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RENEWABLES AND DECARBONISATION: IMPLICATIONS FOR ENERGY POLICY IN THE EUROPEAN UNION

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Abstract

The study examines the contribution of low-carbon and fossil electricity sources to environmental degradation in the European Union countries, modelled by economic development and globalisation. We ensure the robustness of the results by exploring the concurrent and individual effects of the alternative electricity sources on GHG emissions. Consistent GMM estimators indicate that all low-carbon sources have a mitigating effect on environmental degradation in the EU, in a context of persistent pollution fuelled by fossil-fuels-based electricity. Hydropower and wind emerge as the most efficient electricity generation sources in the fight against climate change. Countries' development level, globalisation and population were not found to significantly impact pollution in EU countries. Our results have important implications for energy policy, suggesting that replacing fossil fuels in electricity generation with low-carbon sources, in particular wind and hydro, is a beneficial path to achieve decarbonisation while also decreasing the EU's reliance on foreign oil and gas.

Keywords: Energy policy, European Union, decarbonisation, low-carbon electricity, renewable energy, system-GMM.

JEL Classification: C23, O13, Q56, Q58.

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Introduction

The year 2022 will go down in the energy market history as a watershed year. The Russian Federation's invasion of Ukraine in February 2022 has severely disrupted energy markets, resulting in soaring and volatile prices resembling the 1970s oil crises (Meckling et al., 2022). Countries' responses to the energy crisis have ranged from hastening the green transition to cleaner energy sources, as many European Union (EU) countries have decided, to increasing fossil fuel production, such as Germany. At the same time, the EU is strongly engaged in the fight against climate change through efforts to decarbonise its economic activities.

Energy was one of the first concerns of European countries, as the European Coal and Steel Community, established in 1951, served as the foundation for the European Economic Community (EEC). Furthermore, the European Community of Atomic Energy (Euratom) treaty was signed in 1957, coinciding with the birth of the EEC. But it was not until the Lisbon Treaty in 2009 that energy became its own policy area, shaped since then by three frames - energy supply security, sustainability, and competitiveness - embedded in the 2015 Energy Union strategy (Knodt, 2018). The Energy Union aims to diversify energy sources, establish a fully integrated energy market, improve energy efficiency, reduce reliance on energy imports, decarbonise economic activities, and promote energy-related research and innovation (European Parliament, 2021). The European Commission (EC) proposed in 2016 the "Clean energy for all Europeans" package, consisting of eight legislative proposals that were fully adopted by 2019, addressing all the objectives encompassed by the Energy Union strategy. The energy policy framework was revised in 2018 to include specific 2030 targets for energy efficiency (improvement of 32.5%), GHG emissions (reductions of at least 40%), renewable energy consumption (increase to 32%), and the EU's electricity systems (interconnection of at least 15%).

It should be noted that recent changes in the EU's energy policy have been designed to ambitiously converge with the European Green Deal, in which all 27 EU members committed to developing sustainable and decarbonised economies by improving energy performance, fostering environmental degradation reduction, and combating climate change (European Commission, 2021a). Furthermore, the "Fit for 55" component of the European Green Deal, adopted in 2021 is a 55% reduction target in greenhouse gases (GHG) emissions in the EU by 2050 and a 32% share of renewable energy sources in energy consumption by 2030 (European Commission, 2021b).

As part of its RePowerEU policy, the EU plans to reduce imports from foreign countries by two-thirds in 2022. RePowerEU pushes EU countries to accelerate the green transition and invest in clean energy sources, decarbonisation programs, and hydrogen accelerators, while adding to EU regulatory complexity and overlapping with other EU aims and rules (Kankaanpää, 2022). Furthermore, the European Commission proposed a rise in the 2030 target for renewable energy to 45% (European Commission, 2022). The EU's energy strategy became more entangled with environmental and sustainability goals and the inclusion of low-carbon and renewable sources in production and consumption is crucial to achieve the decarbonisation targets.

Our research analyses the importance of alternative electricity-generating sources in the EU and contributes to the knowledge on energy policy and environmental quality by addressing fossil versus low-carbon power sources in the decarbonisation framework. First, we include several sources in electrical production to accurately assess the relationship between effects

(output) and causes (electricity sources). Second, the system-GMM econometric methodology we adopt is well-known for its robustness for panels of various dimensions, its capacity to manage heteroscedasticity, autocorrelation, and endogeneity, and its ability to handle weak instruments and omitted dynamics in static panel models. Third, we assess the influence of electricity sources on GHG emissions in a combined framework that considers both their cumulative and individual effects on environmental quality and emissions. This lets us rank electricity sources by environmental impact and study their relationships. Given the constraints on EU countries to minimise their reliance on oil and gas imports while addressing major environmental concerns, we believe our findings support a well-balanced and efficient energy strategy that addresses both environmental challenges and imported energy dependence risks.

