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The carbon dioxide neutralizing effect of energy innovation on international tourism in EU-5 countries under the prism of the EKC hypothesis

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ABSTRACT

Mitigation of carbon dioxide emissions has become an utmost important global agenda, keeping into consideration the associated environmental hardships. As a result, it is important to unearth the factors which can neutralize carbon emissions to transform the world economy into a low-carbon one. Against this backdrop, this study explores the carbon dioxide neutralizing effects of economic growth, international tourism, clean energy promotion, and technological innovation in the context of five European Union (EU-5) nations during the 1990–2015 period. This study's main contribution is in terms of its approach to test the interaction effect between foreign direct investment (FDI) inflows and energy innovation on carbon dioxide emissions. The econometric analysis chronologically involves the employment of unit root, cointegration, causality, and regression methods. Overall, the findings support the inverted-U-shaped economic growth-carbon dioxide emissions nexus to verify the Environmental Kuznets Curve (EKC) hypothesis. Besides, the Pollution Haven Hypothesis in the context of the selected panel is also verified as higher FDI inflows are seen to boost the carbon dioxide emission levels. The results also confirm that energy innovation moderates the harmful effect of air transport (a proxy for international tourism) on carbon dioxide emissions during the developing stage of the tourism industry. On the other hand, renewable energy promotion is found to curb carbon dioxide emissions. These findings suggest that the European governments need to enhance investments in their respective renewable energy sectors and simultaneously ensure the development of clean industries, which can collectively help these nations become carbon-neutral in the future.

1. Introduction

International tourism has been acknowledged to play critical roles in developing the global tourism industries, facilitating the globalization processes, and developing the world economies, in particular (Brida et al., 2015; Balsalobre et al., 2020; Leitão and Balsalobre-Lorente, 2020). Throughout the middle of the last century, the expansion of the global air transport industries has significantly contributed to developing the international tourism industries worldwide. Before the emergence of the novel coronavirus (COVID-19) pandemic, the size of the global international tourism industry was projected to grow, on average, by more than 44 million international arrivals each year and reach to a figure of near about 2 billion international arrivals by 2030, thus, generating seven times more than the number of international arrivals recorded in the 1970s (OECD, 2018). Hence, it can be claimed that international air transport causes an induced effect on the economies of the tourism-hosting nations whereby robust growth of their respective international tourism sectors can be expected to take place in the long run (Khan et al., 1990; Brida et al. 2008, 2009, 2009; Balsalobre et al., 2020). Consequently, the economies of these nations can also be

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assumed to grow in tandem.

However, despite exerting such favourable economic impacts, the international air transport industry does inflict environmental pollution problems across the tourism-hosting economies, especially during the initial phase of economic development when the air transport industry is expected to be underdeveloped as well (Stabler et al., 2010; Balsalobre et al., 2020). On the other hand, it is also believed that further long-run development of the air transport industries is likely to reduce environmental pollution due to these industries are likely to become more environmentally friendly with time. The favourable environmental outcomes associated with the development of the international air transport industries are said to take place due to technological innovation, which neutralizes the initial environment-damaging impacts of international tourism (Adedoyin et al., 2020a). Hence, it is important to assess the possible non-linear association between international air transport (a proxy for international tourism) and carbon dioxide emissions for efficient policymaking purposes.

Against this background, this study explores the carbon dioxide neutralizing effects of economic growth, international tourism, clean energy promotion, technological innovation, and Foreign Direct Investment (FDI) inflows for the cases of five European Union (EU-5) nations during the 1990–2015 period. This study is important from the perspective of attaining the common goal of the European Union (UN) member countries that have vowed to become carbon-neutral by 2050. Besides, these nations have also committed under the Paris Accord and the Sustainable Development Goals (SDG) agenda to significantly reduce their respective greenhouse gas emissions, especially carbon dioxide (Murshed and Alam, 2021; Murshed and Tanha, 2021). The major factor behind the aggravation of the greenhouse gas emission figures in Europe is the predominant reliance of the European nations on fossil fuels for energy production and consumption purposes. Hence, keeping the carbon-neutrality agenda into cognizance, it is pertinent for these nations to reduce fossil fuel use and, therefore, green the existing consumption and production processes. Besides, since the European international tourism industry is also believed to be a major factor contributing to the surging trends in the carbon dioxide emission figures of the European nations, it is also important for these countries to transform their international air transport industries in an environmentally sustainable manner. The outcomes from this study are expected to facilitate these causes and help the selected EU-5 countries become carbon neutral in the future.

The econometric analysis is conducted under the theoretical underpinnings of the EKC hypothesis (Balsalobre et al., 2020). The EKC framework admits a non-linear linkage between economic growth and environmental degradation, where additional driving forces are included to enrich empirical results (Alola and Ozturk, 2021; Khan et al., 2021; Le and Ozturk, 2020; Nathaniel et al., 2021). The study also explores the impact of a dynamic energy innovation (Álvarez et al., 2017) and renewable energy promotion (Sinha et al., 2017) for the selected panel. Following previous empirical literature, this study also analyses how foreign direct investment (FDI) damages the environment, validating the Pollution haven Hypothesis (PHH) (Balslaobre et al., 2019; Shahbaz et al., 2019; Guzel and Okumus, 2020). Moreover, the non-linear linkage between air transport and carbon emissions is also scrutinized (Chang et al., 2012; Zhao and Mao, 2013). Furthermore, this study analyses the interaction effect between air transport and FDI inflows on carbon emissions in the selected EU-5 countries.

