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Patents on Environmental Technologies and Environmental Sustainability in Spain

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Abstract: Through an in-depth evaluation of the potential effectiveness of intellectual property protection on environmental technologies, the aim of the present research is to investigate the effect of patents on environmental innovation, energy use, GDP, and trade openness on environmental deregulation in Spain using nonlinear ARDL techniques. Specifically, the study findings indicate that patents on environmental technologies enhance environ-mental sustainability in Spain, as evidenced by the novel results from the nonlinear ARDL. Secondly, our study reveals that Spain's growing economy degrades the quality of the environment. Based on the findings of the study, positive changes in trade openness could have positive effects on Spain's environmental sustainability, suggesting that better productivity, more international trade, and increased economic openness could facilitate an improvement in Spain's environmental impact. Lastly, this study provides evidence demonstrating that Spain's environmental quality could suffer due to excessive energy consumption. In the light of this study's policy recommendations, the policymakers and the Spanish government should encourage collaboration between private and public partnerships on environmental technologies to address global climate change or regional pollution. It is necessary for research and development to contribute to the development of technological progress in the Spanish energy sector; however, promoting patenting should be prioritized. By expanding patent protection, eco-friendly technologies that can combat carbon emissions can be developed swiftly in Spain, which will enable life to be more sustainable by lowering the use of energy and resources. A strong patent protection sys-tem will foster environmentally-friendly technologies and economic development while reducing CO_2 emissions in Spain.

Keywords: patents; environmental innovations; sustainability; carbon emissions; Spain

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1. Introduction

Carbon dioxide, the key greenhouse gas driving global climate change, continues to rise. The effects of greenhouse gases on the environment and health are extensive. In addition to causing climate change, GHGs can also harm human health by contributing to smog and air pollution. Other effects of climate change include extreme weather, food shortages, and wildfires. Climate patterns will change as a result of global warming, which could cause some species to disappear, whereas others will migrate or grow.

The environment faces a long-term challenge due to global warming. The stable growth in greenhouse gas emissions is a consequence of the human race, and this affects food, and lives, among others, ultimately impacting socio-economic activities and human

lives [1]. A plethora of studies has mentioned that a vast proportion of the problem can be attributed to high CO_2 emission levels and this is one of the many factors driving the development of sustainable societies. The economic development of our planet is not immune from such impacts on its current trajectory [2]. Several contemporary problems are caused by deregulation of the environment, natural resources being endlessly exploited, and the increasing inequalities among people [3]. Human activities cause almost 9% of global warming due to human-induced greenhouse gas emissions. If international climate action is not strengthened, the global average temperature may increase to 20 degrees Celsius, resulting in worsening natural disasters (hurricanes, floods, decreases in agricultural productivity, melting mountain glaciers, rising sea levels, and so on) and irreversible effects on ecosystems. It was emphasized at the COP26 meeting in Glasgow that countries must set ambitious targets for reducing emissions by 2030 that are aligned with the goal of achieving net-zero emissions by 2050. To integrate economic growth, social progress, and environmental conservation holistically, the UN's 2030 Sustainable Development Goals (SDGs) aim to eradicate poverty, advance social equality, tackle injustice and inequality, safeguard the environment, and mitigate global climate change. Maintaining global temperatures below 2 °C is one of the goals of the Paris Agreement, in addition to protecting human health, food security, and the environment. In the Paris Agreement, the Intergovernmental Panel on Climate Change emphasizes the connection between climate change's effects and its reaction, as well as the fairness of access to sustainable development. To help countries reach their goals and reduce pollution while promoting sustainable development, the intergovernmental panel on climate change has stated that comprehensive, balanced, and integrated nonmarket measures are needed. From a long-term perspective, technological innovation could result from local or domestic innovations and research, as well as from foreign technology transfers; however, in reality, either option produces similar effects and a combination of both has frequently provided historical accelerations of innovation and expansion [4].

Environmental innovation is increasingly receiving attention from policymakers and environmental researchers globally, which makes an understanding of its peculiarities increasingly important when developing policies [5,6]. In terms of eco-innovation, Spain has maintained an above-average ranking, but in recent years, its ranking has slipped among the EU28 [7]. Collaboration on technology development is particularly valuable when it comes to climate change or global pollution, especially for a country like Spain. With a total population of over 47 million inhabitants [8], this represents 10.5% of the total population of the EU. Spain's emissions increased significantly between 1970 and 2007, peaking at 380.5 MtCO2, subsequently experiencing a decline. However, emissions from transport are on the rise. Transportation is Spain's largest emitter, accounting for more than 27%, followed by the energy sector with 16%. One of the goals of the Spanish government is to have a global economy by 2030(with includes diminishing domestic consumption by 30% in comparison with 2010 figures, getting rid of 15% more waste than in 2010. Developing comprehensive food waste reduction strategies that include a 50% reduction in retail and consumer waste and a 20% reduction in supply chains and production from 2020, thereby advancing the Sustainable Development Goals (SDGs), increasing the proportion of sustainable energy percentage in the energy mix to 42%: a sharp increase from the level of 20% of the energy mix in 2020 [8]. The country plans to primarily deploy solar and wind power. By implementing the pro-posed measures, energy efficiency is expected to improve by over 39%. The question is, how? We believe that patents on environmental technologies are vital to reduce emissions, as this will be beneficial for the advancement of environmental innovations; however, their interplay has never been thoroughly explored. Another question that can be asked is why Spain is chosen for the investigation? Spanish carbon emissions are relatively modest and have been decreasing over the years when compared to those of other nations. Spain has continued to implement environmental policies through frameworks such as the Spanish Strategy on Circular Economy, while also addressing climate change. Moreover, Spain has developed a long-term decarbonization