The rest of the paper is structured as follows. The following section summarises the main takeaways from the existing literature that are relevant to our endeavour, followed by the presentation of research methodology. The Results and Discussion section highlights the most significant findings and relates them to previous contributions. The main implications of our research, as well as limitations and future research avenues, are outlined in the Conclusions section.

1. Literature review

In recent decades, the scholarly literature on environmental and energy economics has flourished, driven by the affirmation of climate change realities, volatile fossil fuel prices, and political uncertainties. A Web of Science topic search reveals that 13,402 contributions addressing “energy policy” or “energy policies” were published between 1975 and 2021, with 9,061 (67.6%) published in the last ten years. Furthermore, there were 1,050 publications linking energy policies to the EU since 1975, with 75.7% of them published after 2012 (795). This clearly demonstrates the global interest in energy issues, which is related to a wide range of topics such as renewable energy, sustainability, emissions, environmental quality, and so on. Remarkably, the most cited paper in this field according to Web of Science is Gielen et al. (2019), which addressed the role of renewable energy in global energy transformation. The authors emphasised that, when combined with energy efficiency, electrification, and end-uses, renewable energy could meet two-thirds of global energy demand while also significantly reducing emissions by up to 94%.

The shift in countries’ energy mix toward renewable energy sources aimed at reducing emissions and pollution while also reducing the reliance on energy imports is well documented in the scientific literature. Extant research on the impact of energy sources on emissions is mixed, with reference to low-carbon and renewables. However, it shows that high shares of fossil fuels in the energy mix led to significant increases in emissions - see, in this regard, Bond’s (2022) thorough analysis of the relationship between fossil fuels and the environment, or Buck’s (2021) strong plea to end fossil fuel dominance. Many researchers have emphasised the positive impact of renewable energy on emissions in various modelling frameworks. Saidi and Omri (2020) concluded that low-carbon energy consumption reduces carbon emissions in OECD countries, but that a combination of renewable and nuclear energy is the best option for combating emissions. Similarly, Bhat, Sofi and Sajith (2020) highlighted the deterioration in environmental quality caused by non-renewable energy consumption in G20 countries, as well as economic growth and urbanisation, while demonstrating that increases in renewable energy significantly improve environmental quality. In addition, Horobeţ et al. (2022) demonstrated in a study

involving a large global panel of countries that all renewable sources reduce GHG emissions; however, they did not confirm the findings in the case of nuclear energy. However, the positive impact of renewables on the environment, at least not better than non-renewable energy sources, could not be detected in several studies: Sinha et al. (2019) for the BRICS and Next 11 countries, Hasnisah, Azlina and Taib (2019) for several Asian developing countries, and Amer et al. (2020) for all countries, in an analysis of four income-based panel at global level. Furthermore, Dogan and Seker (2016) discovered a bidirectional causality between carbon dioxide emissions and renewable energy in the EU and advised policymakers to adopt policies that encourage greater use of renewable energy as this would not harm economic development.

Concerning nuclear energy, a low-carbon but contentious energy source due to the risks to human life and the environment in the event of major accidents (Mata, Neto and Mesquita, 2017), scholars have demonstrated that it can be effective in reducing emissions: Iwata, Okada and Samreth (2012) for a sample of OECD countries, Baek and Pride (2014) for major nuclear power producers, and Nathaniel et al. (2021) for G7 countries. Azam et al. (2022), on the other hand, discovered a negligible contribution of nuclear power to reducing emissions in the most polluting countries, while other researchers discovered an increasing effect of nuclear energy on pollution (Apergis et al., 2010), discouraging its use in the energy mix.

However, renewable and nuclear energy sources are beneficial not only in terms of pollution reduction, but also in reducing countries' energy dependence. According to Boneva (2018), the EU's overall energy dependency increased by 20% between 1990 and 2016, with six countries (Cyprus, Malta, Luxembourg, Italy, Lithuania, and Belgium) having dependency ratios greater than 75% in 2016. The author also claims that available indigenous resources, energy generation and distribution infrastructure are important factors in countries' energy dependence. In an analysis of 29 European countries, Martins, Felgueiras and Smitková (2018) concluded that while fossil fuel consumption is slightly positively correlated with energy dependence, renewable energy is critical to reducing fossil fuel usage. Gecevičius et al. (2021) show that renewable energy, particularly wind power, and the development of climate-neutral technologies supported declines in energy dependence in Lithuania.