The novelty of this study can be highlighted as follows: Firstly, the existing studies have primarily explored the linear impacts of air transport on carbon emissions (Khan et al., 2017a,b). As opposed to this approach, this study evaluates the non-linear nexus between air transport industry development and carbon dioxide emissions for the EU-5 countries. Secondly, apart from examining the direct impacts, this study also considers the interaction impacts of international air transport and FDI inflows, investment in energy innovation and international air transport, and investment in energy innovation and FDI inflows on the carbon dioxide emission figures of the these nations. Not many previous studies, especially for the case of the European countries, have emphasized these interaction effects; however, this is extremely important for interactive policymaking purposes. Hence, this study presents a comprehensive understanding of the overall connection between international air transport industry development, FDI inflows, promotion of clean energy sources, and environmental degradation in the EU-5 context.

The rest of the paper is structured as follows: Section 2 contains the Literature review. Section 3 contains the empirical methodology, and Section 4 includes the discussion of results. The final section considers the main conclusions and policy implications.

2. -literature review

The impacts of economic growth, international air transport, FDI inflows, energy innovation, and renewable energy consumption on carbon dioxide emissions have been widely discussed in the empirical literature (Balsalobre-Lorente et al., 2021b). Among the previous studies, the economic growth-carbon dioxide emission nexus has been popularly explored under the theoretical framework of the EKC hypothesis. The conclusions put forward in these studies have been equivocal, which implies that the authenticity of the EKC hypothesis is not always guaranteed (Shahbaz et al., 2018; Shahbaz and Sinha, 2019). In a study on the Belt and Road Initiative (BRI) countries, Rauf et al. (2018) concluded that the EKC hypothesis for carbon dioxide emissions holds for all regional panels of the countries under the BRI. Similarly, Işık et al. (2019), in the context of 10 states across the United States of America, verified the EKC hypothesis since economic growth was found to initially boost the carbon dioxide emissions but eventually mitigate the emissions. On the other hand, Leal and Marques (2020) stated that the EKC hypothesis for carbon dioxide emissions holds only for the highly globalized economies but not for nations with low degrees of globalization. In another study on South Korea, Koc and Bulus (2020) found evidence of the economic growth-carbon dioxide emissions relationship to exhibit an N-shape; thus, the EKC hypothesis could not be verified. In another recent study on Bangladesh, Murshed et al. (2021a) concluded in favour of the EKC hypothesis holding in the long run. Similarly, the EKC hypothesis for carbon dioxide emissions was also verified in the recent studies on selected South Asian nations (Murshed and Dao, 2020) and the members of the Organization of the Petroleum Exporting Countries (OPEC) (Murshed et al., 2020).

The empirical studies on the effects of international air transport and carbon dioxide emissions have primarily highlighted the adverse environmental implications of international tourism. Anser et al. (2020) claimed that higher international tourism receipts, synonymous with international tourism development, boost carbon dioxide emissions in the G7 countries. In another relevant study, Leitão and Balsalobre-Lorente (2020) considered the relationship between carbon dioxide emissions, renewable energy, tourism, and international trade. The authors used panel data applied by the European Union (EU). The empirical results demonstrated that international tourism is negatively correlated with carbon dioxide emissions. Besides, international trade and renewable energy consumption were also evidenced to encourage environmental sustainability.

Similarly, for the Asia Pacific countries, Shakouri et al. (2017) highlighted that a rise in the number of international tourist arrivals leads to an increase in the carbon dioxide emission levels. In another relevant study on the top-visited countries globally, Koçak et al. (2020) also found the international tourist arrivals-carbon dioxide emissions to be positive. In contrast, Liu et al. (2019) asserted that although economic growth and energy consumption are key determinants of Pakistan's carbon dioxide emissions, international tourism does not affect the nation's carbon dioxide emission figures. Besides, few studies have also assessed the non-linearity between international tourism and carbon dioxide emissions. Ehigiamusoe (2020) showed that tourism presents a U-shaped non-linear effect on African countries' environmental degradation. The empirical results evidenced that the tourism industry is a determinant of environmental degradation, concluding that governments need to emphasize clean tourism to achieve sustainable development. Sherafatian-Jahromi et al. (2017) also claimed that international tourism initially triggers more significant carbon dioxide emissions, but international tourism reduces the emission levels later on.

The adverse environmental implications associated with FDI inflows in the host economies have popularly been analyzed under the theoretical framework of the PHH (Leitão, 2014; Omri; Kahouli, 2014; Neeqaye; Oladi, 2015; Nasir et al., 2019). However, the findings in this regard have been mixed (Khan and Ozturk, 2020; Mert and Caglar, 2020; Murshed, 2020, 2021; Solarin et al., 2017). Among the existing studies that have verified the PHH, Naz et al. (2019) asserted that inward FDI results in higher carbon dioxide emissions, thus degrading the environmental quality in Pakistan. In another study on 52 high and low-income countries, Essandoh et al. (2020) claimed that only in the context of the low-income countries, the PHH holds. The PHH was also supported in the existing studies by Chishti et al. (2021) and Khan et al. (2021). Conversely, several previous studies have also nullified the existence of the PHH. Haug and Ucal (2019) opined that FDI inflows could not explain the variations in Turkey's carbon dioxide emission levels in the long run. Similarly, Xie et al. (2020) asserted that although FDI inflows directly enhance the carbon dioxide emission levels in the emerging economies, a spillover environmental effect of FDI on carbon dioxide emissions takes place, whereby the total effect stimulates a reduction in these emissions.