strategy for 2050, which aims to address the climate crisis while also taking advantage of the opportunities to modernize its economy and compete on a global scale. However, the total energy mix of Spain is still largely dominated by fossil fuels, despite its considerable progress in decarbonizing and increasing the share of renewables in the energy sector. To meet the country's new targets for renewable energy penetration and energy efficiency in the transport, industry, and building sectors, patents are considered an effective and potent option. Additionally, due to these interesting facts about Spain, it makes sense that Spain would require an inclusive policy framework to progress towards achieving the Sustainable Development Goals by 2030. To achieve this goal, the current research examines the asymmetric effects of patents on environmental innovation on CO_2 emissions in Spain [8]. A primary focus of the current study is whether or not patents on technology in Spain can improve environmental degradation using patents on environmental technology as a determining factor. Crucial questions then arise. Does patenting environmental innovations increase the efficiency of alternative energy solutions? Are patents necessary to diminish carbon emissions and increase sustainable energy production? Moreover, the nation intends to primarily use solar and wind power and, according to the proposed measures, energy efficiency will improve by over 39 percent [8]. If the Spanish government wants to accelerate innovation and increase the composition of sustainable energy in the 2030 energy mix, patents on technology seem to be one of the best options. The intuition here is that government collaboration (patents right) in both ecological innovation as well as research and development can make market entry more attractive and enable local/small businesses to take advantage of existing technologies. Since global warming variability poses one of the greatest threats to our planet's future, intellectual property protection is a necessity for any new, innovative technology options to explore. However, to accelerate such solutions and enable idea sharing, patents appear poised to be one of the viable options. Green technology innovation can act as a tool for managing the economic-environmental conflict. In addition, the number of patents relating to low-carbon technologies worldwide is also increasing. There is a risk that this new innovation could be copied, misappropriated, or used unlawfully in a technology-driven world [9]. We can expect rising competition, as well as the possibility that it will be copied or misappropriated. Therefore, carbon capture technologies should be trademarked to maximize their value. As we transition towards a genuinely green economy, patents are essential to protect and minimize competitive advantage in a market that is becoming increasingly competitive and busy. Furthermore, the use of collaboration, such as cooperation, is more likely to scale up intellectual property. However, which factor is most critical for scaling up remains unclear: green technological innovation or patents on environmental innovation.

Environmental destruction has been caused by deregulatory processes. Deregulatory processes are, therefore, claimed to cause enormous ecological damage by many environmentalists. At least in advanced economies with few implementation gaps, strong regulations typically entail stronger regulation of emissions, pollution, and resource use. There is a plethora of studies on the influences of carbon dioxide emissions on the ecosystem's health and other strong determinants triggered by some microeconomic and macroeconomic factors. For economic prosperity, a sustainable environment is crucial [10]. Hence, with the expansion and evolution of countries around the world, researchers are becoming increasingly interested in shedding further light on complex associations between these variables. As a result, there have been interactions between emerging and advanced economies, which have inevitably led to an increase in economic activity. All governments should prioritize managing the pace of financial and economic development so that this does not negatively impact climate quality [11]. Ecological improvement happens when economic growth reaches an affluent level where environmental concerns begin to increase. Therefore, deterioration of the environment and economic growth have a U-shaped relationship [12]. Climate change debates place great emphasis on energy because both growth and consumption must be considered. Thus, finding a healthy balance between growth and the environment is a critical concern for policymakers. When energy demand increases,

developing a zero-carbon economy is a financial and social burden as fossil fuel is the principal source of carbon emissions [13]. Empirical studies on foreign direct investment and research development are essential to further understanding the energy industry's role in economic growth, carbon emissions, and energy investment for a low-carbon society. Energy investments for zero-carbon economies must be addressed through research and development, and foreign direct investment must be addressed as well. The EU is a global economic leader; it is expected to grow by 4.3% in 2022, so generating social capital is necessary [12]. Energy investment can stimulate economic growth while decreasing the carbon content of the energy sector and stabilizing total greenhouse gas emissions. Thus, many empirical studies have proposed that green growth be viewed as a crucial strategy in the attainment of sustainable development [14,15]. The utilization of ecofriendly alternative sources of energy (biomass, hydro, solar) is necessary for neutral atmospheric CO_2 emissions [16]. In comparison with the damage it has on economies, it is imperative that nations of the world invest in renewable and environmentally friendly technologies. However, green alternatives are widely considered to be too expensive, which might discourage nations, especially emerging countries, from changing their behavior. As a result of renewable sources, nations can lower their dependency on imported energy sources that are not renewable. In what ways does trade openness influence carbon intensity? In addition to providing a theoretical basis for developing trade policies in the future, the above questions can also help determine how foreign trade activities can be regulated in order to achieve low-carbon development goals, thus helping to develop trade policies in the future. Depending on the channel, trade can have a direct or indirect effect on carbon emissions; however, the interrelationship between the two is unclear [17,18]. Several studies have posited that there exists an underlying linkage between trade openness and economic growth [19–23]. Ecologists and trade economists believe the role of trade liberalization in creating conditions for environmental improvement can be enhanced by utilizing resources efficiently and maintaining a sustainable growth rate [24]. Lastly, the study claimed that liberalizing trade and protecting the environment will boost economic growth and benefit society by strengthening the internalization of environmental instruments, improving the allocative efficiency of markets, and correcting market failures. Trade liberalization will also improve the quality of life in many developing countries and minimize poverty, which has been attributed to environmental degradation. Evidence that trade openness contributes to environmental degradation differs among countries according to their income levels. This may be due to different policies, economic structures, economic openness levels, and country-specific characteristics that could explain these different factors. Therefore, renewable sources stabilize the macroeconomic performance of nations [25,26]. The principal novelty of this study is that it examines the role of patents on environmental innovation as a socioeconomic driver of Spain's carbon emissions in addition to some vital economic, social, and atmospheric metrics. Previously, patents on environmental innovation have received insufficient to no attention. Thus, this study provides new evidence for executing specific CO_2 policy by including patents in the total energy needs, as well as expanding the common EKC model by including patents as a new variable. Secondly, by examining the connection between energy consumption and environmental patents using advanced economic techniques, this study is useful since the Spanish government is focused on the increase of environmental technologies; environmental sustainability; stimulating the economy; creating jobs; modernizing industry; strengthening competitiveness; enhancing energy security; and supporting research, development, and innovation, which are necessary for economic growth, but at the expense of the environment; hence, this study offers many potential benefits. Patents on environmental innovation are a powerful tool for achieving the aforementioned objectives. Hence, our paper seeks to examine two key environmental issues: (i) Is there a significant relationship between patents on environmental innovation and environmental sustainability? (ii) Do Spain's patents on environmental innovation contribute to reducing pollution? Further, GDP, trade openness, and energy use are also included in the current study due to their important role in affecting CO_2 emissions.