The Russian Federation - Ukraine war tested the EU's energy policy by exposing EU countries' dependence on Russian Federation's oil and gas. In 2020, the country contributed 29% of non-EU crude oil and 43% of natural gas imports, with Germany's dependency reaching 65% (European Commission, 2021). The EU's reliance on energy imports was 58% in 2020, slightly lower than 60% in 2019 due to the Covid-19 pandemic, but higher than 56% in 2000, with Malta, Cyprus, and Luxembourg reaching over 90% (European Commission, 2021). As several EU countries (Belgium, France, Greece) phased out coal production in accordance with the UN Paris Climate Agreement and the European Green Deal, and nuclear power was fiercely disputed as a clean energy source (Echavarri, 2006), Russian gas became appealing due to its ease of transportation and high availability (Washington Post, 2022). Scholars have warned before 2022 that the EU's dependency on Russian oil and gas is a political controversy and stressed the need for the EU to secure reliable energy suppliers so that it can further develop and mitigate energy issues (Acevedo and Lorca-Susino, 2021). Recently, even more voices drew attention to the chain-type effects of the war, observable in tensions over energy and commodities' prices, declining production, postponed investments, rising inflation, and destabilising global value chains, and urged the EU and the EU countries policymakers to accelerate the green transition, thus diminishing the dependence on imported fossil fuels (Celi et al., 2022).

2. Research methodology

We used annual data for all EU-28 countries for the 2000-2021 period, in a balanced panel that includes 616 observations (N=28 and T=22). We employ greenhouse gas (GHG) emissions as a proxy for environmental degradation in our empirical models as a dependent variable, thus integrating in the modelling the “Fit for 55” target to reduce EU’s GHG emissions by 55% until 2050. The main regressors are the shares of energy sources in electricity production (nuclear, wind, solar, biofuels, hydro, and fossil). We include economic development (as GDP per capita - GDPC), population (POP), and globalisation (as trade openness - TRDOP) as control variables in our estimates, but we also consider their role in pollution, as evidenced by previous research - see, for example, Horobeţ et al. (2022) and Yang and Zha (2022). Our World in Data was the source for the dependent variable and main regressors, while World Bank was used to collect data for control variables. Table no. 1 presents more details about the variables employed in our models.

Table no. 1. Variables’ description and data sources

Variable	Acronym	Definition	Source
Total GHG emissions	GHG	Electricity production generated emissions, in million tonnes of CO2 equivalent	Our World in Data (OWID) database, based on BP Statistical Review of World Energy and Ember
Nuclear energy	NUCL	Total share of nuclear power in electricity production (%)	
Solar energy	SOLAR	Total share of solar power in electricity production (%)	
Wind energy	WIND	Total share of wind power in electricity production (%)	
Biofuels energy	BIOF	Total share of biofuel power in electricity production (%)	
Hydropower energy	HYDRO	Total share of hydropower in electricity production (%)	
Fossil fuel energy	FOSSIL	Total share of fossil fuels (coal, oil, and gas combined) in electricity production (%)	
Population	POP	Total population, in million persons	World Bank
Economic development	GDPC	GDP per capita, constant 2015 US\$	
Globalisation (trade openness)	TRDOP	Sum of exports and imports of goods and services divided by GDP (%)	

Considering the results highlighted by the scientific literature and our intended contributions to its development, we formulate the following hypotheses that will be further tested in our research:

- H1: Nuclear energy and renewable energy have a significant and positive impact on environmental degradation in EU countries (higher shares of these types of energy in the energy mix lead to a decrease in environmental degradation).
- H2: There are significant differences between low-carbon energy types (nuclear and renewable) in terms of their impact on greenhouse gas emissions in EU countries.
- H3: Energy based on fossil fuels has a significant and negative impact on environmental degradation in EU countries (higher shares of this type of energy in the energy mix lead to increased environmental degradation).

We estimate the relationship between the variables of interest in a general dynamic system-GMM model, as presented below:

$$GHG_{it} = \beta_0 + \beta_1 GHG_{it-1} + \beta_2 NUCL_{it} + \beta_3 SOLAR_{it} + \beta_4 WIND_{it} + \beta_5 BIOF_{it} + \beta_6 HYDRO_{it} + \beta_7 FOSSIL_{it} + \beta_8 \ln(GDPC)_{it} + \beta_9 TRDOP_{it} + \beta_{10} POP_{it} + \mu_i + \varphi_t + \varepsilon_{it} \quad (1)$$

Where:

μ_i - indicate country fixed specific effects;

φ_t - are the time-effects;

ε_{it} - depicts the zero-mean error term, $i = 1, \dots, 28$, and $t = 2000, \dots, 2021$.

For robust and consistent findings, we assess both the concurrent impact on GHG of the various energy sources in the production of electricity, as well as the individual impact of each energy source. In the first estimation (concurrent energy sources), we are interested in investigating the importance of non-fossil (low carbon emission) sources for environmental degradation, while the individual estimations also include fossil fuels to evidence an estimated negative effect on emissions and carbon intensity. Thus, we estimate seven dynamic system-GMM models following the general model depicted in Eq. (1). In all estimates, the main regressors are accompanied by economic development (GDPC), globalisation (TRDOP), and population (POP) as control variables. Also, the model includes the lag of the dependent variable among the regressors.