Although international tourism induces environmental problems, numerous studies suggest increasing more efficient and clean energy sources to control carbon emissions associated with the air transport industry. In this regard, enhancing renewable energy resources plays a decisive role in reducing carbon emissions (Uusitalo et al., 2013). Likewise, the study of Chandran and Tang (2013) showed that energy-efficient transportation technologies would improve environmental quality. Saleem et al. (2018) directly confined air-railways transportation on carbon emissions. Hence, energy innovation is key to reducing the adverse environmental impacts associated with the transport sector, including the air transport industry. Among the studies scrutinizing the energy innovation-carbon dioxide emissions nexus, Alvarez-Herranz (2017) concluded that energy innovation helps to improve environmental quality by reducing carbon dioxide and other greenhouse gas emissions in the cases of selected Organization for Economic Cooperation and Development (OECD) countries. On the contrary, Sarkodie and Owusu (2021) showed that energy innovation is motivated by the aggravation of fossil fuel consumption-induced carbon dioxide emissions.

Apart from energy innovation, several studies have also advocated for boosting renewable energy use to mitigate emissions (Dong et al., 2020; Dogan et al., 2020). Among these, Dauda et al. (2021) asserted that renewable energy and technological innovation could reduce Africa's atmospheric carbon dioxide emission figures. Similarly, in the context of China, Chen et al. (2019) claimed that facilitating renewable energy use is a means of cutting the nation's fossil fuel dependency, which, in turn, can be hypothesized to decrease the emissions of carbon dioxide. Cherni and Jouini (2017) showed that fossil fuel consumption is one of the key facilitators of carbon dioxide emissions in Tunisia and suggested that replacing fossil fuels with renewable energy alternatives can be the panacea to the nation's carbon dioxide emission woes. As far as the environmental impacts of renewable energy consumption across the European Union countries are concerned, Bekun et al. (2019) also documented evidence that higher renewable energy use and lower fossil fuel consumption result in lower carbon dioxide emissions.

In this context, the recent empirical studies of Koengkan et al. (2021), Balsalobre-Lorente et. (2021a), and Maneejuk et al. (2020), the authors demonstrated that renewable energy contributes to environmental improvements.

Based on the literature summarized above, we formulate several hypotheses:

H1. The validation of a non-linear linkage between economic growth and carbon dioxide emissions validates the U-inverted EKC hypothesis.

H2. The existence of a non-linear connection between air transport and environmental degradation validating the non-linear tourism-led growth hypothesis.

H3. We expect a direct connection between per capita carbon dioxide emissions and FDI inflows in the EU-5 countries; thus, confirming the PHH.

H4. We hypothesize an indirect connection between renewable energy, energy innovation, and carbon dioxide emissions.

H5. The energy innovation processes are expected to dampen the pernicious environmental effects of FDI inflows and air transport industry development on the environment.

3. Data and methodology

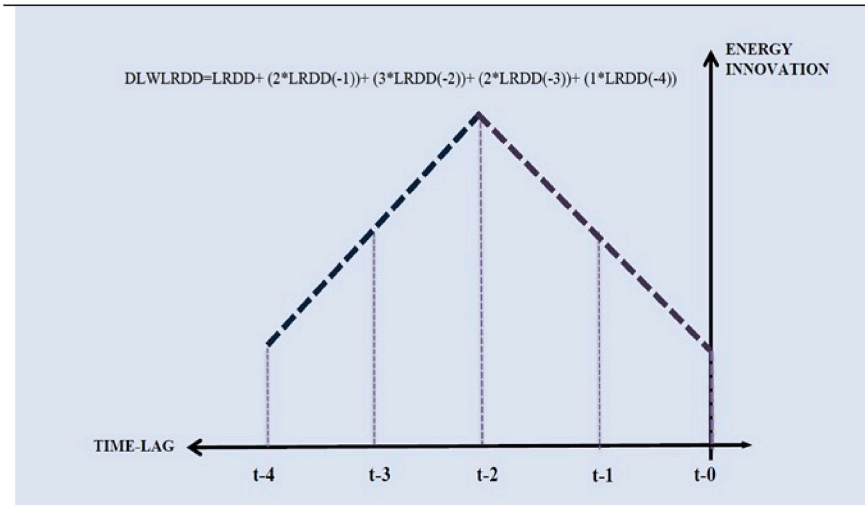
Contemplating the previous empirical literature, we try to validate the inverted-U-shaped EKC hypothesis for selected EU-5 countries. Through three different equations, we explore a non-linear linkage between the development of the international air transport industry and environmental quality. The study also examines the effects of FDI inflows, renewable energy, and energy innovation on carbon emissions, assuming the main contribution of interaction between FDI inflows and air transport (as a proxy of international tourism) and between energy innovation and FDI inflows on carbon emissions. The following dynamic equations (as shown in Fig. 1) consider our mains hypotheses:

Table 1 shows the general statistics presented in this empirical study. The variables foreign direct investment (LFDI), the air transport passenger (LAT), and income per capita (LGDP) are the higher values of Maximum. The Skewness statistics show that the variables of income per capita (LGDP), foreign direct investment (LFDI), and energy innovation present an asymmetric distribution.