Findings of this empirical evidence will be useful for policymaking as well as strategic environmental planning. After this introductory section, the next part is a brief summary of the literature, followed by Part 3 which includes econometric methods and data sources. After this the empirical findings are presented, and the subsequent section provides an interpretation. In the final section, the conclusions and policy implications are discussed.

2. Reviews of Published Works of Literature

We present empirical evidence that supports the relationship between greenhouse gas emissions, patents on environmental innovation, GDP growth, trade openness, and consumption of energy. In the current literature, environmental innovations are extensively discussed in terms of how they can protect environmental health and prevent pollution. The perception of environmental impact and what role technologies may be able to play in limiting CO_2 emissions has been the subject of previous research. Environmental degradation can be caused by a variety of factors, such as population and technology [24–27]. In addition to creating technologies that address their pollution-related needs, a wide variety of technologies have been developed by industries, businesses, and individuals. The concept of ecological innovation not only refers to technology development, but also to any products geared toward a greener environment. Patents should be granted for new technologies in the area of pollution reduction, as suggested by [28]. Ref. [29] showed that within a country, patents and innovations for climate change-related technologies are determined by CO_2 emissions and other greenhouse gases. The level of greenhouse gas emissions in a country influences the invention and patenting of technologies associated with climate change. Innovative products or technology are best developed by using brands as a tool (branding is the best strategy to develop technology or innovative products) [30]. In addition, brands also serve as a means of distinguishing products from each other and identifying their source [31]. As a result, trademarks have an advantage over more established brands by protecting their products and creating valuable products [32,33]. The literature on innovation and emissions has neglected the role of trademarks and patents in emissions. In addition to using patents as a data source, they can also provide details on current research in this field.

Consistent with our study, the empirical study of [34] mentioned that patents and trademarks are key indicators of innovation and industrial change. Similarly, our study attempts to analyze the impact of trademarks and patents on pollution reduction as a means of bridging the knowledge gap on how environmental technology patents can lead to novel high impact innovations that reduce global emissions. In order to reduce emissions, environmental innovations must be implemented. Choosing the right channel to implement innovation is important in many areas, including pollution control. The in-novation of both products and processes goes hand-in-hand. It is necessary to update the production process and to upgrade the channel by which the changes are implemented in order to make changes to the product. Several channels have been identified in the empirical literature as being responsible for innovation's effect on emissions. Productivity improvements are one way in which innovation can affect emissions. Developing global inventions and innovations through patenting is another method of enhancing global technological innovation. Using scarce resources more efficiently can also translate to faster technological progress. For this reason, industry, businesses, and staff must keep up with new technologies as they emerge in order to collectively combat the rise in carbon emissions. It is possible for firms to copy a successful invention, industry, or company, instead of dedicating their R&D efforts to creating novel products and services that can help com-bat carbon emissions. These are global issues that can hamper the development of environmental technologies. Patents on technology in environmental innovation provide a significant insight into the technical knowledge embedded in technology as a starting point for analyzing its development. Developing and adopting new technologies is essential to meet the current and future demands of the planet. Patents can provide valuable in-sights

into the development of new technologies since they show the specific innovations in the invention, as well as who the inventors and applicants are.

Further, the empirical research of [35] evaluated the effects of green energy on the ecological performance quality of the G-7 economies. This study showed that green energy and energy prices impacted carbon dioxide emissions negatively, while the positive effect on the carbon emissions can be attributed to trade volumes. The study of [36] assessed the effects of electric energy consumption, GDP growth globalization, and its consequences on ecological stability in Turkey during the period of 1970 to 2014. According to the results, the researcher recommended that an energy mix that is low in carbon and eco-friendly should be pursued, sustainable energy sources should be prioritized, electric vehicles should be adopted and higher taxes and subsidies to reduce carbon emissions should be included in the global efforts to decarbonize. Using the nonlinear ARDL, ref. [37] examined how renewable energy affected the environment in North-Western China over a two-decade period. Based on the findings, renewable energy negatively affected carbon emissions in North-Western China. Research evidence revealed a positive linkage between GDP and non-renewable energy, which increased both long-term and short-term ecological destruction. Ref. [38] explored the linkage between GDP and carbon pollution based on a sample of European countries from 2010-2014. Despite robust export growth from Germany, the findings of the authors showed that Europe increased its territory-based carbon emissions and decreased its consumption-based carbon emissions from global trade. The study of [39] explored the linkages between CO_2 emissions and GDP. The findings demonstrated that GDP growth and emissions in carbon dioxide were correlated in an N-shaped pattern under the Environmental Kuznets Curve (EKC) structure. As [20] theorized, economic growth follows a rise in income inequality. Both developing and developed countries have seen environmental degradation increase with economic growth. Similarly, growth in GDP growth enhances carbon emissions, as reported by [40]. In line with this finding, ref. [41] found that China's expansion has resulted in increased carbon emissions. The growth in economic activity, which is associated with climate change, is negatively affected by increased energy consumption and CO_2 emissions. A rise in economic activity translates into an increase in the demand for energy, which results in a reduction in environmental quality. The study of [42] explored the nexus between GDP growth, energy usage, and CO_2 emission in Pakistan, covering data from 1972 to 2015. According to robust econometric techniques, energy intensity in Pakistan caused CO_2 emissions to increase in both the short and long term. The recommendations of the study suggested that policymakers in Pakistan should embrace and promote such renewable energy sources to meet the increased demand for energy and to replace the traditional energy sources.

