Determinants of CO_2 emissions in European Union countries: Does environmental regulation reduce environmental pollution?

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Resumo

O crescimento económico é uma das principais causas da poluição. As alterações climáticas causadas pelo aumento das emissões têm efeitos prejudiciais e irreversíveis nas economias como um todo. Atualmente, as alterações climáticas representam um desafio para os formuladores de políticas. Esta pesquisa pretende contribuir para o debate atual sobre os fatores que contribuem para a redução das emissões, fornecendo evidências empíricas do papel da regulação ambiental nesse processo. Em detalhe, esta pesquisa visa preencher uma lacuna na literatura, dando especial atenção aos efeitos da regulação baseada no mercado, políticas regulatórias de incentivo à implementação de energias renováveis e investimento direto estrangeiro nas emissões de dióxido de carbono. Para atingir esse objetivo, foram utilizados dados anuais de 1995 a 2017 para 17 países da União Europeia (UE). Para controlar alguma possível endogeneidade e estudar os efeitos de curto e longo prazo individualmente, o modelo *Autoregressive Distributed Lag* (ARDL) foi usado com o estimador *Driscoll-Kraay*. As principais conclusões mostram que a regulação ambiental é eficaz no decréscimo as emissões de CO2 a longo prazo. Além disso, as políticas de apoio às fontes de energia renováveis afetam negativamente as emissões de CO2 no curto e no longo prazo. A eficácia dessas políticas é demonstrada ainda mais, uma vez que o investimento direto estrangeiro reduz as emissões de dióxido de carbono, sugerindo que a UE está a conseguir atrair investimento inovador e de alta qualidade. A hipótese *pollution halo* foi validada para os países da UE.

Palavras-chave:

Emissões de CO_2; regulação ambiental; energia renovável; investimento direto estrangeiro; hipótese *pollution halo*; ARDL

Resumo Alargado

O crescimento económico tem-se mostrado como uma das principais causas do nível de poluição atmosférica verificado nas últimas décadas. As alterações climáticas são um dos maiores problemas que a sociedade atual enfrenta tendo forçado os países a intervir de forma a reduzir o impacto negativo das atividades económicas no ambiente. Sendo que o crescimento económico dos países está associado a um crescimento dos níveis de poluição (Acaravci and Ozturk, 2010; Al-Mulali and Ozturk, 2015), é essencial permitir que as economias continuem a crescer economicamente sem que esse crescimento deteriore ainda mais o ambiente. A regulação ambiental desempenha um papel preponderante no alcance desse desígnio. De facto, num mercado desregulado, os agentes económicos não têm incentivos para adotar um comportamento ambientalmente menos nocivo, uma vez que, geralmente, esta mudança está associada a elevados investimentos. No entanto, o papel da regulação ambiental não deve ser apenas o de permitir a criação de políticas de proteção ambiental, mas também o de tornar essas políticas equitativas para todos os agentes.

O principal objetivo desta pesquisa é estudar os determinantes das emissões de CO_2 na União Europeia (UE), com foco principal nos efeitos da regulação ambiental. Considerando a escassez de estudos focados na análise da regulação ambiental no contexto da UE e o facto da literatura não ser consensual acerca da mensuração do rigor regulatório, a avaliação empírica da regulação ambiental torna-se desafiante e este estudo demonstra ser pertinente e necessário. Assim, esta pesquisa contribui para a literatura fornecendo evidências empíricas acerca dos efeitos da regulação sobre as emissões de CO_2. Esta pesquisa aplica um modelo dinâmico que permite determinar os efeitos de curto e de longo prazo separadamente. A análise dos países da UE é de especial relevância não apenas porque a UE é líder na promoção de políticas e tecnologias que direcionadas à redução das emissões poluentes, mas também pela existência de uma regulação rigorosa das atividades poluidoras. A regulação ambiental representa um papel essencial para atingir um crescimento sustentável. O conhecimento de todos os envolventes do problema da poluição é crucial para que se possam avaliar as soluções para o mesmo e delinear medidas regulatórias eficientes. Assim, as principais questões que esta pesquisa procura responder são: (i) a regulação ambiental tem demonstrado ser eficaz na redução das emissões de CO_2? (ii) as políticas regulatórias de incentivo ao desenvolvimento das fontes de energias renovável contribuem para reduzir a degradação ambiental? e (iii) os países membros da União Europeia estão a atrair investimento em tecnologias amigas do ambiente?

Esta pesquisa utiliza dados anuais compreendidos entre 1995 e 2017 para 17 países membros da UE. As variáveis utilizadas são: as emissões de Dióxido de Carbono *per capita*

(*CO_2pc*); o Produto Interno Bruto *per capita* (*GDPpc*); a receita proveniente dos impostos ambientais (*REG*); o Investimento Direto Estrangeiro (*FDI*); o número acumulado de políticas regulatórias de incentivo às fontes de energia renovável (*POL*); o consumo de energia renovável e proveniente de resíduos (*RESpc*) e o consumo de energia primária (*ECpc*). Os dados utilizados foram retirados das seguintes bases de dados: *British Petroleum statistics*, *World Bank* (WDI), Eurostat, *United Nations Conference on Trade and Development* (UNCTAD) e *International Energy Agency* (IEA). A fim de garantir que a metodologia aplicada é adequada, os testes de raízes unitárias de primeira e segunda geração, propostos por Pesaran (2007) e Maddala e Wu (1999), foram realizados e todas as variáveis demonstraram ter uma ordem de integração inferior a dois. Face a esses resultados, a utilização do modelo *Autoregressive Distributed Lag* (ARDL) é apropriada. Este modelo permite adicionalmente a análise individual dos efeitos de curto e de longo prazo e controlar a possível endogeneidade entre variáveis. De forma a garantir a robustez dos resultados, o modelo foi sujeito à realização de vários testes de especificação que indicaram a presença de *cross-sectional dependence,* heterocedasticidade e autocorrelação. Deste modo, o estimador Driscoll-Kraay foi aplicado nesta pesquisa por ser robusto na presença dessas características.

Foram estimados dois modelos: o modelo completo e o modelo parcimonioso. A consistência entre os dois modelos, revela a robustez dos resultados encontrados. Os principais resultados evidenciam que a regulação ambiental contribui para o decréscimo das emissões, suportando a sua eficácia no longo-prazo. Pelo contrário, o crescimento económico e o consumo de energia primária são os principais fatores impulsionadores das emissões de CO_2. Apesar de a UE estar a atrair investimento direto estrangeiro "limpo", como demonstra o modelo, este resultado sugere que os setores produtivos da economia estão ainda dependentes de tecnologias intensivas em carbono. Para reduzir essa dependência, a UE deve continuar a criar políticas capazes de atrair investimento tecnologicamente inovador, e as políticas regulatórias devem fomentar o uso de energias renováveis, permitindo que estas sejam utilizadas em substituição das convencionais. Ações regulatórias são necessárias quer do lado da oferta, quer do lado da procura, para que as políticas possam ser eficientes. Ao mesmo tempo, a implementação de sistemas e equipamentos energeticamente eficientes deve ser incentivada juntamente com a adoção da mobilidade elétrica. Para instigar essas práticas no lado da procura a regulação por meio da dissuasão, como, por exemplo um imposto sobre atividades poluidoras, associado à regulação baseada em ações positivas para reforçar atividades menos poluentes, usando, por exemplo, subsídios ou benefícios fiscais, poderá ser um mecanismo eficaz para promover a redução de emissões e ao mesmo tempo, estimular o crescimento económico.