The three models used in this study represent the stochastic version of the Impact, Population, Affluence, and Technology (IPAT) model which is referred to as the STIRPAT model. Several previous studies have used this model to assess the environmental impacts of different macroeconomic aggregates (Ahmad et al., 2021; Zeraibi et al., 2021). In the context of this study, we measure environmental impact in terms of carbon dioxide emissions and use a non-linear modelling approach in light of the EKC hypothesis. Several preceding studies have acknowledged that carbon dioxide is a major greenhouse gas; thus, the carbon dioxide emission figures of a country can be indicative of its quality of environment (Adedoyin et al., 2020b; Banerjee and Murshed, 2020; Farhani and Balsalobre-Lorente, 2020; Li et al., 2016; Yuping et al., 2021). Accordingly, we propose the first model (Equation-1) as follows:

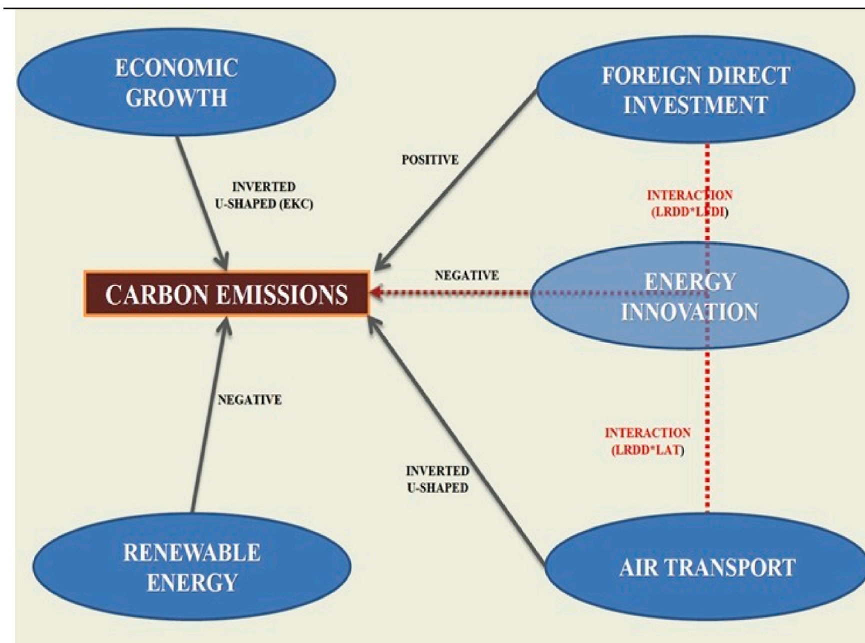
$$\mathrm{LCO2}_{it} = \beta_0 + \beta_1 \mathrm{LGDP}_{it} + \beta_2\ \mathrm{LGDP}^2_{it} + \beta_3 \mathrm{LFDI}_{it} + \beta_4 \mathrm{LRNW}_{it} + \beta_5 \mathrm{LRDD}_{it} + \beta_6\ \mathrm{LAT}_{it} + \beta_7\ \mathrm{LAT}^2_{it} + \varepsilon_{it} \tag{1}$$

where LCO2 is the per capita carbon emissions, LGDP is per capita income level (current USD), LFDI is net inflows foreign direct investment net inflows (%GDP); LRNW is renewable energy production, LRDD is the public budget in energy innovation (OECD database), and LAT is air transport. All variables are expressed in logarithm Equation-1 explores the existence of a direct relationship between per capita CO_2 and FDI in EU-5. We also try to validate the U-inverted EKC. Based on previous empirical evidence (e.g., Adedoyin et al., 2020a; Balsalobre et al., 2020), this study advances in empirical literature assessing the existence of a non-linear linkage between economic growth and carbon emissions and air transport and carbon emissions (Chang et al., 2012; Zhao and Mao,



*Source: Prepared by authors based in Álvarez et al. (2017). Note: Deleuw: DLWLRDD=LRDD+ (2*LRDD(-1))+ (3*LRDD(-2))+ (2*LRDD(-3))+ (1*lLRDD(-4))*

Fig. 1. Deleuw Finite Lags Distribution Scheme. Source: Prepared by authors based in Álvarez et al. (2017). Note: Deleuw: DLWLRDD = LRDD+ (2*LRDD(-1))+ (3*LRDD(-2))+ (2*LRDD(-3))+ (1*lLRDD(-4)).



Source: Prepared by authors

Fig. 2. Graphical Scheme: FMOLS econometric Results. *Source: Prepared by authors*.