In addition, the study by [43] evaluated the pollution haven hypothesis in Ghana using the (ARDL) method for the period 1980–2012. In contrast, institutional quality increases greenhouse gas emissions, while FDI, GNP, financial development, technological in-novation, and urbanization cause a decrease. According to [44], trade openness influences the environment based on the composition effect, scale effect, and technology effect. As a result of trade, economic growth results in higher carbon emissions because more energy is consumed and produced. However, as levels of development increase, freer trade and higher incomes can provide environmental improvements. Based on the comparative advantage approach, the composition of production changes across countries. Polluted goods tend to be produced when the demand for tradable goods produced by polluting methods increases. In practice, this process favor developed countries.

3. Methodology

The current research aims to explore the effect of patents on environmental innovation on carbon emissions in Spain while taking into account economic growth, trade openness, and energy consumption between 1990Q1–2018Q4. We employed the nonlinear ARDL model and other robust econometric technique, which was applied by [45–47] in a similar study. in a similar study. The variables used in this paper have been sourced from the

database of the World Bank (2020) and OECD (2021), respectively. As shown below, Table 1. presents a short description of our time-series variables. Considering the limited data and sample size, we transformed time-series data from annual to quarterly using the quadratic match sum method. Figure 1 illustrates the analysis flowchart for the present study.

Table 1. Descriptive Statistics.

	LCO2	LPATENT	LTRA	LGDP	LENE
Mean	5.431048	2.106650	11.46357	24.16477	3.172979
Median	5.420836	1.903416	11.53897	24.23227	3.197235
Maximum	5.552997	2.783992	11.69250	24.38295	3.266827
Minimum	5.328290	1.372244	11.05903	23.87282	3.021352
Std. Dev.	0.063958	0.439341	0.184800	0.164319	0.071971
Skewness	0.347060	0.045509	−0.803801	−0.494069	−0.720078
Kurtosis	2.031000	1.389373	2.290400	1.689565	2.219527
Jarque-Bera	6.867031	12.57829	14.92495	13.01933	12.96873
Probability	0.032273	0.001856	0.000574	0.001489	0.001527

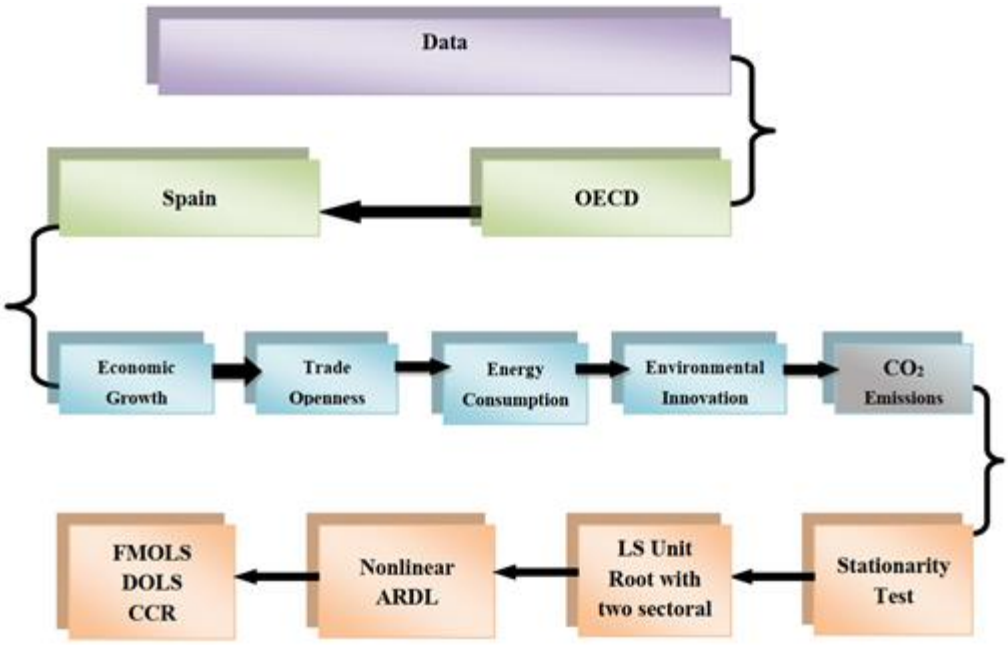

Figure 1. Analysis flowchart.