Difference and system GMM are the two types of GMM estimators. In difference-GMM, first-differences of variables are used to eliminate fixed effects, while system-GMM enhances difference-GMM by estimating the connection between the dependent variable and regressors in differences and levels simultaneously and distinctly instrumenting both equations (Holtz-Eakin, Newey and Rosen, 1988). Both are used to fit linear models with one dynamic dependent variable, fixed effects, and additional controls (Roodman, 2009). This study uses the system-GMM estimator proposed by Arellano and Bover (1995) and Blundell and Bond (1998), recognised in the literature as a robust estimator (Vithessonthi, 2016). The system-GMM can handle heteroscedasticity and autocorrelation within individual cross-sections (Roodman, 2009); it is robust to regressors' endogeneity (Judson and Owen, 1999); it overcomes the problem of weak instruments in difference-GMM (Blundell and Bond, 1998); and it does not suffer from omitted dynamics typical to static panel models (Omri and Nguyen, 2014). We utilised one-step and two-step techniques to implement system-GMM and difference-GMM estimators. Several contributions (Blundell and Bond, 1998; Blundell and Bond, 2000) have highlighted the downward bias of two-step estimators in finite samples; hence we provide one-step system-GMM estimates, similar to Tudor and Sova (2022) and Filippetti and Sacchi (2006).

Several diagnostics were conducted on estimated models to verify system-GMM consistency. Thus, we have obtained the p-values of the J-test of overidentifying limitations for instrument validity (Sargan, 1958; Hansen, 1982) and the Arellano and Bond test for second-order serial correlations in residuals (Arellano and Bond, 1991). We also include the Wald test for coefficients and time dummies, recommended by Wooldridge (2010). These are added to capture any structural discontinuities in time series (Rahman, Rana and Barua, 2019). All estimations were implemented in R using the "pgmm" function in the Croissant and Millo (2008) "plm" package.

3. Results and discussion

Our study investigates the dynamic impact of low-carbon energy sources on the GHG emissions generated by electricity production using a system-GMM estimate. We proceed by showing the main descriptive statistics for our variables in Table no. 2. They show a rather high heterogeneity of GHG emissions in EU countries around an annual mean of 40.29 million tonnes of CO₂ equivalent. However, this is accompanied by a significant decline in the EU average over time, which reflects to a high extent the falling importance of fossil fuels as a source of electricity production in EU-28 countries and reveals the progress achieved towards decarbonisation (Figure no. 1).

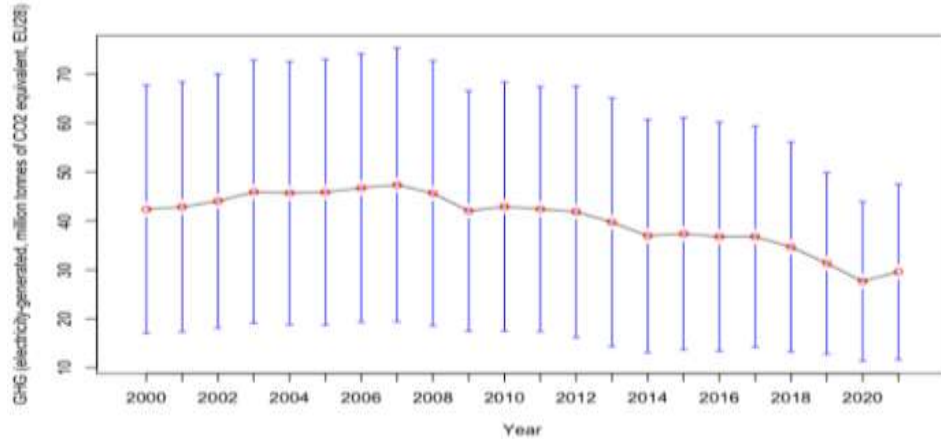


Figure no. 1. Total GHG emissions in EU-28, 2000-2021

Source: Authors' representation in R based on Our World in Data (OWID)

Similar variation is found for GDP per capita (mean of 29,807 US dollars), TRDOP (mean of 17.61%) and POP (mean of 17.92 million people). For what concerns electricity sources, data shows that during the 2000-2021 period, fossil fuels were the most used source (mean of 55.37%, varying between 1.42% and 100%), while nuclear energy was the most employed low-carbon source in electricity generation (mean of 18.57% with a maximum of 82.95%), followed by hydropower (mean of 14.24% and a maximum of 69.90%). Solar energy is the least used source for electricity production in the EU, with a mean share of only 1.44% and a maximum of 18.38%.