Abstract

The economic growth is one of the main drivers of pollution. Climate change caused by the increase in emissions has harmful and irreversible effects on economies as a whole. Currently, climate change represents a challenging issue for policymakers. This research intends to contribute to the current debate on the factors that contribute to reducing emissions, supplying empirical evidence of the role of environmental regulation in this process. In detail, this research aims to bridge a gap in the literature by giving special attention to the effects of market-based regulation, regulatory incentive policies for renewables deployment, and foreign direct investment on carbon dioxide emissions. To accomplish this objective, it uses yearly data from 1995 to 2017 for 17 European Union (EU) countries. To control for some possible endogeneity, and to study the short- and the long-run effects individually, an Autoregressive Distributed Lag (ARDL) model was used with a Driscoll-Kraay estimator. The main findings show that environmental regulation is effective in cutting CO_2 emissions in the long-run. Additionally, the policies supporting renewable energy sources negatively affect CO_2 emissions in both the short- and long-run. The effectiveness of these policies is further demonstrated, with foreign direct investment reducing carbon dioxide emissions, suggesting that the EU is managing to attract high quality and innovative investment. The pollution halo hypothesis was validated for EU countries.

Keywords

CO_2 emissions; environmental regulation; renewable energy; foreign direct investment; pollution halo hypothesis; ARDL

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Acronyms list

ARDL	Autoregressive Distributed Lag
BP	British Petroleum
CIPS	Cross-sectionally augmented IPS
CSD	Cross-sectional Dependence
CO_2	Carbon Dioxide
DI	Direct Investment
DK	Driscoll-Kraay
EEA	European Environment Agency
EKC	Environmental Kuznets Curve
EPS	Environmental Policy Stringency
EU	European Union
FDI	Foreign Direct Investment
FE	Fixed Effects
FER	Fixed Effects Robust
FFI	Fiscal/Financial Incentives
GDP	Gross Domestic Product
GHG	Greenhouse Gases
IE	Information and Education
IEA	International Energy Agency
LCU	Local Currency Unit
MB	Market based
MBI	Market-based Instruments
MBR	Market-based Regulation
NMB	Non- market based
MW	Maddala and Wu
OECD	Organisation for Economic Co-operation and Development
PACE	Pollution Abatement Costs and Expenditures
PH	Pollution Halo
PHH	Pollution Haven Hypothesis
PPSR	Public Policies Supporting Renewables
PS	Policy Support
R&D	Research and Development
RDD	Research, Development, and Deployment
RES	Renewable Energy Sources

RI	Regulatory Instruments
SO	Sulfur Dioxide
STIRPAT	Stochastic Impacts by Regression on Population, Affluence and Technology
R&D	Research and Development
UECM	Unrestricted Error Correction Mechanism
UNCTAD	United Nations Conference on Trade and Development
VA	Voluntary Approaches
VIF	Variance Inflation Factor
WDI	World Development Indicators

1. Introduction

Over the last few decades, economic development around the world has put pressure on the environment. This means that environmental regulation is expected to be requisite to reducing emissions. However, the fact is that in a deregulated market, economic agents are not incentivised to change their behaviour to one more environmentally friendly, as generally this is associated with higher investment costs. Thus, effective policies are needed to encourage sustainable growth. Carbon Dioxide (CO_2) emissions represent around 81% of the European Union's (EU) total Greenhouse Gases (GHG) emissions (Eurostat, 2019)[1]. The severity and complexity of climate change have forced countries to intervene in the markets in order to contract the negative effects. Examples of the interventions to advertise climate change are the "Earth Summit" in 1992 and the Kyoto Protocol in 1997. More recently, the Paris Agreement entered in force in 2020 and its main goal is fighting against climate change, aiming to keep global average temperatures below 2°C above pre-industrial levels (United Nations, 2015). In this sense, environmental regulation is essential to allow economies to achieve economic growth without an increase in emissions. It is essential, not only to allow the creation of policies with the main goal of protecting the environment but also to make environmental protection equitable for all agents.

The analysis of EU countries is of particular relevance not only because the EU is a leader in the promotion of policies and technologies aimed at reducing polluting emissions, but also as a consequence of the established stringent regulations for polluting activities already in place there. In fact, by 2050, EU emissions should be reduced by 80% to 90% compared to 1990 levels (Eurostat, 2019). Thus, European Union has been working together among all its member states and implementing policies to achieve all climate change targets. Consequently, environmental taxes have been studied as a legislative instrument to combat environmental pollution. "An 'environmentally related tax' means a tax whose tax base is a physical unit (or a proxy of a physical unit) of something that has a proven, specific negative impact on the environment" (p.6 Regulation (EU) No 691/2011, 2011). The main objective should be to penalize all negative externalities arising from polluting activities, as well as, to encourage the transition to the use of less polluting technologies. Environmental regulation can be addressed by market-based (MB) and non-market based (NMB) regulation. MB takes on environmental policy instruments and is oriented towards the market where environmental taxes are applied.

[1] The citation style used throughout this dissertation is the APA 6th edition (American Psychological Association).

NMB depends mainly on the imposition of obligations, like emissions standards, by governmental entities (Xie et al., 2017). In general, the literature suggests that MB regulation could be more effective than NMB in acting for environmental protection (Wang and Shao, 2019).

The policy supporting the deployment of renewable energy sources (RES) has been accomplished to reduce the emissions related to energy production and consumption. In the EU context, the RES deployment could even contribute to reducing the energy dependence, namely by promoting the harnessing of the endogenous potential of the countries. In fact, Public Policies Supporting Renewable (PPSR), have been an instrument used by the policymakers to introduce RES within energy mixes and it also have attracted considerable attention to the literature (see e.g. Marques et al., (2019)). Moreover, the implementation and promotion of RES could also be one way to attract Foreign Direct Investment (FDI) in environmentally friendly technologies.

The contribution of this research to the literature is threefold. Firstly, it is focused on the study of environmental regulation in European Union countries, an area which is little explored in the literature. Secondly, it applies a dynamic model which can determine the factors that influence CO_2 emissions in both the short- and long-run. Thirdly, alongside the proxy for environmental regulation, it includes a policy variable that can induce a more in-depth understanding of the regulatory effect in countries. In sum, the main objective of this paper is to answer the following central questions: (i) have environmental regulations been effective in reducing CO_2 emissions? (ii) are regulatory incentive policies for RES deployment contributing to reducing environmental degradation? and (iii) are countries attracting investment in environmentally friendly technologies? To accomplish this paper's objectives, it uses yearly data from 1995 to 2017 for 17 EU countries. To control for some possible endogeneity, and to study the short- and the long-run effects individually, an Autoregressive Distributed Lag (ARDL) model was used with a Driscoll-Kraay estimator with fixed effects.

The main findings suggest that environmental regulation has been effective in the reduction of CO_2 emissions. The regulatory policies to incentivise RES deployment have a negative influence on CO_2 emissions, although with a smaller magnitude than an environmental regulation proxy. Economic growth, together with primary energy consumption, continue to be the main factors contributing to the level of emission growth. Additionally, foreign direct investment, and renewables and waste consumption prove to be effective in reducing CO_2 emissions. The pollution halo (PH) hypothesis in the EU is confirmed.

The remainder of this paper is organized as follows. Section 2 provides a debate on the determinants of CO_2 emissions. Section 3 is dedicated to showing the description of the data and methodology applied. The results are presented in Section 4 and discussed in Section 5. Lastly, Section 6 discloses the concluding remarks.

2. Literature Review

For some time, the literature has been studying the effectiveness of environmental regulation, focusing on the role of different variables that can, together with regulation, influence the level of environmental pollution around the globe. Promoting the use of renewable energy seems to be one of Europe's pathways to achieving CO_2 emissions targets. Generally, the main goal and challenge is to maintain levels of economic growth while at the same time, reducing emissions.