Theoretical Underpinning

A theoretical framework for the current study is given by the Environmental Kuznets Curve (EKC). GDP growth is a principal driver of pollution across countries [48] This theory proposes that income in a country affects pollution in an inverted U-shaped way. There was a broad discussion about this phenomenon in [49], which suggests that advancement in the economy lessens environmental quality, but contributes to it once a specified degree level of growth is reached [49]. Hence, GDP is incorporated into our study. Further, it is important to have eco-friendly growth policies in order to facilitate the overall wellbeing of the environment. Thus, GDP is necessary for the present study. The theoretical underpinning for incorporating patent technology is multifaceted: firstly, whether competition promotes innovative activities is certainly not a new question. Theories such as the innovation regime theory [50] emphasize the importance of protecting small and innovative firms. Research innovation results in a more efficient system. To add to this argument, enhancing the innovative capacity of the country through a national scientific and technological framework usually fosters a culture of innovation through the use of technology. Additionally, the use of patents on environmental innovation appears to be growing more popular in climate

change research because protection of intellectual property makes new solutions to climatic issues feasible. Research and development in technological advancements can contribute to limiting environmental contamination and enhancing the economic growth as well as economic stability of all sectors in a given country. Renewable energy supplies are considered to improve the environment by reducing the extraction of fossil fuels and reducing greenhouse gas emissions [50]. High energy consumption results in high emissions of carbon (the principal greenhouse gas responsible for global warming), which leads to greater environmental damage. Economic growth is the driving force behind environmental degradation. The major causes of energy consumption are rising incomes, urbanization, and access to electricity. There is widespread debate on whether or not trade openness reduces carbon emissions since free trade fosters greater research and development. Many scholars claim that trade openness increases pollution, while others claim it leads to a reduction [51,52] We include the conclusion that trade openness reduces carbon emissions in our study since the evidence is mixed. Further, the effects of ecological and environmental pollution cannot be considered without considering human behaviors. Environmental psychology refers to environmentally sustainable behavior as being pro-environmental (protective behaviors that individuals engage in towards the environment). Sustainable behaviors are those that are supportive of the environment. This means the type of behavior that supports environmental sustainability. For instance, the amount of CO_2 emissions (CO_2E) a person emits during a daily commute can vary depending on whether they use a bicycle, car, or public transportation. Consumer behavior that is environmentally sustainable is a critical aspect of pro-social consumption, ultimately benefiting the environment and society as a whole. Circular economy principles, or what is known as closed-loop economics, can contribute to sustainable consumption and sustainability. By reusing, sharing, borrowing, repairing, recycling, and renewing existing materials and products, this type of economy keeps existing resources flowing for the longest amount of time [53–56].

A plethora of studies [57–63] have investigated the various determining factors that might increase the carbon footprint of several nations. However, the use of patents on environmental technologies innovation is novel to the body of research model is represented in Equations (1) and (2) showed thus;

$$CO_2E = f(\ PATENT, GDP, TRA,\ ENE) \tag{1}$$

$$CO_2E_{it} = \vartheta_0 + \vartheta_1 PATENT_{it} + \vartheta_2 GDP_{it} + \vartheta_3 TRA_{it} + \vartheta_4 ENE + \varepsilon_{it} \tag{2}$$

Hypothesis 1 (H1). *Patents on environmental technologies negatively affect carbon emissions.*

We hypothesize that patents on environmental technologies significantly help in mitigating the carbon emissions in the environment in Spain because the patent system is an important economic mechanism for promoting the development of technologies. As technical innovation or new processes are most commonly protected by patents, patents are most relevant to the mitigation of climate change. Patents provide a strong economic incentive for innovators. In the current mitigation technology development and commercialization framework, patent rights are considered to be two major components. Hence, we hypothesize that patents reduce carbon emissions. i.e., $\vartheta_1 = \frac{\partial CO_2E}{\partial patent} < 0$. O Our expectation is line with the studies of [64–66].

Hypothesis 2 (H2). *There is a positive relationship between GDP and CO_2E.*

Our model projects a positive relationship between economic growth and the environment; similar to other studies, increasing per capita GDP is associated with increased carbon dioxide emissions i.e., $\vartheta_2 = \frac{\partial CO_2E}{\partial GDP} > 0$, and this empirical evidence is the same as a recent study by [67].

Hypothesis 3 (H3). *Energy consumption reduces environmental sustainability.*

We also believe that energy consumption increases CO_2E in both developed and developing countries. This is because fuels are used in transportation, processing, exploration, production, and storage, all of which contribute to the production and utilization of emissions associated with energy, $\vartheta_4 = \frac{\partial CO_2E}{\partial ENE} > 0$. The study of [68,69] corroborates our findings in its empirical evidence.

Hypothesis 4 (H4). *Trade openness negatively affects environmental deregulation.*

The theory of economic integration suggests that common trade rules aim to reduce environmental damage while promoting sustainable practices. A favorable relationship is expected given that trade openness is a core variable in economic expansion, which triggers increased carbon emissions, i.e., $\vartheta_3 = \frac{\partial CO_2E}{\partial TRA} < 0$ [61].

4. Empirical Findings

The present study emphasizes the complex relationships between carbon dioxide emissions, energy efficiency, economic growth, trade openness, and patents on technological innovation using the nonlinear ARDL technique for Spain for the period from 1990 to 2018. We provide a preliminary assessment of the order of the time-series integration in the current analysis. Conventional unit-root tests frequently reject the null hypothesis of unit roots erroneously. It is true that several different unit-root tests can be used for deter-mining the stationarity characteristics of variables. These tests were not considered in this study due to the claims made by [46,70].