Table no. 2. Descriptive statistics

Variable	Mean	Standard Deviation	Min	Max
GHG	40.29	62.27	0.12	308.99
NUCL	18.57	22.83	0.00	82.95
SOLAR	1.44	2.60	0.00	18.38
WIND	6.02	9.02	0.00	56.84
BIOF	4.24	4.97	0.00	31.09
HYDRO	14.24	17.88	0.00	69.90
FOSSIL	55.37	27.22	1.42	100.00
GDPC	29,807.71	20,743.52	3,717.67	112,417.90
TRDOP	117.61	63.12	45.41	388.84
POP	17.92	22.64	0.39	83.90

We further report in Table no. 3 the results of estimating Equation (1) when electricity sources are considered as concurrent, while table no. 4 presents the findings when the impact of electricity sources on GHG emissions is explored individually.

Table no. 3. One-Step System GMM estimates - concurrent electricity factors

Independent variables	Coefficients – Model 1
GHG (-1)	0.95***
NUCL	-0.02
SOLAR	-0.17
WIND	-0.09*
BIOF	-0.01
HYDRO	-0.14*
GDPC	0.73
TRDOP	-0.01
POP	0.00
Hansen/Sargan J-test (p-value)	0.97
AR2 test (p-value)	0.33
Wald test for coefficients (p-value)	0.00
Wald test for time dummies (p-value)	0.00

Note: *significant at 10%; ** significant at 5%; *** significant at 1%. Instruments are collapsed; robust inference is performed in the summary.

First, the statistically significant and positive coefficient of lagged GHG emissions indicates the persistence of environmental damage. This means that GHG emissions in the previous period (previous year) contribute to increased pollution in the current period: a 1% increase in one-year past GHG emissions creates an almost similar (0.97%) increase in current GHG emissions at EU level – see table no. 3. Individual factor coefficients for one-year lagged GHG vary between 0.93 and 0.97 and are all statistically significant. These findings are consistent with those of Solarin, Gil-Alana and Gonzalez-Blanch (2021) for sulphur dioxide emissions in OECD nations, and Horobeț et al. (2022) for a large global panel.

Most importantly, our results acknowledge the beneficial impact that low-carbon and renewable energy sources have on GHG emissions, indicated by the negative coefficients in all models, although not all statistically significant. Wind and hydro were found to be the most significant factors that support the mitigation of GHG emissions in Model 1, which includes electricity sources concurrently in the estimation, as indicated by the statistically significant and negative coefficients in Table no. 3. These coefficients have magnitudes of -0.09 and -0.14, respectively. This means that increasing the share of wind and hydro energy by 1% reduces GHG emissions by 0.09% and 0.14%, respectively. Other low-carbon sources have negative coefficients ranging from -0.01 (biofuels) to -0.17 (solar), but they are not statistically significant.

Moreover, when low-carbon sources are individually included in estimations (Models 2 to 7 in Table no. 4), the negative slope coefficients reported in Model 1 are confirmed – they vary between -0.02 (nuclear) and -0.23 (hydro). However, as in the case of electricity sources considered concurrently, the only factors with statistically significant coefficients are wind (-0.07) and hydro (-0.23), indicating declines in GHG emissions at a 1% increase in their shares of 0.07% and 0.23%, respectively. Our findings thus show that hydro is the most efficient electricity source to be used in the EU's endeavour to mitigate emissions and fight climate change, followed by wind. These results are in line with Horobeț et al. (2022) for a

global panel of 163 countries, Saidi and Omri (2020) for OECD countries, and Bhat, Sofi and Sajith (2022) for G20 countries.

Table no. 4. One-Step System GMM estimates - individual electricity factors

Independent variables	Coefficients					
	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
GHG (-1)	0.94***	0.94***	0.94***	0.93***	0.93***	0.97***
FOSSIL	0.13***					
NUCL		-0.02				
SOLAR			-0.07			
WIND				-0.07*		
BIOF					-0.09	
HYDRO						-0.23**
GDP	-1.05	1.12	1.15	1.80	1.63	1.65
TRDOP	0.00	-0.01	0.01	-0.01	-0.01	-0.02
POP	0.09	-0.03	-0.03	-0.03	-0.04	-0.09
Hansen/Sargan J-test (p-value)	0.75	0.75	0.75	0.75	0.75	0.75
AR2 test (p-value)	0.34	0.31	0.31	0.31	0.31	0.30
Wald test for coefficients (p-value)	0.00	0.00	0.00	0.00	0.00	0.00
Wald test for time dummies (p-value)	0.00	0.00	0.00	0.00	0.00	0.00

Note: *significant at 10%; ** significant at 5%; *** significant at 1%. Instruments are collapsed; robust inference is performed in the summary.