The relationship between economic growth and GHG emissions has been a hot research topic in the literature, arousing interest in finding out what is the impact of gross domestic product on the level of greenhouse gases produced by countries. Besides economic growth, there are other drivers of emissions that have merited the attention of the literature. Undoubtedly, population and economic growth are the two factors that have the greatest impact on the environment. Some authors have relied on a Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model to study, in the most part, the impact of Gross Domestic Product (GDP) and population on the environment (Bargaoui et al., 2014; Martínez-Zarzoso et al., 2007; Hashmi and Alam, 2019; Shafiei and Salim, 2014). In EU countries, economic growth is considered to be one of the biggest factors responsible for increasing CO_2 emissions. An enlargement of GDP is seen to boost emission in both the short-run (Acaravci and Ozturk, 2010) and the long-run (Al-Mulali and Ozturk, 2015). The Environmental Kuznets Curve (EKC) was validated in the literature for new EU members, supporting the idea that real income increase beside carbon emissions before de turning point (Kasman and Selman, 2015).

Energy consumption is important for economic growth. However, the strong dependence on energy consumption from fossil sources, makes energy consumption a significant driver of emissions (Shafiei and Salim, 2014; Iwata et al., 2012). It is crucial to reduce the consumption of fossil fuels, policies which support energy efficiency and the implementation of renewables have been followed to achieve this objective. This means that renewables should be able to reduce countries' dependence on fossil fuels, while maintaining levels of economic growth. The literature has focused on this issue, analysing, on the one hand, the possible existence of a substitution effect between RES and fossils, and on the other hand, the role of these sources in economic growth. Using the Autoregressive Distributed Lag (ARDL) model, Acaravci and Ozturk (2010), evidenced that energy consumption increases the amount of CO_2 emissions in some of the European countries. Additionally, the literature also supports that the deployment of

RES contributes to reducing the environmental impacts related to energy use (Cherni and Jouini, 2017; Jebli et al., 2016; Shafiei and Salim, 2014).

As the reduction of emissions remains dependent on RES deployment, the impact of different variables that represent RES has been studied and considered by the scientific community. Regarding the share of renewable energy in energy production in EU countries, it is stated that it decreases CO_2 emissions (Albulescu et al., 2019). This evidence highlights that the share of RES in gross final energy consumption should be enlarged, and for that, they must be able to replace the conventional ones. However, RES deployment is still dependent on the public policies supporting it, a lack of maturity in the market and its high implementations costs. The literature argues that it is important to increase financial incentives for renewable energy production in order to promote the use of this energy source (Albulescu et al., 2019). Given that the implementing costs of renewables is much higher than non-renewables, one solution may be to increase the support for research and development (R&D) by European governments with the aim of developing new technologies to make renewable production costs lower (Dogan & Seker, 2016). These authors essentially advocate public awareness of governments emphasizing the need to create regulatory policies that improve the use of RES.

Renewables have undergone a huge technological breakthrough in the past decade and, indeed, could lead Europe to a more sustainable future, as their application can be directed towards the same goal: the reduction of CO_2 emissions. What follows is the IEA Global Renewable Energy Policies and Measures Database that disaggregates the Public Policies Supporting Renewables (PPSR) into the following types: Direct Investment (DI); Fiscal/Financial Incentives (FFI); Market-based Instruments (MBI); Information and Education (IE); Policy Support (PS); Research, Development, and Deployment (RDD); Voluntary Approaches (VA); and Regulatory Instruments (RI). This research focuses only on the study of regulatory policies and their effect in the fight against pollution. Regulatory instruments are composed of various instruments that the government uses to define targets and standards, obligation schemes and other mandatory requirements to policy destinations (Abdmouleh et al., 2015; Marques et al., 2019). This policy type can work as an instrument for reducing environmental degradation as it can attract investment and lead to increased consumption of energy from renewable sources.

Understanding the connection between the economy, the environment, and Foreign Direct Investment (FDI) is crucial so that policymakers can ensure that policies are aimed at sustainable economic growth (Omri et al., 2014). Through technology and know-how transfer, spillover effects and increased productivity, FDI promotes economic growth (Batten and Vo, 2010). Regarding the effects on environmental pollution, the literature is not consensual. On the one hand, this type of investment can enlarge emissions (Xing and Kolstad, 2002). In this case, highly polluting industries are installed in a host country, contributing thus to aggravating environmental issues there. On the other hand, FDI could reduce emissions showing that there is a transfer of eco-friendly technology to the host countries (Albulescu et al., 2019). Some authors advocate that through the transfer of innovative technologies, FDI helps the host countries to achieve low carbon economic growth (List and Co, 2000).

The pollution halo (PH) hypothesis and pollution haven hypothesis (PHH) resulted from the trend of the literature to analyse the relationship between FDI and emissions. On the one hand, when the FDI contributes to increasing emissions in the host countries, the pollution haven hypothesis (PHH) is confirmed see, e.g. (Baek, 2016). In this case, countries with weak environmental regulations, and no interest in increasing their environmental stringency, becoming pollution havens (Mabey and Mcnally, 1999). On the other hand, when inward FDI reduces the emissions of host countries, the PH hypothesis is validated see, e.g. (Shao et al., 2019). The PH hypothesis is validated in the EU, stating that investors are concerned about investing in countries with high levels of environmental pollution (Albulescu et al., 2019).

Environmental regulation plays a critical role in achieving the goal of environmental quality. Overall, environmental regulation intends to appease the negative externalities of economic activities in the environment. It imposes restrictions on polluting agents in order to increase the cost of polluting activities, making them less attractive. The existence of an inverted "U-shaped" relationship between regulation and environmental pollution (Zhang et al., 2020), is maybe the explanation for countries with less stringent regulation to continue to increase their pollution levels until they reach the turning point. Therefore, in these countries, regulation must be stricter in order to become effective (Ouyang et al., 2019; Zhang et al., 2020).

Some authors address environmental regulation by using market-based instruments and non-market based regulation (Xie et al., 2017). Market-based regulation takes on environmental policy instruments (taxes, trading schemes, feed-in tariffs, and premiums and Deposit & Refund Scheme), and they are oriented towards the market. Non-market based or command-and-control regulations provide emission standards for greenhouse gases (GHG) and government R&D expenditure on renewable energy (OECD, 2016). It can be stated that this type of regulation depends mainly on the imposition by governmental entities. Wang and Shao (2019) argue that the impact produced by these two types of regulation is different and it should not be applied with the same force, suggesting that MB regulations could be more effective.

There are also authors who admit to a third type of regulation: informal regulation[2]. It mainly depends on the environmental awareness held by society (Wang and Shao, 2019; Xie et al., 2017). As an example, the press can act as an informal regulatory mechanism producing positive effects on pollution control at the local level (Kathuria, 2007). The informal regulation has been operationalized in the literature by using, for instance, the share of patents in environment-related technologies and the ratio of total enrolment at tertiary education levels (Wang and Shao, 2019). The literature is not consensual about the regulation stringency measurement yet, which makes this study pertinent and necessary. The empirical assessment of environmental regulation has been a challenge for the literature. Composite indicators that incorporate MB and NMB regulations at country level, like Environmental Policy Stringency (EPS) index have been used in the literature as they have the advantage of bringing both, MB and NMB, types of information (Hille and Möbius, 2019; Ouyang et al., 2019; Georgatzi et al., 2020). According to Ouyang et al. (2019), this indicator shows an effective, but weak, effect on air pollution. This result could be related to the "U shaped" relationship between environmental regulation and environmental pollution; the increasing effect of both being verified in the first stage of the curve (Ouyang et al., 2019).

Other studies use other perspectives to measure environmental regulation stringency by employing indicators based on market and non-market instruments separately. Examples of NMB indicators used in the literature are greenhouse gas (GHG) emissions, indicators focused on industry like the ratio between the output value of comprehensive utilization of the "three wastes" (i.e., waste gas, waste water, and industrial residue) to GDP (Hao et al., 2018), proportion of industrial pollution control investment in industry value added (Pan et al., 2019), or coverage rate of urban green space (Lin and Zhu, 2019). Pollution Abatement Costs and Expenditures (PACE) by private firms (Rubashkina et al., 2015) and total revenue from environmental taxes to measure the government efforts on pollution control (Wang and Wei, 2019; Hashmi and Alam, 2019; Hille and Möbius, 2019; Leiter et al., 2011) have also been used as proxies for environmental regulation.