A unit-root test developed by [71] was intended to address the invalid rejection problem arising from the Zivot–Andrews and Phillips–Perron unit root tests. We employed the Lee and Strazicich unit-root tests as conceptual models to examine the integration order of patent technology, economic growth, trade openness, energy consumption, and CO_2 emissions. Meanwhile, ref. [72] suggests that a possible alternative hypothesis could be "structural breaks are present", which could involve a unit root with breaks. The outcomes from the Lee and Strazicich unit-root test are reported in Table 2. The outcomes clearly reveal that the integration of order of the timeseries is mixed—I(0) and I(1). Therefore, in this study, the asymmetric ARDL method is employed for integrating parameters at I(0) and I(1). It is important to choose an appropriate lag length for nonlinear ARDL applications, as this allows endogeneity to be addressed. Ref. [73] noted that adequate lags are also effective in mitigating the effects of multicollinearity in nonlinear ARDL. Ref. [74] found that the optimal lag period can also be used to solve multicollinearity issues in asymmetrical ARDL. In order to separate parameters into negative and positive shocks, causal asymmetries is a reasonable approach since the reactions between positive and negative shocks are always different. In addition, it is capable of separating parameters into negative and positive shocks by introducing nonlinear effects. Within a VAR frame-work, parameters are methodically separated into shocks, and then the shocks are tested to see if they are causally related from negative to negative and positive to positive.

This study explores the effects of patents on environmental technologies, economic growth, trade openness, and energy consumption on carbon emissions, which is the main objective. The empirical study employed a nonlinear ARDL after the prerequisite requirement was met. The results of the long-run nonlinear ARDL are illustrated in Table 3. As reported, the findings from the bounds test revealed long-run cointegration between patents on environmental technologies, economic growth, trade openness, and energy consumption and carbon emissions in Spain. The empirical findings from the nonlinear ARDL revealed that a positive increase in patent technology innovation does not harm the quality of the environment. This implies that keeping other indicators constant, a 1% increase in patent technology decreases environmental degradation by −0.036%. Also, a reduction in economic growth deteriorates the quality of the environment. Thus, a 1%

decrease in patent technology would increase environmental degradation by 0.0146% when other parameters are held constant. The long-run outcomes suggest that increases and decreases in patent technology increase environmental degradation in Spain. The economy and environment are intertwined in multiple ways: the environment contributes resources to the economy, while it is also a sink for pollution and waste. Natural resources are crucial inputs for the production of many goods and services; however, production and consumption also cause pollution and other environmental problems.

Table 2. Unit Root Tests.

		At Level				
		LCO2E	**LPATENT**	**LTRA**	**LGDP**	**LENE**
LS	t-Statistic (tau)	−4.190	−5.217 *	−4.899	−5.312 *	−4.497
	Break Points	1998Q3 2008Q2	2006Q3 2009Q3	1998Q2 2008Q4	2002Q1 2010Q4	1998Q4 2007Q4
Test critical values	1% level	−6.107	−5.813	−6.107	−6.005	−6.107
	5% level	−5.495	−5.389	−5.495	−5.461	−5.495
	10% level	−5.221	−5.064	−5.221	−5.217	−5.221
		At First Difference				
		LCO2E	**LPATENT**	**LTRA**	**LGDP**	**LENE**
LS	t-Statistic (tau)	−5.9170 ***	−6.525 ***	−6.073 ***	−5.369 **	−6.280
	Break Points	2006Q3 2009Q3	2000Q3 2002Q1	2006Q3 2011Q2	2006Q4 2008Q3	1995Q2 2007Q3
Test critical values	1% level	−5.813	−5.975	−5.813	−6.006	−6.101
	5% level	−5.389	−5.336	−5.389	−5.304	−5.490
	10% level	−5.064	−5.024	−5.064	−5.055	−5.217

Note: *, **, *** indicates 10%, 5%, and 1% significance levels, respectively.

Hence, economic growth and wellbeing are affected by poor environmental quality, which lowers the quality and quantity of resources or has a detrimental impact on health, etc. The economy's negative feedback on the environment can be curtailed through environmental policies. Economic crises can make it difficult for the government instead of focusing on keeping the environment clean, and businesses will thus turn to polluting fossil fuels instead of renewable energy sources. Hence, a decline in economic growth can impose a greater burden on the environment than a rise in income. The study of [75] showed that economic growth increases environmental degradation, while economic contraction results in a reduction in environmental degradation. A decline in economic activity can lead to a reduction in investments in environmentally-friendly activities. The findings of our study suggest that a reduction in economic growth is more damaging to developing nations like Spain, which have experienced substantial growth in recent decades. Hence, it is imperative that the Spanish government considers the outcomes of our study when developing its growth and environmental policies, which recommend that it should focus on achieving economic stability through the transition to green energy. Furthermore, the outcomes of our study indicate that a 1% positive increase in trade openness will result in a reduction in environmental quality by −0.29%, while a negative in trade openness increases environmental degradation. Lastly, both increases and decreases in energy supply are detrimental to ecological quality. Based on the Ramsey test, the model shows no signs of heteroscedasticity or serial correlation. In addition, the J-B test shows that the distribution is normal. The CUSUM and CUSUMSQ in Figures 2 and 3 also illustrate the stability of the model. The paper focuses on the long-run estimates found in Table 3.

Table 3. Nonlinear ARDL long-run form and bounds test.

Nonlinear-ARDL Long Run Form				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LPATENT_POS	−0.036359	0.009741	−3.732584	0.0003
LPATENT_NEG	0.014676	0.012196	1.203308	0.2320
LTRA_POS	−0.295727	0.071297	−4.147848	0.0001
LTRA_NEG	0.738483	0.127675	5.784079	0.0000
LGDP_POS	0.357159	0.060363	5.916906	0.0000
LGDP_NEG	0.482314	0.253260	1.904422	0.0600
LENE_POS	1.253606	0.179875	6.969309	0.0000
LENE_NEG	0.198025	0.343001	0.577330	0.5652
C	5.325571	0.004880	1091.307	0.0000
Bounds Test				
F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
			Asymptotic: n = 1000	
F-statistic	6.4232 ***	10%	1.85	2.85
k	8	5%	2.11	3.15
		2.5%	2.33	3.42
		1%	2.62	3.77
Reset test				
	Value	df	Probability	
t-statistic	1.199189	71	0.2344	
F-statistic	1.438055	(1, 71)	0.2344	
Likelihood ratio	2.205710	1	0.1375	

Note: *, **, *** indicates 10%, 5%, and 1% significance levels, respectively.

