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Panel Evidence from EU Countries on CO_2 Emission Indicators during the Fourth Industrial Revolution

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Abstract: Research question and the most important issue in this paper relates to the determination of CO_2 emission drivers in EU and the possibility of its reduction in the era of the fourth industrial revolution. EU strategies and economic policies are directed toward sustainable development, with special emphasis on reducing CO_2 emissions towards carbon neutrality. The method used in this research is the Panel Generalized Method of Moments (GMM) two-step dynamic estimator on 27 EU countries in the period 2012–2019. The research resulted with the following findings: innovation activity, industrial structure and development, human capital, and institutional framework; these are all statistically associated with CO_2 emission levels in a negative manner, thus, contribute significantly to the reduction in CO_2 emissions. Following the empirical results, it may be concluded that reaching sustainable development goals requires the EU to enhance innovation activity, technological development, reshape its industrial structure, create high-quality human capital, and increase the quality of its public institutions.

Keywords: EU; CO_2 emissions; innovation activity; human capital; technological development; institutions

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1. Introduction

Climate changes caused by carbon dioxide (CO_2) emissions represent one of major challenges in the 21st century. The World Bank [1] (WB), as the biggest data base, developed its section on sustainable development goals. Sustainable development emphasizes the importance of thinking about the inheritance of future generations. Except economic dimension, sustainable development encompasses social and ecological dimensions. Ecology or environmental pollution is an issue and concern that the world is facing. CO_2 is not only a trace gas vital for the growth of plants, it is also a greenhouse gas posing a variety of threats to society if its concentration in the atmosphere is too high: it endangers human health and increases the global temperature with the consequent rising of the sea level via ice melting. It endangers various species up to their extinction. It is a threat to biodiversity. Increasing CO_2 emissions endanger economic development. Human capital is the key asset to an economy. It determines the productive power of all other resources. Rising CO_2 emissions endanger human capital, mostly by affecting human health. The rising sea level and temperature threatens global tourism vital for some low-income economies. It can cause the disappearance of coastal cities, endanger production facilities, and economies in general.

The fourth industrial revolution is the technological period and phenomenon that society lives in. It affects all aspects of society, including daily life, business, the public sector, education, science, and so on. It is the result of rapid technological advancements and the implementation of technologies such as artificial intelligence, the Internet of Things, virtual and augmented reality, and smart systems in a variety of fields. The fourth industrial revolution and its technologies are expected to bring a variety of benefits to society, such as increased productivity and improved global health due to new methods for discovering cures or vaccines for certain diseases and physical disorders. One of the most significant societal benefits is that it should help to reduce pollution levels through the process of creative destruction and reshaping of industrial structures to become more environmentally friendly. Variables included in the econometric model in this research are recognized drivers of the fourth industrial revolution, as explained more thoroughly in the literature review section. Human capital stands at the forefront of any technological shift and development. Green and eco-innovations will drive industrial and overall economic development, helping to achieve sustainable development goals. CIP, or competitive industrial performance index, is included as an independent variable in the econometric model. Index measures the export competitiveness of an industry in a specific national economy and the level of its transition to the fourth industrial revolution. Restructuring the industry to rely on green energy and innovations, as well as to reduce pollution, is a top priority not only in the EU, but also globally. It will aid in the mitigation of climate change, which is a major challenge for the twenty-first century. Despite its worldwide significance and rising interest, the fourth industrial revolution and associated technologies are an understudied topic. This paper seeks to add to the study of the fourth industrial revolution and its consequences, particularly in the field of pollution reduction, which is a key social concern in the twenty-first century. A reason regarding why it is necessary to study fourth industrial revolution and why it is included in this research is because this topic is not examined enough, despite high interest and a rising number of different studies. Another reason is that it is a relatively new topic due to its short period, since it started in 2011. This is confirmed by different authors such as [2] and [3]. The COVID-19 epidemic accelerated the digital transformation. There is a scientific discussion regarding if it is the beginning of the fifth industrial revolution according to various authors such as [4–7]. It is critical to study and research the effects of the fourth industrial revolution so that this topic does not go unstudied during the period of a possible new industrial revolution, especially focusing on its impact on the most important global challenge—the pollution level.