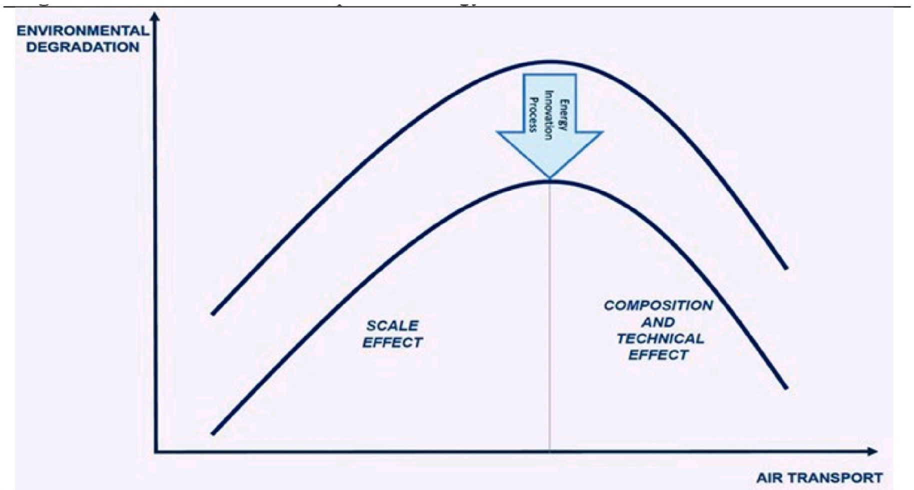
2013; Balsalobre et al., 2020). This hypothesis suggests that advances in the clean air tourism industry will improve sustainable economic growth (Adamou and Clerides, 2009; Zuo and Huang, 2017; Balsalobre-Lorente et al., 2021), generating a reduction in carbon emissions. Equation-1 also explores the impact of the energy innovation processes based on a finite lag distribution. Based on Álvarez et al. (2017), who demonstrated that innovation processes present their highest impact in (t-2), we explore the linkage between innovation processes and environmental degradation.

Equation-2 explores the existence of a dampening effect of AT on FDI to validate how globalization processes, via air transport, reduce the harmful effect of FDI in host countries. Finally, Equation-3 include as additional explanatory variables: the dampening effects of the innovation process on air transport (Equation-2) and FDI (Equation-3):

$$\begin{aligned} \mathrm{LCO2}_{it} &= \beta_0 + \beta_1 \mathrm{LGDP}_{it} + \beta_2\ \mathrm{LnGDP}^2_{it} + \beta_3 \mathrm{LFDI}_{it} + \beta_4 \mathrm{LRNW}_{it} \\ &+ \beta_5 \mathrm{LRDD}_{it} + \beta_6\ \mathrm{LAT}_{it} + \beta_7\ \mathrm{LAT}^2_{it} + \beta_8 \mathrm{LATLFDI}_{it} + \varepsilon_{it} \end{aligned} \tag{2}$$

$$\begin{aligned} \mathrm{LCO2}_{it} &= \beta_0 + \beta_1 \mathrm{LGDP}_{it} + \beta_2\ LnGDP^2_{it} + \beta_3 \mathrm{LFDI}_{it} + \beta_4 \mathrm{LRNW}_{it} \\ &+ \beta_5 \mathrm{LRDD}_{it} + \beta_6\ \mathrm{LAT}_{it} + \beta_7\ \mathrm{LAT}^2_{it} + \beta_8 \mathrm{LATLFDI}_{it} + \beta_9 \mathrm{LRDDLAT}_{it} \\ &+ \beta_{10} \mathrm{LRDDLFDI}_{it} + \varepsilon_{it} \end{aligned} \tag{3}$$

Following Liddle (2012) and Dong et al. (2017), the long-run



Source: Prepared by authors

Fig. 3. Interaction Air Transport & Energy Innovation on Carbon Emissions. *Source: Prepared by authors.*

Table 1
Description of the variables.

	LCO_2	LGDP	LFDI	LRNWP	LRDD	LAT
Mean	1.975	10.248	12.226	0.940	5.831	17.703
Median	1.962	10.248	23.166	0.891	6.054	17.713
Maximum	2.471	10.825	25.803	3.276	7.181	18.694
Minimum	1.486	9.495	−25.875	−1.660	4.009	16.751
Std. Dev.	0.241	0.336	20.200	1.347	0.932	0.493
Skewness	0.106	−0.311	−1.197	0.105	−0.509	0.153
Kurtosis	1.880	2.269	2.455	1.868	1.955	2.150
Jarque-Bera	6.930	4.919	32.153	7.064	11.356	4.348
Probability	0.031	0.085	0.000	0.029	0.003	0.113
Correlation-Matrix						
	LCO2	LGDP	LFDI	LRNWP	LRDD	LAT
LCO2	1.000					
LGDP	0.092	1.000				
LFDI	0.165	0.144	1.000			
LRNWP	−0.101	0.605	−0.043	1.000		
LRDD	−0.123	0.437	0.156	0.029	1.000	
LAT	0.259	0.714	0.010	0.464	0.080	1.000

Source: Own composition based on World Bank Development (2020)

elasticity parameters are predicted using the Fully Modified Least Square (FMOLS) panel data regression estimator. However, before applying this econometric technique, we check the selected variables' stochastic properties to disclose long-term policy recommendations in the first steps of our empirical analysis (Muntasir et al., 2021b). Firstly, we apply the traditional Im et al. (2003), ADF test (Dickey and Fuller, 1981), and PP test (Phillips and Perron, 1988) (Choi, 2003) unit root tests to test the null hypothesis on the presence of unit root. Several existing studies have used similar methods to assess the unit root properties of the variables (Harris et al., 2010). Table 2 presents the unit root properties of selected variables through the traditional Im et al. (2003), ADF–Fischer Chi-square, and Phillips–Perron (e.g. Choi, 2001) unit root test.