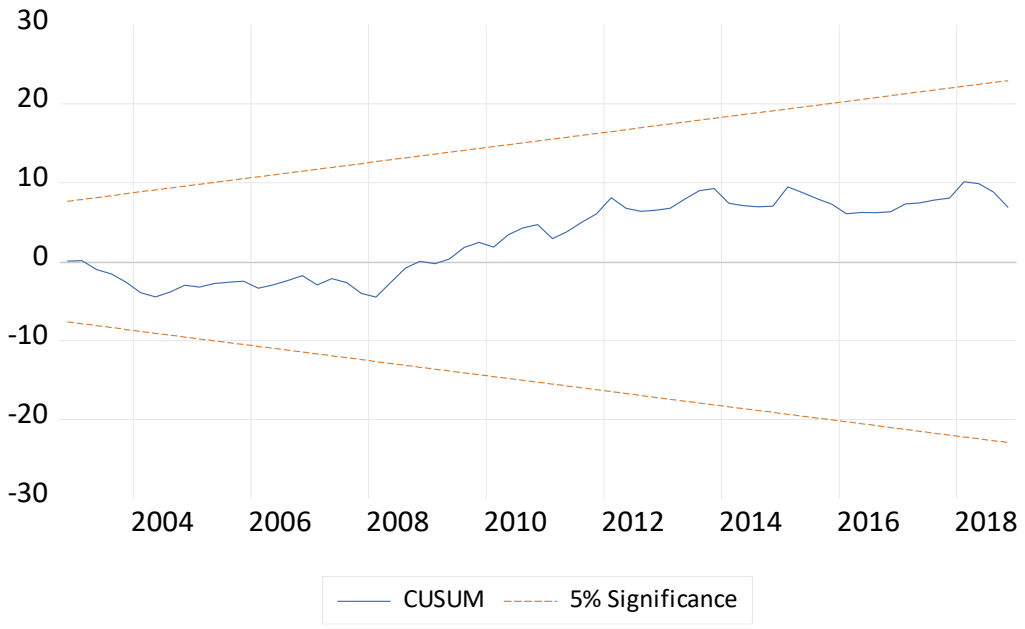

Figure 2. CUSUM.

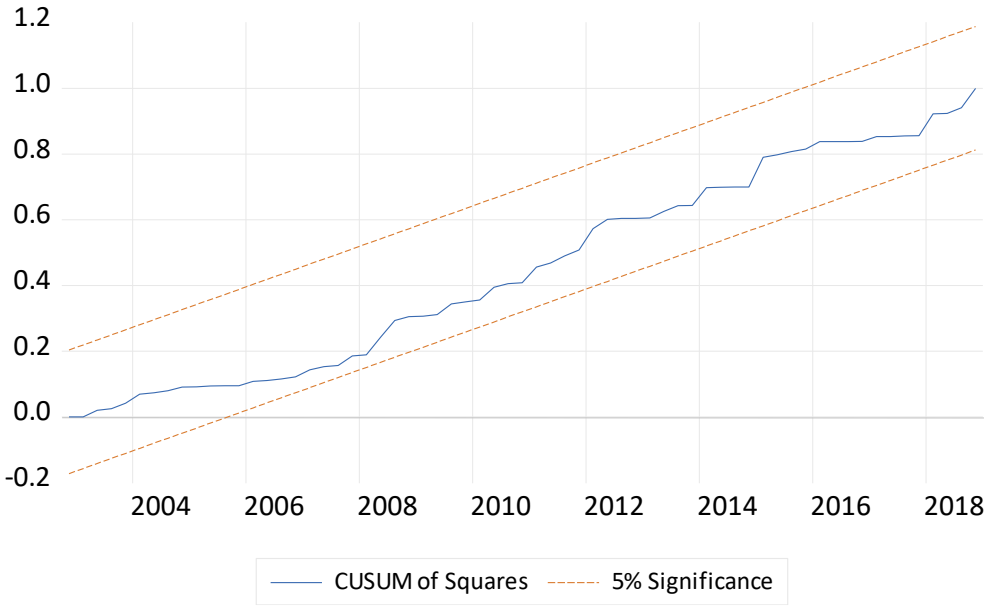

Figure 3. CUSUM of Squares.

By using data from 1990Q1 to 20181Q4, this study further assesses the long-run effect of patents on environmental innovation, energy use, GDP, and trade openness on environmental deregulation using different robustness checks and estimators (FMOLS, DOLS, and CCR), the outcomes of which are depicted in Table 4. Patents on environmental technology play a critical role in the reduction of environmental deregulation in Spain. In other words, the effect of patents on environmental technology on CO_2 emissions is negative and significant, which implies that holding all indicators constant, a 1% upsurge in the patents on environmental technologies will cause carbon emissions to decrease by 0.0452% (FMOLS), 0.0535% (DOLS), and 0.0429% (CCR). Moreso, we find that trade openness is helpful in environmental sustainability, wherein a 1% rise in trade openness will lead to a decline in carbon emissions by 0.369% (FMOLS), 0.5027% (DOLS), and 0.405% (CCR). Like many other studies, GDP growth is a major contributor in escalating the emissions within a country. In Spain, the influence of GDP on carbon emission is positive but not significant, which suggests that, holding all indicators constant, a 1% rise in GDP will cause carbon emissions to rise by 0.110% (FMOLS), 0.280% (DOLS), and 0.136% (CCR). Finally, energy consumption has a beneficial influence on carbon emission, such that a 1% rise in energy use will cause carbon emissions to increase by 1.533% (FMOLS), 1.526% (DOLS), and 1.54% (CCR). The NARDL results are consistent with the outcomes of FMOLS, DOLS, and CCR. Moreover, Figure 4 reports the outcomes of the present study.