Considering the estimates presented in Tables no. 3 and no. 4, we partially confirm H1 only for wind and hydropower, since for nuclear, solar and biofuels, the regression coefficients are statistically insignificant. At the same time, we confirm H2 by the different, albeit positive, importance of renewable energy sources in environmental degradation.

Furthermore, these outcomes strongly support the EU's plans to reconfigure the energy system toward renewables with a double target: increasing energy efficiency and fighting environmental pressures. Figure no. 2 shows the fall of fossil fuels in EU electricity generation from 66% in 1985 to 45% in 2021, with coal and oil having the largest declines. Natural gas, partly based on cheap and readily available imports from Russia, boosted its contribution to over 20% by 2021. Between 1985 and 2021, the share of low-carbon sources (nuclear electricity and renewables) climbed from 15.14 to 37.19%. Wind became the most used renewable electricity source in 2021 (13.71%), up from zero in 1985, followed by hydropower and solar.

When assessing strategic energy paths, the diverse reliance of EU countries on low-carbon sources cannot be ignored. According to OWID and the BP Statistical Review of World Energy (2022), only four EU nations used hydropower to produce more than 40% of their electricity in 2021: Austria, Croatia, Latvia, and Sweden. Romania, Portugal, Slovenia, and Finland had 20%-30% hydro-power shares, while the rest had less than 15%. Only Denmark and Ireland had wind energy shares in power production above 30% at the end of 2021, while Lithuania, Portugal, Spain, and Germany had shares above 20%. Spain, Greece, Portugal, and Italy hold close to 10% of solar power, but other Central European nations have invested considerably in solar units in recent years (Germany, Netherlands, and Hungary). Ireland and Croatia had less than 1% each. Nuclear power's role as an EU electricity source varies the most, as seen by the countries' stance on including specific nuclear source activities in the 2023 EU taxonomy for sustainable activities. France is the most nuclear-

intensive country, using 69.33% nuclear power in 2021, followed by Slovakia (53.1%) and Belgium (50.48%). 13 EU countries do not use nuclear power.

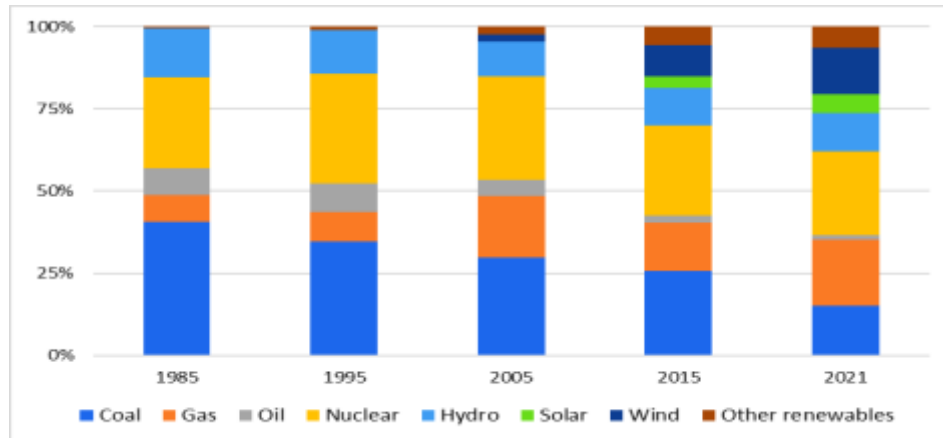


Figure no. 2. Share of electricity from fossil fuels and low-carbon sources in European Union (%), 1985 to 2021 (right)

Source: Authors' representation based on OWID data

However, one should note that both hydropower and wind are highly dependent on countries' natural endowments, and this may represent a hindrance in terms of their use in the EU. Regrettably, since 2011 – when a significant increase in the construction of new hydro-power plants of almost 10,000 MW was seen – only 4,000 MW of new plants have been developed (Eurostat). To blame for this shallow construction activity are the low electricity prices on the European spot market until mid-2021 (Hydropower Europe, 2022), but the rising inflation impact and the Ukraine-Russian Federation war in 2022 have driven electricity prices considerably up, and this raises expectations towards substantial investments in hydro-power plants.

Unfortunately, the EU-27 countries installed only 11 GW of new wind capacity in 2021 and are expected to install 90 GW of new wind farms (mostly onshore wind plants) between 2022 and 2026, but this is insufficient to meet the EU's new 40% renewable energy target, according to WindEurope (2022). Despite the advantages of wind energy as a renewable source, scientists emphasise the need to balance its use against its disadvantages: fluctuations in wind energy, complexity and size of plants, securing the best locations for wind energy generation, high storage and transportation costs of electricity and environmental impact (Kammen and Sunter, 2016).

