos Cantos, J.M., 2023. Revisiting the effects of energy, population, foreign direct investment, and economic growth in Visegrad countries under the EKC scheme. *Environmental Science and Pollution Research*, *30*6, pp.15102-15114. https://doi.org/10.1007/s11356-022-23188-1.

Majewska, A. and Gierałtowska, U., 2022. Impact of economic affluence on CO2 emissions in CEE countries. *Energies*, *15*1, 322, pp.1-21. https://doi.org/10.3390/en15010322.

Martínez-Zarzoso, I., Vidovic, M. and Voicu, A.M., 2017. Are the Central East European countries pollution havens?. *The Journal of Environment and Development*, *26*1, pp.25-50. https://doi.org/10.20472/iac.2016.022.063.

Pesaran, M.H. and Smith, R., 1995. Estimating long-run relationships from dynamic heterogeneous panels. *Journal of econometrics*, *68*1, pp.79-113.

Saint Akadiri, S., Alola, A.A., Akadiri, A.C. and Alola, U.V., 2019. Renewable Energy Consumption in EU-28 Countries: Policy Toward Pollution Mitigation and Economic Sustainability. Energy Policy 132, pp.803–810. doi:10.1016/j.enpol.2019.06.040.

Saud, S., Chen, S., Haseeb, A., Khan, K. and Imran, M., 2019. The nexus between financial development, income level, and environment in Central and Eastern European Countries: a perspective on Belt and Road Initiative. *Environmental Science and Pollution Research*, *26*, pp.16053-16075. https://doi.org/10.1007/s11356-019-05004-5.

Simionescu, M., 2021a. Revised environmental Kuznets Curve in CEE countries. Evidence from panel threshold models for economic sectors. *Environmental Science and Pollution Research*, *28*43, pp.60881-60899. https://doi.org/10.1007/s11356-021-14905-3.

Simionescu, M., 2021b. The nexus between economic development and pollution in the European Union new member states. The role of renewable energy consumption. *Renewable Energy*, *179*, pp.1767-1780.

Simionescu, M., Radulescu, M., Balsalobre-Lorente, D. and Cifuentes-Faura, J., 2023. Pollution, political instabilities and electricity price in the CEE countries during the war time. *Journal of Environmental Management*, *343*, 118206. https://doi.org/10.1016/j.jenvman.2023.118206.

Simionescu, M., Strielkowski, W. and Gavurova, B., 2022. Could quality of governance influence pollution? Evidence from the revised Environmental Kuznets Curve in Central and Eastern European countries. *Energy Reports*, *8*, pp.809-819. https://doi.org/10.1016/j.egyr.2021.12.031.

Simionescu, M., Szeles, M.R., Gavurova, B., and Mentel, U., 2021. The Impact of Quality of Governance, renewable energy and foreign direct investment on sustainable development in cee countries. *Frontiers in Environmental Science*, *9*, 765927. https://doi.org/10.3389/fenvs.2021.765927.

Spatareanu, M., 2007. Searching for pollution havens: The impact of environmental regulations on foreign direct investment. *The Journal of Environment and Development*, *16*2, pp.161-182. https://doi.org/10.1177/1070496507302873.

Tamazian, A., and Rao, B.B., 2010. Do economic, financial and institutional developments matter for environmental degradation? Evidence from transitional economies. *Energy economics*, *32*1, pp.137-145. https://doi.org/10.1016/j.eneco.2009.04.004.

Yang, B., Ali, M., Hashmi, S.H. and Shabir, M., 2020. Income inequality and CO2 emissions in developing countries: the moderating role of financial instability. Sustainability, 1217, 6810, pp.1-24. https://doi.org/10.3390/su12176810.

Appendix

	ln_co2	ln_gdp	ln_fdi	ln_ief	ln_w	ln_ief	ln_gpg
ln_co2	1.0000						
ln_gdp	-0.1087	1.0000					
ln_fdi	0.0421	-0.1742	1.0000				
ln_ief	-0.1382	0.3999	0.3462	1.0000			
ln_w	-0.0983	0.9426	-0.2156	0.2393	1.0000		
ln_ief	-0.1382	0.3999	0.3462	1.0000	0.2393	1.0000	
ln_gpg	-0.1639	0.0332	0.6282	0.4191	-0.0318	0.4191	1.0000
ln_hdi	-0.1571	0.9042	-0.2259	0.3564	0.8639	0.3564	0.0646
ln_rc	-0.4183	0.2694	-0.1484	-0.1402	0.2557	-0.1402	-0.2795

	ln_hdi	ln_rc
ln_hdi	1.0000	
ln_rc	0.3269	1.0000