Table 4. Robustness test.

DOLS				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LPATENT	−0.053855 **	0.020591	−2.615466	0.0107
LTRA	−0.502786 ***	0.082855	−6.068275	0.0000
LGDP	0.280540 ***	0.102474	2.737660	0.0077
LENE	1.526068 ***	0.105342	14.48676	0.0000
C	−0.332801	1.744983	−0.190719	0.8493
CCR				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LPATENT	−0.042921 *	0.025824	−1.662092	0.0993
LTRA	−0.405622 ***	0.102656	−3.951297	0.0001
LGDP	0.136345	0.113126	1.205247	0.2307
LENE	1.543956 **	0.197816	7.805004	0.0000
C	1.978864	2.058224	0.961443	0.3384

Table 4. *Cont.*

FMOLS				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LPATENT	−0.045282 ***	0.011887	−3.809294	0.0002
LTRA	−0.369883 ***	0.070802	−5.224204	0.0000
LGDP	0.110820	0.097278	1.139217	0.2571
LENE	1.533490 ***	0.106758	14.36416	0.0000
C	2.220897	1.585968	1.400341	0.1642

Note: *, **, *** indicates 10%, 5%, and 1% significance levels, respectively.

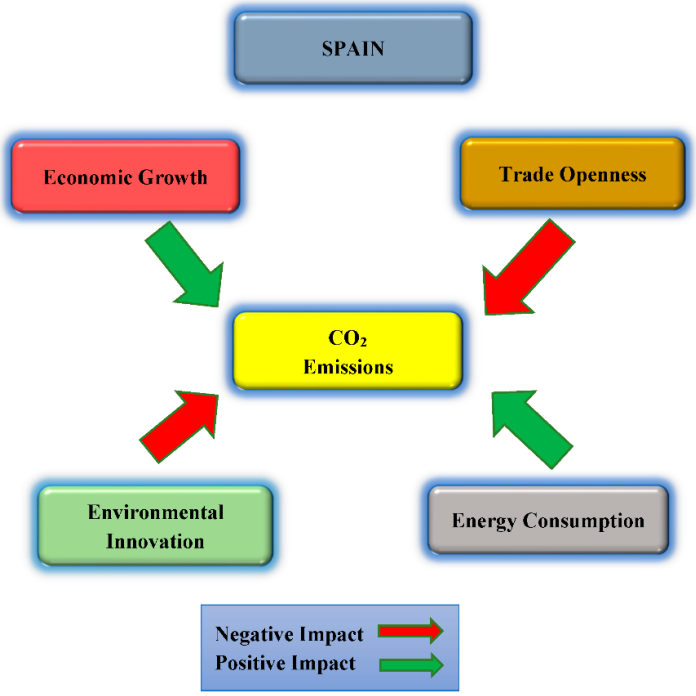

Figure 4. Graphical representation of the outcomes.

5. Conclusions and Policy Direction

Intellectual property protection is vital for cutting-edge technologies since changes in the ecosystem are among the most concerning threats to its future, with limited technology options to mitigate this issue. However, to accelerate such solutions and enable idea sharing, patents appear poised to be a viable option. Green technology innovation can act as a tool for managing the economic-environmental conflict. In addition, the number of patents relating to low-carbon technologies worldwide is also on the rise. Consequently, trademarking carbon capture technologies is the best option for maximizing the potential value of ecological technology. As the world transitions towards a sustainable economy, patents will play an increasingly important role in protecting and maximizing commercial advantage. Moreover, if collaboration and cooperation are widely adopted, intellectual property will play a more prominent role in scaling up environmental technologies that can counter global warming. Additionally, this empirical research paper investigated whether patents on environmental technologies influence carbon emissions while con-trolling the energy supply, economic growth, and trade openness using the Spanish economy as a case study. In order to investigate these dynamics, the nonlinear ARDL technique was applied. One of the advantages of the nonlinear ARDL technique is that it can capture both the positive and negative impacts of regressors on environmental deregulation in Spain. The results from the nonlinear ARDL model indicate that a long-term relationship exists between CO_2 emissions, patents on environmental technology, economic growth, trade openness, and energy consumption in Spain. GHG emissions fall when there are more patents on environmental technologies, as demonstrated by the non-linear ARDL

results, while decreases in patents on environmental technologies are linked to an increase in CO_2 emissions. Further, increased trade openness significantly influences CO_2 emissions, while decreased trade openness lowers CO_2 emissions. The findings of the study demonstrate that Spain's economic expansion negatively impacts environmental sustainability. A significant increase in energy consumption has an adverse effect on the quality of the environment. Our paper suggests that patents on environmental technologies represent a strong and useful tool for measuring environmental innovations, including pollution control, renewable energy technologies, as well as general technological innovations that have an environmental benefit. Moreover, based on our research, we recommend that the Spanish government encourage the adoption of electric vehicles since transportation and energy contribute the largest amount of CO_2 emissions to global warming. As a final point, the government of Spain should ensure that clean energy sources continue to drive economic growth because economic growth negatively impacts environmental quality. In order to reduce energy consumption, policymakers should increase energy conservation and carbon reduction policies.

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