This study aims to identify the variables that significantly contributed to the EU's lower CO_2 emissions throughout the fourth industrial revolution, long after the European Union Environmental Trading System was implemented (EU-ETS). The fourth industrial revolution represents a new paradigm for EU development, and new technologies are expected to help reduce CO_2 emissions.

This research provides some new contributions in terms of hypothesis testing, coefficient estimation, and policy recommendations. The literature review section and the discussion sections are sources of discussions on CO_2 and overall emission levels and its determinants. The variables of interest are industrial and technological development, institutional quality, innovation activity and human capital. As far as the authors know, there is no study showing statistical associations between the same set of variables on the same or similar set of countries using the same methods of analysis, thus, making it an understudied field. This research is focused on the period of the fourth industrial revolution marked by the EU with the goal to increase European competitiveness. Pollution reduction, sustainable development and industrial revolutions are driven by human capital. In this study, human capital and innovation activity factors are represented by the knowledge and technology output as well as patent per capita indicators. Both variables are incorporated in the model explained in detail in chapters 3 and 4. Technological development and upgraded industrial structure are necessary for lowering pollution levels, industrial revolution and sustainable development, and this variable is incorporated in the model together with the competitive industrial performance index that is further explained in the Results and Discussion section. Since progress does not happen in a societal vacuum, these variables are supplemented by measures of societal institutional quality: the rule of law and corruption perception index (inverted). This research contributes to the scientific discussion twofold. It tests the hypotheses and coefficients regarding independent variables and their statistical association to the dependent variable: CO_2 emissions. Some of these variables, such as human capital, industrial and technological development and innovation activity, are recognized drivers of fourth industrial revolution. By testing these hypotheses, it provides new insights about the fourth industrial revolution and its effects on the environment. The use of the two variables related to institutional quality is in line with the importance of public organizations in promoting environmental norms and rules at the EU level, such as the EU-ETS, and with the idea that institutional framework is important in enhancing technological development and the transition toward the fourth industrial revolution. New cognitions from this research may ultimately help create better policies related to reducing pollution levels and combating climate changes at the EU and global levels.

The paper is divided into sections. The first section is the Introduction. Section 2 provides a review of the literature. Section 3 represents the Materials and Methods. The econometric model used for the purposes of this research is shown in Section 4. Section 5 is a discussion of the model's results. In the final and concluding section, a conclusion with policy recommendations is provided.

2. Literature Review

The literature review will provide a discussion and theoretical background related to CO_2 emissions, its determinants and harmful effects. The EU wants to become carbon neutral, and not just to reduce CO_2 emissions. Developed countries agreed to reduce emission levels according to the Kyoto Protocol. Consequently, since it represents a departure from the customary technologies, the reduction in CO_2 emissions has implications on the selected variables.

2.1. CO_2 Emissions—Effects and Determinants

There are different drivers of environmental pollution. According to the Environmental Kuznets Curve (EKC) hypothesis, environmental pollution should decrease with increasing human development above a certain threshold. This theory is subject to harsh disagreement. Rahmal and Alam [8] were not able to reject the EKC hypothesis on their set of data. According to their findings, pollution levels increase throughout the early stages of economic development while decreasing during later stages because of improved national economic standards that enable technical advancement. They discovered that higher levels of energy consumption, trade volume, and enterprise credit amounts have a detrimental impact on the environment through higher CO_2 emissions. They advocate advancements in renewable energy to lower pollution. They state that CO_2 emissions are key drivers of climate change and environmental pollution.

Erdogan, Kirca and Gedikli [9] stated that CO_2 emissions represent the most important indicator of environmental pollution. Their analysis of six countries confirmed that rising CO_2 emissions negatively affect human capital by causing various diseases, affecting working efficiency and productivity, and subsequently, causing a rise in public costs of healthcare. Instead of being directed towards economic growth or education, these costs are directed towards consequence remediation of environmental pollution. They suggest to raise awareness among populations about harmful effects of CO_2 emissions and emphasize technological progress as a driver of declining the emissions. The reduction in CO_2 emissions represents a challenge for governments, institutions, multinational enterprises (MNEs), small and medium enterprises (SMEs) and the overall global community. The EU, a leading global trader and investor and one of the most important players in the global economy in its development strategies, emphasizes sustainable development as its priority. A reduction in CO_2 emissions and becoming carbon neutral are among their sustainable development goals. Harvard School of Public Health [10] states that environmental researchers from Harvard University found that CO_2 emissions endanger human health and increase poverty and the risk of undernourishment, especially in less-developed economies, by reducing crop quality.