As a result of the growing concern and necessity to achieve environmental goals and objectives, governments are increasing the use of instruments such as environmental taxes. The various types of taxes may charge for energy (electricity included), power and heat generation, as well as CO_2 and SO_2 emissions (EEA, 2001). Environmental taxation has been used as a mechanism to encourage the use of RES to the detriment of fossil fuels. In this way, RES diversifies the energy mix as well as stimulates new energy

[2] Market based regulation and non-market-based regulation can be designated together as formal regulations.

business models. This type of policy can bring both environmental and economic benefits, as revenues are used to decrease the distortion in taxation on labour and production, and, at the same time, help to decrease pollution (Bosquet, 2000). In addition, it is a mechanism capable of encouraging investment in RES. In fact, the achievement of environmental goals remains dependent on regulation stringency. RES deployment should be accompanied by a strict regulation for the polluting activities. This regulation should punish not only polluting activities but also incentivize the use of RES. The effect of environmental regulation on emissions is not unanimous within the scientific community. On the one hand, there is evidence that environmental regulation has been effective in reducing emissions (Hashmi and Alam, 2019). On the other hand, environmental regulation may not be effective due to the ineffectiveness of environmental policies (Hao et al., 2018). Many articles have looked closely at environmental regulation, studying their impact on several variables, as mentioned above. However, there are no studies that address the effects of environmental regulation on CO_2 emissions in the EU, considering the short- and the long-run effects individually.

3. Data and Methodology

This research uses annual data for a sample of 17 EU countries over the period from 1995 to 2017. The criteria selection of data was mainly based on its availability for the largest number of countries in the European Union as well as the longest period available. The countries under analysis are Austria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Lithuania, Poland, Portugal, the Slovak Republic, Spain, Sweden, and the United Kingdom. Table 1 summarizes the data used, their units of measurement and respective sources.

Table 1. Variables description and source

Variable	Definition	Source
CO2pc	Carbon Dioxide emissions (tonnes per capita)	BP statistics
GDPpc	Real Gross Domestic Product per capita (constant LCU)	World Bank (WDI)
REG	Real Environmental Tax Revenue (million euros)	Eurostat
FDI	Inward Foreign Direct Investment (% of GDP)	UNCTAD
POL	Accumulated number RES policies (Regulatory instruments type)	International Energy Agency (IEA)
RESpc	Renewable and waste energy consumption (tonnes per capita)	International Energy Agency (IEA)
ECpc	Primary energy consumption (tonnes per capita)	BP statistics

Notes: BP means British Petroleum; LCU means Local Currency Unit; UNCTAD denotes United Nations Conference on Trade and Development; RES indicates Renewable Energy Sources; EC means Energy Consumption

Considering that this paper aims to investigate the factors explaining environmental pollution, CO_2 emissions were used as the dependent variable such as Dogan and Seker, (2016). Concerning the independent variables, environmental stringency was expressed by using Environmental Tax Revenue (*REG*). Previously, environmental taxes have been used in the literature as a proxy for environmental regulation, under the argument wherein these increase emissions costs and, a higher tax is associated with a stringent regulation (Leiter et al., 2011). Figure 1 shows the environmental tax revenues (*LREG*) for the countries under analysis, a growing trend for most countries can be observed.

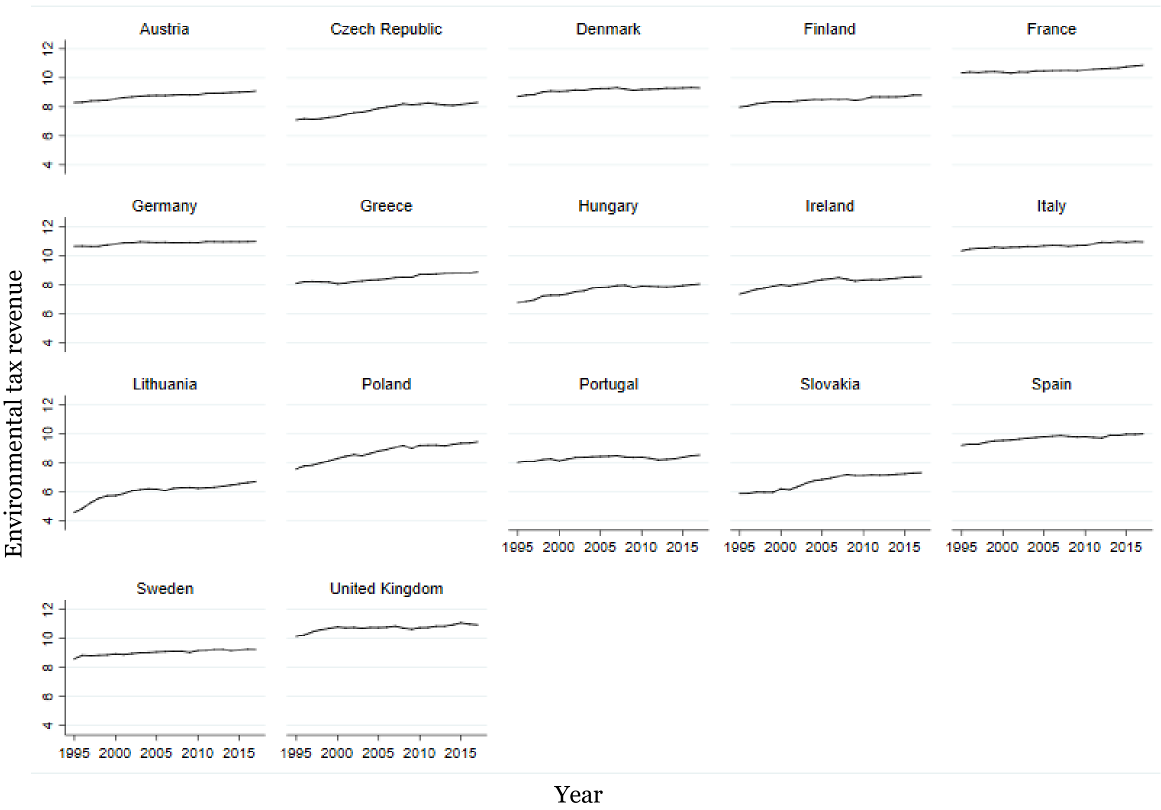

Figure 1. Environmental tax revenue in EU countries. Notes: The Stata command *xtline* was used to obtain this graph.

Considering that primary energy consumption drives CO_2 emissions, primary energy consumption (*ECpc*) was taken as representative, and in addition, used as a control variable.

Environmental regulation and environmental awareness of the countries has stimulated the introduction of RES to promote the reduction of emissions. To analyse this effect, the accumulated number of RES incentive policies in force (regulatory type) and Renewable and Total Waste consumption were considered. On the one hand, the accumulated number of regulatory policies supporting RES could be considered as a regulatory proxy as it allows us to assess the impact of government intervention on the deployment of RES and consequently their environmental concern. On the other hand, RES consumption is an alternative to fossil fuels, and it is important to understand if RES has been responsible for the reduction in fossil fuel use and the consequent reduction in CO_2 emissions. Figure 2 shows the evolution of the cumulative number of regulatory policies to encourage the development of RES. In all countries there is a very significant increase, especially during the last decade, evidencing the government's efforts to introduce RES in their energy mix.