Table 2 shows that most of the tests confirm that the proposed variables are I(1). According to the p-values reported in Table 2, the series are non-stationary at level. At the first difference, we reject the hypothesis of non-stationary, so all the variables are integrated at the first difference I(1). Once we have confirmed the non-stationarity property of the selected variables, the next step is to confirm the long-run relationship among selected variables, applying Kao (2000) and Johansen Fisher(1988) cointegration tests (Table-3). In comparison, Kao (2000) cointegration test considers homogeneity in the panels. The Johansen-Fisher (Johansen, 1988) panel cointegration test connects tests from individual cross-sections. These tests were also considered in the study by Ajmi and Inglesi-Lotz (2020).

Table 3 confirms the existence of a long-run relationship between the selected variables: carbon emissions, economic growth, air transport, foreign direct investment, renewable energy production, and energy

Table 2
Unit root analysis.

Null: unit root (assumes individual unit root process)						
	Im, Pesaran and Shin W-stat		ADF - Fisher chi-square		PP - Fisher chi-square	
	t-statistic	p-value	t-statistic	p-value	t-statistic	p-value
LCO2	3.435	(0.999)	2.973	(0.982)	3.442	(0.969)
LGDP	0.586	(0.721)	4.737	(0.908)	4.041	(0.945)
LFDI	−2.012**	(0.022)	18.159**	(0.052)	45.375*	(0.000)
LRNW	2.499	(0.993)	4.271	(0.934)	2.455	(0.991)
LRDD	1.317	(0.906)	4.285	(0.933)	6.000	(0.815)
LAT	−0.582	(0.280)	10.268	(0.417)	8.616	(0.568)
ΔLCO2	−3.794***	(0.000)	33.209***	(0.000)	86.5206***	(0.000)
ΔLGDP	−4.600***	(0.000)	39.460***	(0.000)	40.3095***	(0.000)
ΔLFDI	−8.985***	(0.000)	81.106***	(0.000)	156.118***	(0.000)
ΔLRNW	−1.675**	(0.046)	17.230***	(0.069)	39.6285***	(0.000)
ΔLRDD	−4.902***	(0.000)	44.135***	(0.000)	92.4581***	(0.000)
ΔLAT	−4.621***	(0.000)	40.069***	(0.000)	73.4060***	(0.000)

Source: Own composition based on World Bank Development (2020). Notes: ***, ** and * significance at 1 %, 5 % and 10 %.

Table 3
Panel Cointegration test.

(A) Kao Residual Cointegration Test				
			t-Statistic	Prob.
ADF			−2.523*	(0.005)
Residual variance	0.007			
Heteroskedasticity- and- serial correlation- consistent (HAC) variance	0.007			
(B) Johansen Fisher Panel Cointegration Test				
Unrestricted Cointegration Rank Test (Trace and Maximum Eigenvalue)				
Hypothesized No. of CE(s)	Fisher Stat.* (from trace test)	Prob.	Fisher Stat.* (from max-eigen test)	Prob.
None	115.80***	(0.000)	71.12***	(0.000)
At most 1	56.22***	(0.000)	32.88***	(0.000)
At most 2	31.03***	(0.000)	24.53***	(0.006)
At most 3	16.09**	(0.097)	11.57	(0.315)
At most 4	20.75**	(0.022)	20.75**	(0.022)

Source: Own composition based on World Bank Development (2020). Notes: Probabilities are computed using asymptotic Chi-square distribution.*

innovation. Before proceeding with the applied FMOLS econometric estimation methodology, it is pertinent to check for the endogeneity and serial correlation problems in the data, which can be done by conducting the causality analysis. Hence, following Haseeb et al. (2018), we employ the Dumitrescu-Hurlin (DH) (Dumitrescu and Hurlin, 2012) causality test (Table-4) to check for the causality among variables. This test assumes the homogeneous non-causality hypothesis by considering the regression model's heterogeneity and the causal relation. We apply a 1-lag order selection as the appropriate lag length. By using lag 1, according to Schwarz information criteria (SIC), we obtain the Wbar and Zbar statistics, allowing common factors in the cross-equation covariance to be detached:

Table 4 presents the causality among the variables, using Dumitrescu-Hurlin (DH) pairwise causality. We observe a bidirectional causality between carbon dioxide emissions and economic growth and carbon dioxide emissions and energy innovation regarding the DH test results. Similar bidirectional causal associations between carbon emissions and economic growth were highlighted by Tong et al. (2020) for Brazil. Mexico, India, and China, while Ali et al. (2020) put forward the bidirectional causality between energy innovation and carbon dioxide emissions across Europe. We also observe the same casual tendency between energy innovation and renewable energy production. Besides, there is a unidirectional causality between economic growth and foreign direct investment inflows. The variables economic growth and renewable energy production also show a unidirectional causality. The results also reveal a unidirectional causality between air transport and economic growth, renewable energy production, and foreign direct investment.

The following section presents the empirical results and discussion from the FMOLS econometric technique (Table 5).

Table 4
Pairwise dumitrescu-hurlin panel causality tests.