At the other end, the results reported in Tables no. 3 and no. 4 confirm our expectations that fossil fuel-based electricity stimulates environmental degradation (hypothesis H3), highly acknowledged by many existing studies – see, for example, Xu et al. (2019), or Le Quéré et al. (2021). The slope coefficient for FOSSIL in Model 2 is positive and statistically significant, indicating that a 1% increase in the share of fossil fuels leads to a 0.13% increase in GHG emissions. The EU countries are still strongly dependent on fossil fuels for electricity production but also for consumption (Martins, Felgueiras and Smitková, 2018), but the net-zero emissions target set for 2050 and the objective of significantly reducing the dependence on Russian oil and gas are expected to put pressure on all the EU countries to reduce fossil fuels usage (Osička and Černoch, 2022).

Economic development, as measured by GDP per capita, was found to have no statistically significant effect on GHG emissions in any of our models, consistent with Jain and Kaur (2022) for South Asian countries. The panel regression coefficients, on the other hand, are positive in all models except Model 2, which considers FOSSIL individually as a regressor. This implies that a higher GDP may act as a counterbalance to the use of fossil fuels in electricity generation. At the same time, this means that the more developed countries in the EU have the potential to devote more resources to reshaping their energy policy. At the same time, the negative coefficients for all low-carbon electricity sources in the presence of positive per capita GDP coefficients clearly show that these sources can successfully mitigate the impact of economic development on the environment. Furthermore, they highlight the positive externalities that will emerge if EU members transition away from unsustainable fossil energy sources.

These implications are confirmed by illustrating the relationship between GDP per capita and the share of fossil power in electricity generation in figure no. 3 and between GDP and the share of wind power in electricity generation in figure no. 4 for 2021 at the EU level. Clearly, GDP per capita for EU countries is negatively related to fossil share and positively related to wind power share, indicating that the more advanced economies (perhaps with the notable exception of Germany and the Netherlands) understood the need for energy mix restructuring before the Ukraine-Russian Federation war bluntly exposed it.

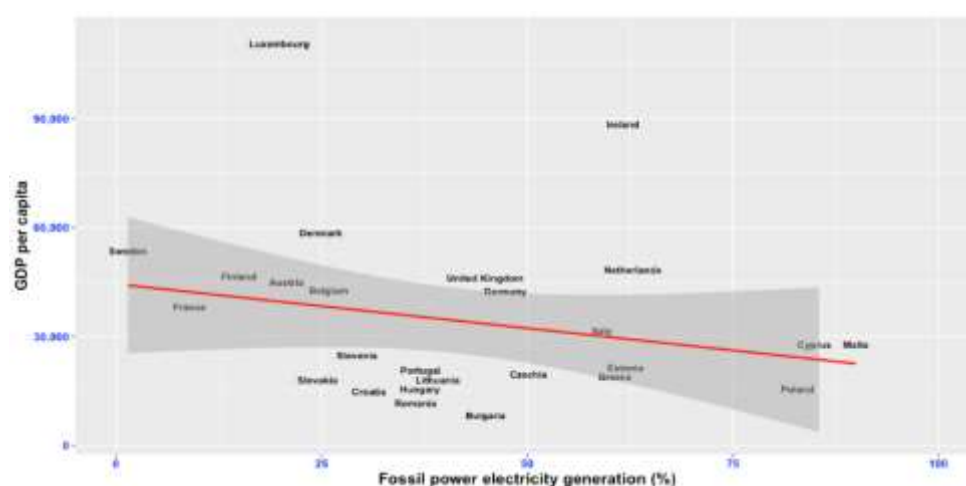


Figure no. 3. GDP per capita versus fossil power share in electricity generation for EU countries, 2021

Source: Authors' representation in R based on Our World in Data (OWID)

Finally, results indicate that in EU countries, globalisation is not related to electricity-generated GHG emissions over the sample period in any of the specifications, and neither population. In the case of trade openness, this finding may be related to the heterogeneous impact of trade openness on emissions depending on countries' economic development level – it contributes to emissions' mitigation in advanced economies, but negatively impacts the environment in less developed ones, as suggested by Shabaz et al. (2017) and Wang and Zhang (2021).