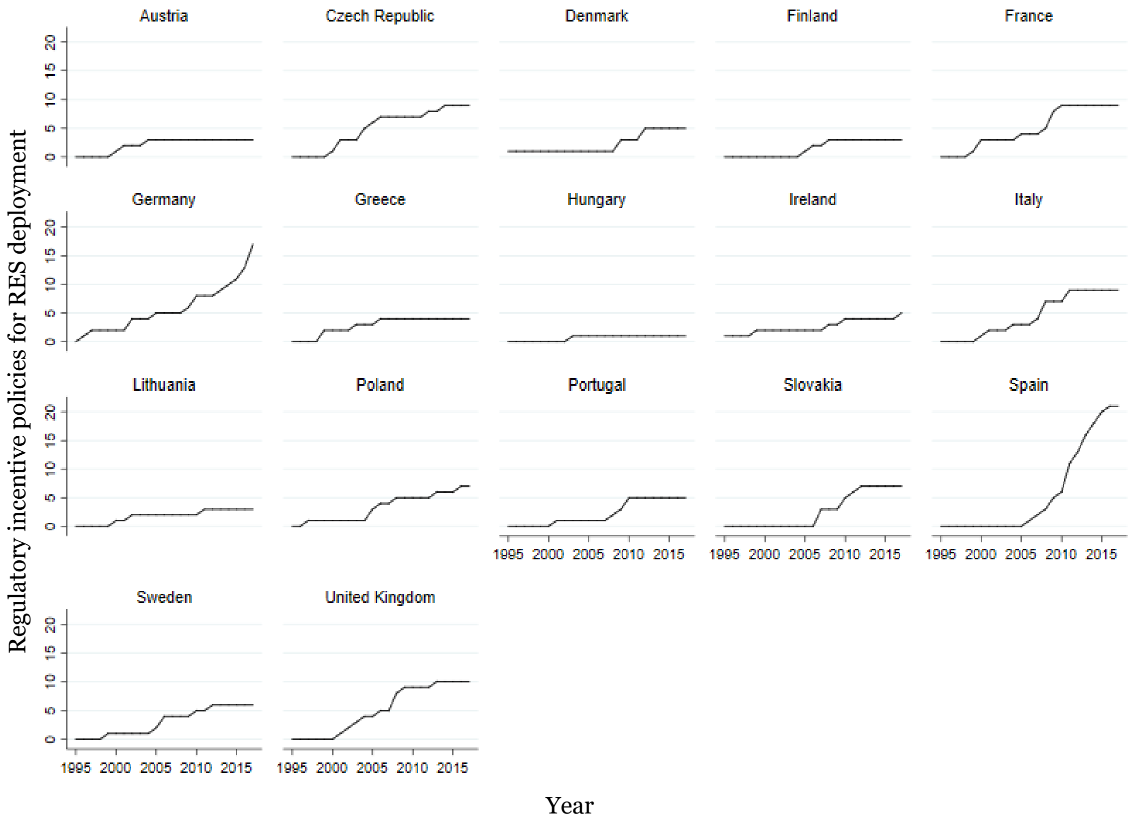

Figure 2. Regulatory incentive policies for RES deployment. Notes: The Stata command *xtline* was used to obtain this graph.

Since the technologies associated with RES involve large amounts of investment (Marques and Fuinhas, 2012), inward FDI was included too verify if the investment was made to reduce environmental pollution (Zhang et al., 2020). This inclusion aims to ascertain the capacity of EU countries to attract eco-friendly investment, testing thus the pollution hallo hypothesis. Given that economic growth has been presented as one of the main causes of CO_2 emissions, the GDP per capita is used as a proxy for economic growth (Al-Mulali and Ozturk, 2015). The variables *CO_2pc, GDPpc, RESpc,* and *ECpc* have been divided by the total population to convert the series into per capita values. All the variables, except *POL,* were converted into their natural logarithm. Hereafter, "L" means natural logarithm and "D" means first-differences of the series. Table 2 shows descriptive statistics.

Table 2. Descriptive statistics and cross-sectional dependence (CSD)

Variables	Descriptive statistics					Cross-sectional dependence (CD)		
	Obs	Mean	Std. Dev.	Min.	Max.	CD-test	Corr	Abs(corr)
LCO2pc	391	2.1439	0.2757	1.4135	2.774	45.33***	0.811	0.811
LGDPpc	391	10.7772	1.4921	8.2989	14.9984	33.39***	0.597	0.679
LREG	391	8.8058	1.3857	4.5746	11.0629	48.49***	0.867	0.867
LFDI	391	0.3037	0.1879	0.0512	1.4006	40.40***	0.722	0.727
POL	391	3.3223	3.5029	0.0000	21	47.87***	0.856	0.856
LRESpc	391	0.1792	0.1597	0.0094	0.7255	28.70***	0.513	0.735
LECpc	391	1.4854	0.2225	1.0238	2.0163	24.00***	0.429	0.556
DLCO2pc	374	-0.0082	0.0469	-0.1545	0.1719	33.40***	0.611	0.611
DLGDPpc	374	0.0210	0.0323	-.01492	0.2146	16.37***	0.299	0.365
DLREG	374	0.0435	0.0735	-0.1949	0.4323	9.78***	0.179	0.179
DLFDI	374	0.0139	0.0491	-0.2094	0.4227	28.75***	0.526	0.544
DPOL	374	0.3262	0.6951	0.0000	5	1.13	0.021	0.177
DLRESpc	374	0.0038	0.0121	-0.0611	0.0559	1.83*	0.034	0.185
DLECpc	374	-0.0013	0.0333	-0.1907	0.1368	18.56***	0.339	0.356

Notes: CD test has N~(0,1) distribution, under the H0: cross-section independence, ***, and * denote statistical significance at 1%, and 10% level, respectively.

To guarantee the suitability of the methodology being applied and the robustness of the results, the variables were subject to several preliminary tests. To check for the presence of cross-section dependence in the variables, a Cross-Sectional Dependence (CSD) test was performed. This test was introduced by Pesaran (2004), and the null hypothesis predicts the existence of cross-section dependence CD~N(0,1). The results are presented in Table 2, and they support the existence of a cross-section dependence for all the variables in levels and their first differences, except for the variable *DPOL*.

Table 3. Second generation unit root test (CIPS) and first-generation unit root test (MW)

Variables		CIPS (Zt-bar)		MW (Zt-bar)	
		Without trend	With trend	Without trend	With trend
LCO2pc	0	-1.771**	-0.659		
	1	-3.288***	-1.266		
LGDPpc	0	0.798	3.149		
	1	-2.894***	-2.086**		
LREG	0	-1.051	-0.757		
	1	-1.594*	-1.168		
LFDI	0	0.064	0.364		
	1	0.940	0.654		
POL	0	-0.680	-0.626		
	1	-0.342	0.792		
LRESpc	0	-1.497*	-0.715		
	1	-1.860**	-1.099		
LECpc	0	-2.348***	-2.086**		
	1	-3.507***	-2.657***		
DLCO2pc	0	-10.742***	-9.601***		
	1	-8.090***	-6.405***		
DLGDPpc	0	-2.906***	-0.448		
	1	-3.462***	-1.197		
DLREG	0	-10.579***	-8.815***		
	1	-5.218***	-3.033***		
DLFDI	0	-9.642***	-8.150***		
	1	-5.218***	-3.719***		
DPOL	0	-11.327***	-10.295***	-10.096***	-8.310***
	1	-6.407***	-5.482***	-6.407***	-4.939***
DLRESpc	0	-11.692***	-10.295***		
	1	-8.820***	-5.482***		
DLECpc	0	-11.692***	-11.105***		
	1	-8.820***	-7.454***		

Notes: ***, **, and * denote statistically significance at 1%, 5%, and 10% level, respectively.