Cioca et al. [11] agreed with the fact that sustainable development is a major global challenge, with special emphasis on CO_2 emission levels, and that it is the most important issue for each stakeholder in society: governments, regional integrations, business sectors, and science. They focused on EU and found that transport, the manufacturing sector, thermal and electricity production are the biggest drivers of environmental deterioration. They also found that the pollution level is reducing and that the main drivers of the emission level reduction are innovation activity, transition to green energy and technology.

The same variables, according to Mignamisi and Djeufack Dongmo [12], have different consequences in nations with abundant and restricted resources. Urbanization is a major determinant of pollution, but other elements including income per capita, industrial and technological development, energy consumption, institutional quality, agricultural output, and involvement in global trade also have a big role. In terms of income per capita, the article provided evidence in favor of the EKC theory. Globalization levels, GDP per capita, and environmental taxes reduce emission levels, whereas car counts raise emissions, claim Vlahinić Lenz and Fajdetić [13]. Rong et al. [14] found that economic growth and GDP actually increase CO_2 emissions, whereas innovation activity and the move to renewable energy sources have a positive impact.

According to Roth [15], the reduction in emission levels is a top priority for the global community due to the negative effects on human capital. It has a negative impact on children and young people's life quality, cognitive abilities, and educational outcomes, as well as working productivity due to missed days at work. According to Apergis, Bhattacharya, and Hadhri [16], environmental degradation killed 7 million people in 2012. They studied 170 economies and discovered that higher emission levels endanger health and increase healthcare costs, while its drivers are the increase in GDP, energy consumption, and population.

Terjanika and Pubule [17], in their study of the EU economy, found that reducing pollution is the most important social problem today. Countries want to become carbon neutral, but new technologies are the most important factors for this. Since the industrial sector poses significant challenges, it is necessary to advance the industrial structure. The biggest obstacle to reducing CO_2 emissions and moving to green solutions is the high complexity of these processes, the lack of knowledge among managers and workers, and the high costs. Improving institutional quality is one of the key factors in reducing emissions. The regulatory framework is an important driving force in reducing emissions. They agree with several authors [18–20], that barriers include not only cost, but also the speed of ROI (return on investment), the inability of human capital to accept new technologies, maintenance and functionality of existing technologies.

Nguyen [21], when analyzing 100 economies, could not reject the EKC hypothesis in the form that higher industrialization levels reduce pollution. Mahmood, Furquan and Bagais [22] emphasize the importance of declining pollution levels for health and biodiversity. The drivers of higher emission levels are FDI, whereby foreign companies very often export dirty industries to developing countries; trade, whereby dirty production is held at bay in developing countries; and energy usage, whereby most of the energy is still derived from fossil sources. Mance, Vilke and Debelić [23] tested the EKC hypothesis on solid municipal waste by analyzing a panel of Croatian municipalities. Their results show the existence of the EKC due to detailed waste treatment policies in the richest municipalities.

Rios and Gianmoena [24] analyzed the spillover effects of CO_2 emissions from 141 neighboring countries with positive results. Mance et al. [23] found a positive statistical association in a dynamic panel regarding the relation of institutional and human capital quality to environmental indicators [25].

Population levels and the integration into global trade flows do not have any statistically significant effect. Chen [26], when analyzing OECD member states, found that EU countries perform better than other economic or trade associations in reducing pollution levels. This is probably due to the comprehensiveness of the EU-ETS. Results were different for the 18 EU member states from the 32 OECD members. In the EU, the EKC could not be rejected. In both cases, the increased use of fossil fuels increases the pollution level, and the transition to green energy reduces it. Green energy implies innovative energy solutions and confirms that innovation activities reduce pollution levels. Anwar, Younis and Ullah [27] state that an increased urban population, GDP and integration into global trade flows increase the pollution level.