Lags: 1			
Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.
LGDP does not homogeneously cause LCO2	6.395	7.046***	(0.000)
LCO2 does not homogeneously cause LGDP	2.734	2.174***	(0.029)
LFDI does not homogeneously cause LCO2	1.347	0.329	(0.741)
LCO2 does not homogeneously cause LFDI	2.880	2.369**	(0.017)
LRNWP does not homogeneously cause LCO2	8.023	9.214***	(0.000)
LCO2 does not homogeneously cause LRNWP	1.826	0.966	(0.333)
LRDD does not homogeneously cause LCO2	2.779	2.223**	(0.026)
LCO2 does not homogeneously cause LRDD	3.073	2.613***	(0.009)
LAT does not homogeneously cause LCO2	4.872	5.020***	(0.000)
LCO2 does not homogeneously cause LAT	1.039	−0.080	(0.935)
LFDI does not homogeneously cause LGDP	0.760	−0.451	(0.651)
LGDP does not homogeneously cause LFDI	2.878	2.366**	(0.018)
LRNWP does not homogeneously cause LGDP	1.196	0.128	(0.897)
LGDP does not homogeneously cause LRNWP	4.677	4.761***	(0.000)
LRDD does not homogeneously cause LGDP	2.382	1.697***	(0.089)
LGDP does not homogeneously cause LRDD	6.318	6.914***	(0.000)
LAT does not homogeneously cause LGDP	2.346	1.658***	(0.097)
LGDP does not homogeneously cause LAT	1.011	−0.117	(0.906)
LRNWP does not homogeneously cause LFDI	2.960	2.476**	(0.013)
LFDI does not homogeneously cause LRNWP	0.570	−0.705	(0.480)
LRDD does not homogeneously cause LFDI	3.221	2.809***	(0.005)
LFDI does not homogeneously cause LRDD	1.995	1.183	(0.236)
LAT does not homogeneously cause LFDI	3.198	2.792***	(0.005)
LFDI does not homogeneously cause LAT	1.936	1.113	(0.265)
LRDD does not homogeneously cause LRNWP	2.477	1.822**	(0.068)
LRNWP does not homogeneously cause LRDD	5.697	6.091***	(0.000)
LAT does not homogeneously cause LRNWP	4.689	4.776***	(0.000)
LRNWP does not homogeneously cause LAT	2.236	1.512	(0.130)
LAT does not homogeneously cause LRDD	6.490	7.143***	(0.000)
LRDD does not homogeneously cause LAT	1.491	0.515	(0.606)

Source: Own composition based on World Bank Development (2020). Note: ***, ** and * significance at 1 %, 5 % and 10 %

4. Empirical results and discussion

To conclude our empirical analysis, we use the FMOLS technique to check the statistically significant effects of the explanatory variables on carbon emissions. Table 5 presents the econometric results estimated by the Fully Modified Least Squares (FMOLS) econometric technique.

Table 5
Panel Fully Modified Least Squares (FMOLS) estimation results.

Dependent Variable: LCO2 Sample (adjusted): 1990–2015			
Variable	Model 1	Model 2	Model 3
LGDP	2.439***	2.178***	1.833***
	[3.352]	[3.871]	[3.225]
	(0.001)	(0.000)	(0.002)
LGDP^2	−0.110***	−0.105***	−0.087***
	[-3.125]	[-3.839]	[-3.155]
	(0.002)	(0.0003)	(0.0024)
LFDI	4.54E-04***	1.82E-04	0.027***
	[3.513]	[1.400]	[4.985]
	(0.000)	(0.1654)	(0.000)
LRNWP	−0.026**	−0.117***	−0.120***
	[-2.302]	[-20.262]	[-13.804]
	(0.024)	(0.000)	(0.000)
LRDD	−0.005***	−0.006***	−6.75E-03**
	[-5.914]	[-2.610]	[-2.598]
	(0.000)	(0.010)	(0.011)
LAT	14.774***	2.0533***	2.370**
	[12.295]	[2.402]	[2.328]
	(0.000)	(0.018)	(0.023)
LAT^2	−0.410***	−0.047**	−0.055**
	[-12.053]	[-2.001]	[-1.988]
	(0.000)	(0.048)	(0.050)
LAT*LFDI	–	−3.01E-04**	−0.001***
	–	[-2.354]	[-4.505]
	–	(0.021)	(0.000)
LRDD*LAT	–	–	−3.06E-04**
	–	–	[-2.612]
	–	–	(0.011)
LRDD*LFDI	–	–	−3.55E-05**
	–	–	[-2.112]
	–	–	(0.038)
R-squared	0.970	0.959	0.961
Adjusted R-squared	0.964	0.953	0.953
S.E. of regression	0.044	0.051	0.053
Long-run variance	0.000	0.000	0.000
Mean dependent var	1.965	1.962	1.9762
S.D. dependent var	0.239	0.240	0.247
Sum squared resid	0.158	0.207	0.184

Source: Own composition based on World Bank Development (2020). Notes: ***, ** and * significance at 1 %, 5 % and 10 %

From the empirical results shown in Table 5, we confirm the inverted-U ($\beta_1 > 0$ and $\beta_2 < 0$) EKC hypothesis for selected EU countries during 1995–2015. This result implies that the economic growth of these economies is ultimately likely to restore environmental well-being by reducing carbon dioxide emissions across Europe. Similar findings were highlighted in the studies by Rauf et al. (2018) for the BRI countries, Isik et al. (2019 in the studies by Rauf et al. (2018) for the BRI countries, Isik et al. (2019) in the context of the USA, Leal, and Marques (2020) for highly globalized economies. Besides, the estimated coefficient $\beta_3 > 0$ reveals a direct connection between FDI and carbon dioxide emissions, validating the PHH in the context of the EU-5 nations. This finding indicates that these European countries are attracting dirty FDI and producing pollution-intensive goods and services; consequently, financial globalization is axing their environmental well-being. Similar conclusions were made by Essandoh et al. (2020) for low-income countries and Naz et al. (2019) for Pakistan. Moreover, the estimates also prove that renewable energy use and investments in energy innovation contribute to controlling carbon emissions ($\beta_4 < 0$ and $\beta_5 < 0$). These results collectively imply that a technological development-induced clean energy transition effectively controls the carbon dioxide emission figures of the EU-5 countries. These findings corroborate the results put forward by Alvarez-Herranz (2017) for the OECD countries and Dauda et al. (2021) for selected African nations.