As the presence of cross-section dependence is confirmed by the CD test, the second-generation unit root tests, proposed by Pesaran (2007) should be performed since they are more robust than the first-generation tests in the presence of this phenomena. For the variable that does not display cross sectional dependence, i.e., *DPOL*, both first- and second-generation unit root tests are performed. Accordingly, the first generation unit root test proposed by Maddala and Wu (1999) was also applied for *DPOL*. The null hypothesis of unit root tests carried out predicts that the variables are not stationary. The results displayed in Table 3 support that there are variables stationary in levels (I (0)), and others are stationary in their first differences (I(1)). It is important to highlight that there are no variables stationary in their second differences, i.e., there are no variables I(2). The existence of variables I (0) and I(1) makes the use of ARDL model appropriate. Furthermore, the presence of correlation and multicollinearity should be avoided as it could produce biased estimations. To do that, both correlation matrix values and a Variance Inflation Factor (VIF) were analysed. The results of the correlation matrix displayed in Table 4 show that both correlation and collinearity do not compromise the robustness of the estimations.

Table 4. Correlation Matrix

	LCO2pc	LGDPPC	LREG	LFDI	POL	LREpc	LECpc
LCO2pc	1.0000						
LGDPpc	0.0854	1.0000					
LREG	0.2377	-0.0011	1.0000				
LFDI	-0.0493	0.2804	-0.1606	1.0000			
POL	-0.0909	-0.0511	0.4101	0.1884	1.0000		
LRESpc	0.0328	0.1786	-0.1098	-0.0307	-0.0853	1.0000	
LECpc	0.5443	0.1902	0.2897	-0.0073	-0.0156	0.5777	1.0000
DLCO2pc	1.0000						
DLGDPpc	0.3372	1.0000					
DLREG	0.1396	0.4115	1.0000				
DLFDI	0.0013	0.0637	-0.0266	1.0000			
DPOL	-0.0717	-0.0742	-0.1446	-0.0961	1.0000		
DLRESpc	0.0779	0.0039	-0.0027	0.0182	-0.0103	1.0000	
DLECpc	0.6755	0.3800	0.1949	-0.0183	-0.0548	0.0662	1.0000

The results of the correlation matrix displayed in Table 4 show that both correlation and collinearity do not compromise the robustness of the estimations. Additionally, Table 5 discloses the Variance Inflation Factor (VIF) values. The results reveal there are no multicollinearity problems associated with the variables used.

Table 5. Variance Inflation Factor (VIF)

Variables	Variance inflation factor (VIF-test)		
	VIF	**1/VIF**	**Mean VIF**
LGDPpc	1.16	0.8602	
LREG	1.70	0.5882	
LFDI	1.27	0.7884	
POL	1.39	0.7218	
LRESpc	1.78	0.5626	
LECpc	1.95	0.5120	
			1.54
DLGDPpc	1.37	0.7308	
DLREG	1.23	0.8123	
DLFDI	1.02	0.9846	
DPOL	1.03	0.9682	
DLRESpc	1.01	0.9945	
DLECpc	1.18	0.8473	
			1.14

To accomplish this research objective, the Unrestricted Error Correction Mechanism (UECM) form of the Autoregressive Distributed Lag (ARDL) model is applied. Considering the nature of the variables considered, it is expected that the results will be different in the short- and long-run. Therefore, the ARDL model is used to obtain the short- and long-run effects, individually, representing dynamic adjustment and the equilibrium, respectively (Pesaran and Shin, 1997). In other words, this model allows CO_2 emissions (dependent variable) to be explained by its own past and by the past of all the rest of the variables. Additionally, this model has the advantages of dealing with an integration order of I(0) and I(1) (or the combination of both), certifying that none of the variables are I(2) and that they are robust in the presence of endogeneity of variables (Attiaoui et al., 2017; Fuinhas et al., 2017). The robustness in the presence of endogeneity has high relevance to this study since it is expected that the explanatory variables could be endogenous (Albulescu et al., 2019; Sapkota and Bastola, 2017). This endogeneity can be explained by the fact that investors are averse to investing in countries with high levels of pollution, as it is expected that in the future, the costs associated with polluting activities will increase.

Remembering that the main objective of this paper is to analyse which are the main determinants of CO_2 emissions, the ARDL regression that was tested, is in accordance with the following Eq. (1):

$$\begin{aligned} LCO2pc_{it} = {} & \alpha_i + \sum_{j=0}^{k} \alpha_{1ij}\, LGDPpc_{it-j} + \sum_{j=0}^{k} \alpha_{2ij}\, LREG_{it-j} + \sum_{j=0}^{k} \alpha_{3ij}\, LFDI_{it-j} \\ & + \sum_{j=0}^{k} \alpha_{4ij}\, POL_{it-j} + \sum_{j=0}^{k} \alpha_{5ij}\, LRESpc_{it-j} + \sum_{j=0}^{k} \alpha_{6ij}\, LECpc_{it-j} + \varepsilon_{it} \end{aligned} \tag{1}$$

where α_i denotes the intercept, ε_{it} represent the stochastic disturbance terms assuming that they are white noise and Gaussian distributed. The Eq. (2) reproduces the ARDL equivalent of the general unrestricted error correction model (UECM) of Eq. (1) to perform the short- and the long-run effects individually:

$$\begin{aligned} DLCO2pc_{it} = {} & \emptyset_i + \sum_{j=0}^{k} \beta_{1ij}\, DLGDPpc_{it-j} + \sum_{j=0}^{k} \beta_{2ij}\, DLREG_{it-j} \\ & + \sum_{j=0}^{k} \beta_{3ij}\, DLFDI_{it-j} + \sum_{j=0}^{k} \beta_{4ij}\, DPOL_{it-j} + \sum_{j=0}^{k} \beta_{5ij}\, DLRESpc_{it-j} \\ & + \sum_{j=0}^{k} \beta_{6ij}\, DLECpc_{it-j} + \gamma_{1i} LCO2pc_{it-1} + \gamma_{2i} LGDPpc_{it-1} \\ & + \gamma_{3i} LREG_{it-1} + \gamma_{4i} LFDI_{it-1} + \gamma_{5i} POL_{it-1} + \gamma_{6i} LRESpc_{it-1} \\ & + \gamma_{7i} LECpc_{it-1} - \varepsilon_{it} \end{aligned} \tag{2}$$

where $\emptyset_i$ denotes the intercept for each country i(i=1,2,...), β_i represents the estimated parameter in short-run and γ_i the coefficients of parameters in long-run. ε_{it} denotes the error-term.

Posteriorly, the Hausman test was performed, under the null hypothesis that the random effects model is appropriate. Additionally, a set of specifications tests were carried out to ascertain the existence of cross-sectional dependence, namely Pesaran, Free's, and Friedman, the Modified Wald for homoscedasticity and the Wooldridge test for serial correlation.

4. Results

The results of the Hausman test indicates that the null hypothesis within the random effects model is appropriate and is rejected ($\chi^2_{13} = 44.27$ ***). It is emphasizing the idea that the individual effects of each country are significant and important for the estimation. Additionally, the results of the specification tests carried out are disclosed in Table 6. The rejection of the null hypothesis on all the tests performed supports the existence of cross-sectional dependence, heteroscedasticity, and first-order serial correlation.

Table 6. Specification tests

	Statistics
Pesaran's test	2.021**
Free's test	0.698***
Friedman test	35.123**
Modified Wald test	Chi2(17)=1656.96***
Wooldridge test	F(1,16) = 87.429***

Notes: *** and ** denote statistically significance at 1%, and 5% level, respectively.

The presence of these phenomena makes the use of the Driscoll-Kraay (DK) estimator adequate. It is the nonparametric estimator proposed by Driscoll and Kraay (1998), that is able to deal with problems of cross-sectional dependence, heteroscedasticity, and autocorrelation. Furthermore, it allows the execution of fixed effects in the regression (Hoechle, 2007). Table 7 shows the results of the full ARDL model, such as described in Eq. (2) both in their full and parsimonious options. In full option, all the variables were included in the estimation, and in the parsimonious option, only the statistically significant variables were maintained. Additionally, the results of estimations by using both fixed effects (FE) and by using Fixed Effects robust to heteroscedasticity (FE robust) are also displayed as benchmarks for those obtained from DK estimator.