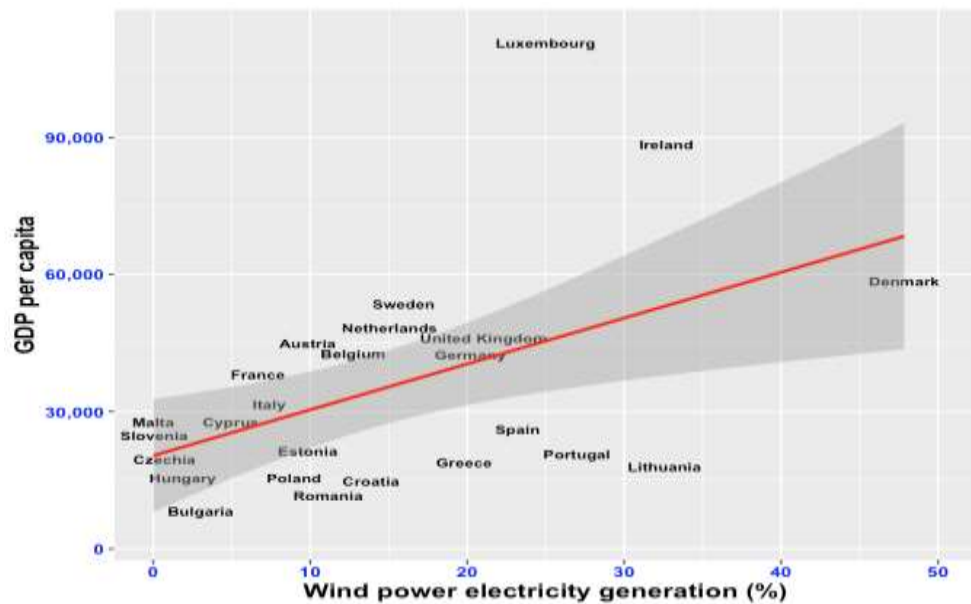


Figure no. 4. GDP per capita versus wind power share in electricity generation for EU countries, 2021

Source: Authors' representation in R based on Our World in Data (OWID)

Conclusions

The European Union's energy policy is critical in light of rising price uncertainties of fossil fuels and the fight against climate change. Furthermore, changes in the energy mix in favour of non-renewable and low-carbon sources are a vital part of the EU's green transition, as research has shown that the latter can successfully mitigate GHG emissions. In this context, we proposed a system-GMM panel data analysis of the importance of alternative electricity generating sources in the EU, thereby contributing to increased knowledge on energy policy and environmental quality through a comparative analysis of energy sources based on fossil fuels and those with low carbon emissions within the decarbonisation process.

Our most important findings demonstrate the supporting impact of low-carbon and renewable energy sources on GHG emissions, with wind and hydro being the most significant factors that support environmental degradation mitigation. Furthermore, hydro is the most efficient electricity source that the EU could use to meet its net zero emissions goal, followed by wind. As a result, the substantial confirmation of our research hypotheses supports the EU's plans to restructure the energy system in favour of renewables, with the dual goal of increasing energy efficiency and combating environmental pressures, as encompassed by the RePowerEU program and the Green Deal. However, it should be noted that these two types of electricity sources are highly dependent on countries' natural endowments, which may pose a barrier to their use in the EU. Intelligent investments in new hydropower plants and increasing the efficiency of existing ones, on the other hand, may overcome the endowment issue, particularly in countries that have developed less than 50% of their economically feasible hydropower potential, as is the case in many Central and South-eastern European countries (Hydropower

Europe, 2022). This approach is especially important in light of Central and Eastern European countries' high vulnerability to fossil fuels imports. Some of them, such as Italy, Finland, or Bulgaria, have secured alternative gas or LNG sources from North Africa, Norway, or Azerbaijan, but these efforts can be supported by a diversification of energy sources toward more renewable energy. Moreover, encouraging investments in wind farms is highly desired, and understanding the economic conditions that support these investments is equally intriguing from a research standpoint - this is a research avenue that we intend to pursue in the future.

At the same time, EU policymakers and private investors should transform the energy sector from a source of crisis to a source of opportunity, taking into account not only the capital required to build low-carbon power plants, but also equipment, storage facilities, and distribution networks. Furthermore, industries that provide minerals needed for batteries and solar panels (for example, lithium, copper, nickel, and rare-earth elements) should be encouraged, as demand for such raw materials is expected to skyrocket in the coming years. Equally important is the development of technologies that enable the expansion and integration of electricity grids to increase their flexibility when faced with problems with energy sources (Clune, Hanzlik and Winter, 2022). Furthermore, technological solutions that can lower the cost of renewable energy should be encouraged, as this will result in a faster adoption of renewables by producers and consumers. Finally, the renewable energy sector may be less affected by potential shocks in fossil fuels prices and markets (Vrínceanu et al., 2020).

As any empirical endeavour, our research has its limitations, being confined to data availability, the time span of the underlying analysis, the variables included in the model, and the empirical model itself. Future research will address these constraints, along with directing the focus toward investigating the economic conditions that facilitate an increased share of low-carbon and renewable sources in the production and consumption of electricity and energy. These conditions refer not only to public support and economic policies, but also to the private sector's strategies to capitalise on the above-mentioned opportunities available in the power sector and related industries. Furthermore, another interesting research avenue refers to exploring the specific contribution that foreign and portfolio investments, as well as international trade, play in fostering the green transition and reducing the EU's dependence on fossil fuels and foreign providers.

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