Furthermore, the coefficients $\beta_6 > 0$ and $\beta_7 < 0$ confirm a non-linear connection between international air transport and environmental degradation, suggesting that international tourism ultimately helps to reinstate environmental well-being in Europe. These empirical results are supported by Sherafatian-Jahromi et al. (2017). On the other hand, the FMOLS estimates for Equation-2 reveal a dampening effect of air transport over the linkage between FDI and carbon emissions ($\beta_8 < 0$). This implies that international tourism can help to negate the detrimental effects of FDI inflows on the environment in the EU-5 countries. Besides, the estimates from Equation-3 also reveal a dampening effect on energy innovation in air transport and FDI inflows on carbon dioxide emissions ($\beta_9 < 0$ and $\beta_{10} < 0$).

The empirical results are consistent with the previous empirical literature (Li et al., 2013; Zhang and Wei, 2015; Zhang et al., 2015; Shahbaz et al., 2020; Nasir et al., 2021; Nguyen et al., 2021). In EU countries, we find as one of the leading global goals carbon mitigating strategies. This aim is desirable for the global sustainability agenda and the achievement of Paris Agreements and Sustainable Development Goals. However, carbon mitigating strategies are chiefly compromised by unsustainable economic growth and high risk to the global sustainability agenda (Li et al., 2013). The prolific growth of carbon emissions is driven by technological innovations, which have not stemmed from environmental sustainability instruments (Zhang and Wei, 2015; Álvarez et al., 2017; Caglar et al., 2021; Nguyen et al., 2021). Zhang et al. (2015) concluded that technological instruments would substantially enhance global air quality. In our proposed model, the transition from scale to technical effect would be inferred due to advances in the air transport industry. The empirical results confirm that sustainable tourism is fundamental to attract clear foreign industries to host countries through the air transportation industry.

5. Final conclusions and policy implications

This study modelled the impacts of international air transport on carbon emissions in selected EU-5 countries, during the period 1990–2015, under the EKC hypothesis framework. Besides, in addition to economic growth and international air transport, the econometric analysis additionally controls for FDI inflows, renewable energy use, and energy innovation. The results from the FMOLS analysis validate the existence of the EKC hypothesis and the PHH for the selected EU nations. Moreover, renewable energy use and investments in energy innovation are found to reduce carbon emissions. On the other hand, the non-linear inverted-U-shaped relationship between international air transport and carbon dioxide emissions is also ascertained. Apart from these direct environmental impacts, several interaction effects are also witnessed in which international air transport is found to interact with FDI inflows to reduce the adverse environmental impacts while energy innovation is seen to interact with international air transport to jointly reduce carbon dioxide emissions in the selected EU-5 countries. Furthermore, investment in energy innovation is also witnessed to interact with FDI inflows to neutralize the adverse environmental impacts associated with FDI inflows. Based on these major findings, several policies can be recommended.

Firstly, since economic growth is found to eventually improve environmental well-being, it is important for the European nations to expedite their growth processes so that the threshold national income level, beyond which further economic growth can be expected to reduce carbon dioxide emissions, can be attained. Secondly, the European nations should revisit their respective financial globalization policies to inhibit the inflows of dirty FDIs. In addition, these nations should rather specialize in producing environmentally friendly goods and services rather than transforming them into pollution heavens. Thirdly, phasing out fossil fuel dependency is critically important for these nations to improve environmental quality.

In this regard, the EU-5 nations should enhance the shares of renewable energy in their energy mixes, which would lessen their predominant reliance on fossil fuels and help these nations tackle their aggravating carbon dioxide emission trends. Fourthly, enhancing investments in energy innovation-oriented projects is also necessary for the European nations to mitigate carbon dioxide emissions. Such investments can also be expected to assist these nations in reducing their traditional fossil fuel dependency to further curb the carbon dioxide emissions in Europe.

Finally, and most importantly, the inverted-U shaped relationship between international air transport and carbon dioxide emissions asks for the governments of the EU-5 nations to adopt policies that would simultaneously expand and develop their respective international tourism industries. This process would also transform this sector in an environmentally sustainable manner so that the adverse environmental impacts associated with international tourism can be neutralized. More importantly, the development of the international tourism industries alongside technological innovation, as certified by the findings of the interaction effects, can also help to reduce the negative environmental effects of FDI inflows and international tourism. Data unavailability was the major limitation endured in conducting this study. Consequently, only 5 of the EU nations were included in the analysis. This study can be replicated on other similar regional economies to assess the generality of the findings. Besides, this stud can also be conducted using alternative indicators of environmental degradation to check the robustness of the findings.

Credit (Contributor Roles Taxonomy)

As the corresponding author, I declare that all co-authors[1] have contributed at the same level during the process of elaboration of this study.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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