Table 7. Estimation results of autoregressive distributed lag model (ARDL)

Dependent Variable	***DLCO2pc***					
	Full models			**Parsimonious models**		
	FE	**FER**	**FE D-K**	**FE**	**FER**	**FE D-K**
DLGDPpc	0.2011***	0.2011	0.2011***	0.1734**	0.1734	0.1734*
DLREG	-0.0421	-0.0421	-0.0421	----	----	----
DLFDI	-0.0297	-0.0297	-0.0297	----	----	----
DPOL	-0.0037	-0.0037	-0.0037**	-0.0031	-0.0031	-0.0031*
DLRESpc	0.0648	0.0648	0.0648	-----	-----	-----
DLECpc	0.9059***	0.9059***	0.9059***	0.9047***	0.9047***	0.9047***
LCO2pc (-1)	-0.2944***	-0.2944***	-0.2944***	-0.2884***	-0.2884***	-0.2884***
LGDPpc(-1)	0.1038***	0.1038**	0.1038***	0.1002***	0.1002**	0.1002***
LREG (-1)	-0.0349**	-0.0349**	-0.0349**	-0.0283**	-0.0283**	-0.0283***
LFDI (-1)	-0.0324***	-0.0324**	-0.0324***	-0.0310***	-0.0310***	-0.0310***
LPOL (-1)	-0.0017**	-0.0017*	-0.0017**	-0.0019**	-0.0019*	-0.0019**
LRESpc (-1)	-0.2624***	-0.2624***	-0.2624***	-0.2632***	-0.2632***	-0.2632***
LECpc (-1)	0.0772***	0.0772***	0.0772***	0.0750***	0.0750***	0.0750***
Constant	-0.3862**	-0.3862	-0.3862*	-0.4133**	-0.4133	-0.4133**
Diagnostic Statistics						
N	374	374	374	374	374	374
Within R^2	0.5393	0.5393	0.5393	0.5357	0.5357	0.5357
F	30.9743***	64.1934***	664.8042***	40.0331***	90.8561***	356.0127***

Notes: ***, **, and * denote statistically significance at 1%, 5%, 10% level, respectively; FE means fixed effects; FER means fixed effects robust to heteroscedasticity; DK means Driscoll-Kraay estimator; L and D denote variables in natural logarithms and the first differences of the variables, respectively.

From Table 7, one can highlight that the consistency between the full and parsimonious model is a sign of the robustness of the results achieved. Overall, it is worthwhile to note that the DK estimator presents high statistical significance for all the variables in the long-run. In the short-run, the same level of statistically significance is not found. Only *DLGDPpc, DPOL*, and *DLECpc* are statistically significant.

In detail, economic growth boosts CO_2 emissions in both the short- and long-run. In contrast, regulatory policies supporting the deployment of RES contribute to reducing emissions in both the short- and long-run. The taxes resulting from the regulation of polluting activities also contribute to decreasing CO_2 emissions in the long-run, highlighting the crucial role of regulation to achieve environmental targets. The EU countries have been able to attract less polluting investment, as *LFDI* decreases emissions, supporting thus, the pollution halo hypothesis.

The elasticities make it possible to measure the magnitude of the impacts of the independent variables on the dependent variable. The elasticities results are in line with the model results. Table 8 displays the semi-elasticities (short-run), elasticities (long-run), and the speed of adjustment (Error Correction Mechanism).

Table 8. Semi-elasticities, elasticities, and adjustment speed

Dependent Variable	***DLCO2pc***					
	Full models			**Parsimonious models**		
Semi-elasticities	**FE**	**FER**	**FE D-K**	**FE**	**FER**	**FE D-K**
DLGDPpc	0.2011***	0.2011	0.2011***	0.1734**	0.1734	0.1734*
DLREG	-0.0421	-0.0421	-0.0421	----	----	----
DLFDI	-0.0297	-0.0297	-0.0297	----	----	----
DPOL	-0.0037	-0.0037	-0.0037**	-0.0031	-0.0031	-0.0031*
DLRESpc	0.0648	0.0648	0.0648	-----	-----	-----
DLECpc	0.9059***	0.9059***	0.9059***	0.9047***	0.9047***	0.9047***
Elasticities						
LGDPpc	0.3525***	0.3525**	0.3525***	0.3476***	0.3476**	0.3476***
LREG	-0.1186***	-0.1186***	-0.1186***	-0.0981**	-0.0981***	-0.0981***
LFDI	-0.1101***	-0.1101**	-0.1101***	-0.1074***	-0.1074**	-0.1074***
POL	-0.0058**	-0.0058*	-0.0058***	-0.0064**	-0.0064*	-0.0064***
LRESpc	-0.8912***	-0.8912***	-0.8912***	-0.9127***	-0.9127***	-0.9127***
LECpc	0.2623***	0.2623***	0.2623***	0.2601**	0.2601***	0.2601***
Speed of adjustment						
Error correction mechanism (ECM)	-0.2944***	-0.2944***	-0.2944***	-0.2884***	-0.2884***	-0.2884***

Notes: ***, **, and * denote statistically significance at 1%, 5%, 10% level, respectively; FE means fixed effects; FER means fixed effects robust; DK means Driscoll-Kraay; L and D denotes variables in natural logarithms and the first differencesof the variables. The elasticities are calculated by dividing the coefficient of the long-run independent variables by the coefficient of the ECM both lagged once and multiplying by -1.

In the full model, the semi-elasticities of D*LGDPpc*, for instance, reveal that an increase of 1 percentual point (pp) in D*LGDPpc*, increases CO_2 emissions to 0.2011pp. In long-run elasticities, an increase of 1% in the economic growth proxy generates an increase of 0.3525% in emissions. All the remaining variables, except *LGDP*pc and *LEC*pc, have a decreasing effect on CO_2 emissions. Environmental regulation, represented by de variable D*LREG*, is reducing emissions by 0.1186%, in the long-run in this sample. Overall, the higher the stringency of environmental regulation and the greater the number of regulatory policies, the lower the level of pollution. The Error Correction

Mechanism (ECM), represented in Table 8 as speed of adjustment. The ECM value is 29.44% in full model and 28.84% in parsimonious model and it is statistically significant at 1% in FE, FER, and DK. This finding reveals that the shocks achieve the equilibrium in a short time. The following diagram summarizes the results obtained from the short and long-term relationships between the variables.

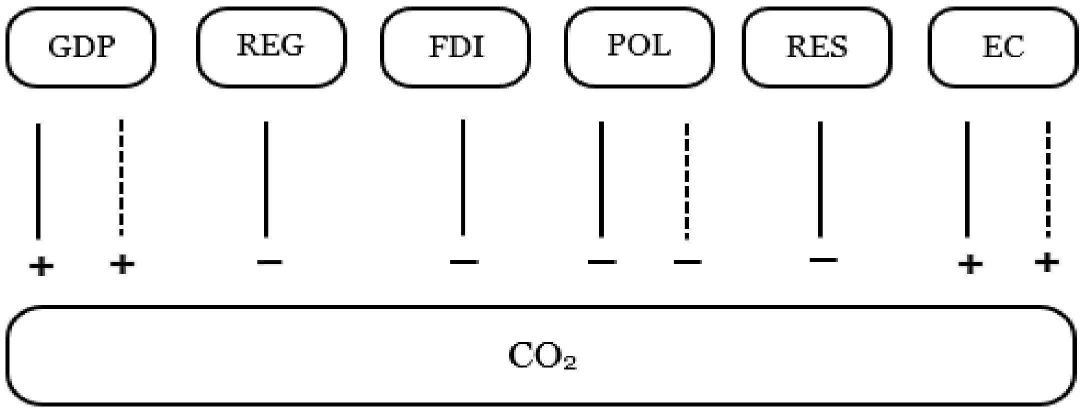

Figure 3. Short- and long-run relationships.

Source: Own elaboration. Notes*:* ---- Short-run relationship —— Long-run relationship

5. Discussion

In order to provide deeper knowledge of the causes of environmental pollution in EU countries, this paper analyses the short and long-run effects of the determinants of CO_2 emissions, mainly focusing on the role of environmental regulation. Primarily, environmental regulation is composed of policies aimed at reducing pollution. Currently, countries must take environmental responsibilities into account while not neglecting economic ones. Since energy consumption proves to be a driver to increase the levels of pollution, in this research, the impact of both renewable and total primary energy consumption on emissions are evaluated.

Economic growth and primary energy consumption are the main contributors to increasing the level of carbon dioxide emissions in both the short- and long-run in EU countries. A positive impact of economic growth on EU emissions is confirmed by countless researchers in the literature (Uzar and Eyuboglu, 2019; Dogan and Seker, 2016; Al-Mulali and Ozturk, 2015; Martínez-Zarzozo et al., 2007). This evidence implies that economically productive sectors of EU countries remain dependent on highly pollutant primary energy sources. Since that energy consumption contributes largely to GDP, it is expected that both these variables increase emissions (Kasperowicz, R; Štreimikienė, 2016). This evidence supports the importance of environmental regulation for energy consumption.

This research proves that the level of environmental regulation has been efficient in reducing CO_2 emissions. This finding is in line with the literature (see, e.g. Albulescu et al., 2019; Hashmi and Alam, 2019; W. Zhang et al., 2020). It highlights that penalizing negative externalities associated with the most polluting activities has been an effective strategy in combating emissions. This means that imposing the internalization of the negative externality dissuades pollution. It implies that policymakers should pursue the application of market-based regulation (MBR). On the one hand, MBR could act as a stimulus for firms to invest in R&D to be competitive with less polluting activities. On the other hand, it increases confidence in the policies of each government, bringing social and political stability to the country. MBR decreases the financial risk of the emitter because they can decide how it will reduce emissions, without having to support the economic losses caused by an obligation imposed by the regulator.

Regarding the effects of the RES, it was found that regulatory incentive policies have a negative impact on CO_2 emissions in the long-run, supporting the effectiveness of these policies. Such as expected, there is a weak significance of the regulatory incentive policies in the short-run because of the time required for policy adaption. This paper provides empirical evidence for the effects resulting from the EU countries' intervention policies and proves their effectiveness. RES consumption itself has also contributed to reducing CO_2 emissions in the EU. However, the potential for non-renewable sources in the EU is low, which makes EU economies still highly dependent on external fossil fuels such as oil and gas. The introduction of the RES in the energies mix allows the countries to explore their endogenous potential on renewable sources, reducing the external energy dependence. In these economies, the deployment of RES has not only a great potential to diminish emissions but also could allow external energy dependence upon fossil fuels to be reduced. The policymakers should encourage investments in R&D, in order to reduce the implementation costs of RES, and permit the development of efficient energy storage systems to allow the accommodation of these sources. At the same time, policymakers should act to raise awareness among the population of the benefits of RES use and incentivize the adoption of decentralized RES generation.

The transport sector is a pivotal area to achieve these objectives. The regulation of energy use in the transport sector is crucial for two reasons. Firstly, to encourage the intensive use of electric vehicles leading to a reduction in the dependence of economies on primary energy. Secondly, to allow economic growth that does not contribute to increasing CO_2 emissions. Additionally, electric mobility could be used as storage capacity for the electricity system, allowing RES accommodation. In other words, extensive use of electric vehicles could allow the storage of renewable electricity in their batteries and replace it posteriorly in the grid when it is required through the use of the vehicle-to-grid (V2G) technology. For that, an investment in R&D for battery development is required to increase the attractiveness of these vehicles. Subsidizing the adoption of energy-efficient technologies, and/or the adoption of electric mobility could be an efficient way to make the sector cleaner. Also, the application of a special tax regime for those industries which show environmental concerns in their production process would be beneficial. For instance, if their vehicles fleets were changed to electric, this could increase the electric vehicle market share and, therefore, promote the decoupling between economic growth and CO_2 emissions.

It is apparent that environmental regulation policies are effective in attracting innovative investments, with inward FDI reducing CO_2 emissions. It implies that EU policymakers are managing to attract high-quality FDI, that is, technologically innovative investment, allowing thus to benefit from the technological spillover effect. This outcome validates the pollution halo (PH) hypothesis, i.e., inward investment in the countries under analysis decreases environmental pollution, agreeing with the conclusions of Albulescu et al. (2019) and Shao (2018). Furthermore, this effect could reveal that the considered countries have regulatory stability, consistency, and transparency, as suggested by Kirkpatrick and Shimamoto, (2008), who argue that these conditions provide security for investors. It is recommended that the EU should continue to promote the benefits of the technological spillover effect, stimulating investment in environmentally friendly technologies, while it is formulating policies that monitoring the behaviour of highly polluting industries. Investment in environmentally friendly technologies should be incentivized through, for instance, a special tax regime.

In sum, economic growth and primary energy consumption are the main driving factors for CO_2 emissions. The dependence of productive sectors of the economy on carbon-intensive technologies needs to be reduced. Undoubtedly, regulatory policies must encourage the use of RES and allow this source to replace conventional ones in final energy consumption. From the supply-side, the implementation of RES should continue to be pursued, and additionally, their accommodation is required in the system as a whole. The demand-side of energy consumption could be key to implementing the efficient accommodation of RES. In fact, both firms and individuals could take responsibility for increasing the efficiency of the system. For that, policymakers could incentivize investment in decentralized energy production by allowing industries/individuals to become prosumers (energy producers that also are consumers). At the same time, the implementation of energy efficiency systems and equipment should be encouraged together with the adoption of electric mobility. To encourage these practices in the demand side, the reduction of taxes for those who have adopted them could be an effective mechanism. It implies that regulation through deterrence, such as a tax on polluting activities, associated with regulation based on positive action to reinforce clean activities, by using, for example, subsidies or fiscal benefits could be an effective way to foster the reduction of emissions and at the same time stimulate economic growth.

6. Conclusion

This paper studies environmental degradation in EU countries, focusing in particular on the role of environmental regulation and renewable energy. In the empirical analysis, annual data was used over a period from 1995 to 2017 for 17 European countries. The main aim of this research is to evaluate the effectiveness of all the efforts made by EU policymakers in terms of pollution regulation and renewables deployment. To accomplish this paper's objective, an ARDL model was used with the Driscoll-Kraay estimator; since it is appropriate to handle the data´s characteristics while also allowing an analysis of the short- and long-run effects individually.

Overall, there is evidence for the effectiveness of market based environmental regulation and policies supporting RES to bring about CO_2 emissions reduction. In the long-run, both environmental tax revenue and regulatory policies supporting RES reduce CO_2 emissions. Inward FDI and RES also present themselves as factors that reduce carbon dioxide emissions in these countries. On the contrary, economic growth and primary energy consumption increase emissions in both the short- and long-run.

This research proves that environmental regulation in the EU has been effective in reducing emissions. The taxation of polluting activities and the promotion of RES have proved to be significant barriers to an increase in CO_2 emissions. Furthermore, the pollution hallo hypothesis is confirmed, supporting that EU countries are benefiting from the technological spillover effect. However, continuous economic growth still remains dependent on an increase in CO_2 emissions. This relationship needs to be changed so that economic growth is not reflected in an escalation in emissions. It implies that policymakers should pursue environmental regulation of the productive sectors in order to promote their decarbonization. However, regulatory frameworks need to be further studied and examined. Any positive actions which encourage clean practices could be an effective way to increase growth without affecting the environment. For instance, subsiding the acquisition of energy-efficient technologies, the deployment of decentralized clean energies and the promotion of electric mobility in the economic sectors or a reduction of the fiscal fees for industries that show environmental concern practices could be an efficient way to allow economic growth that does not result in an increase in CO_2 emissions.

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