To reduce pollution levels, policy priorities have to improve the industrial structure, increase institutional and regulatory quality, enhance innovation activities through transition to green energy and create quality urban policies. Atici [28] analyzed Central and Eastern European countries (CEECs) and found that increased energy consumption increases emission levels, while integration into global trade flows and an increase in the income per capita level reduces pollution. Wu, Zhu and Zhu [29] agree with the fact that pollution is the major global concern and the harmful effects are greater than previously thought. Greenhouse gas emissions affect not only global warming, but also economic performance, quality of life and health. Additionally, industrial structure, industrialization and development may reduce CO_2 emissions.

Khan and Hou [30] were also unable to reject the EKC hypothesis among the 19 EU member states of the International Energy Agency. They investigated the impact of environmental sustainability policies on CO_2 emissions and concluded that shifting toward such policies reduces emissions in the end. Human capital, population, R&D spending, investment, price level and personal consumption were all examined indicators. Natural resources, mortality rates, percentage of land covered by forest, surface area, fertility rate, green energy, and non-renewable sources are examples of environmental indicators. Their conclusion is that if sustainability is implemented in all of these areas, CO_2 emissions will be reduced.

According to Magazzino and Cerulli [31], the main determinants of declining pollution levels are increasing the per capita income and reducing energy intensity, whereas urbanization and economic involvement in global trade flows increase pollution levels.

In a study of 11 CEE economies, Bayar, Diaconu, and Maxim [32] found that economic growth reduces pollution levels, whereas credits provided to businesses and energy use raise pollution levels, not only across the panel of 11 nations, but also when tested individually for each economy in the model.

According to Duro and Padilla [33], the primary factors contributing to the EU's leadership in the world in terms of emissions reduction are its high per capita income and reduced energy intensity. They verified that more developed nations outperform less-developed nations in terms of reducing CO_2 emissions. The EKC theory was verified regarding the long term in the EU, according to Dogan and Seker [34]. While initial development raises CO_2 emissions, development through an increase in the use of innovative and environmentally friendlier technologies manages to decrease the overall environmental impact of development.

The transition toward green, innovative energy solutions, and a higher level of involvement in global trade flows also reduce CO_2 emissions, while the usage of traditional energy sources increases emissions.

Dogan and Inglesi-Lotz [35] examined determinants of CO_2 emissions in EU countries and confirmed the long-run validity of EKC. The usage of traditional energy sources, higher energy usage and the rising population increase the pollution level. The urban population rate can have both negative and positive effects for environment, while industrial development contributes to a reduction in the short and higher emission levels in the end. Aydin and Essen [36] examined determinants of CO_2 emissions in the EU with a special focus on different types of taxation related to pollution. They found that the income per capita and urban population level increase CO_2 emissions, while innovation activity, industrial structure, development, and price level reduce it. Regarding taxation, different types of taxation have different impacts on emission levels. All of them reduce emissions, but with a lower percentage. The total environmental taxes have the highest impact, while energy taxation is second. Transport and pollution taxes have smallest impact on the reduction in CO_2 emissions. Morales-Lage, Bengochea-Morancho and Martínez-Zarzoso [37] analyzed the determinants of CO_2 emissions in the EU. In a panel data analysis that included all 28 members from 1971 to 2012, researchers discovered that a higher population, income level, technological development, and energy consumption all increase emission levels. They did, however, conduct separate analyses of old and new members after that. The results for new members are the same, while technological and industrial development reduces CO_2 emissions in old members, implying that industrialized countries outperform the least industrialized in terms of the reduction in CO_2 emissions.

CO_2 emissions are a complex topic representing huge challenges to reduce its level. There are a variety of determinants that affect it differently in different periods and sets of countries.

2.2. Industrial Structure, Development, and CO_2 Emissions

The pollution level increased with industrial revolutions. People were not aware of the environmental effects of industry and there was no possibility to create environmental laws. With further developments in industry and its upgrading, emissions changed. Technological progress enabled lower emission levels. Bets [38] states that emission levels increased by 50%, from 278 ppm (parts per million) to 417 ppm. The American Chemical Society [39] confirmed a higher level of pollution through time. They measured it from the beginning of the new era and confirmed that emissions of CO_2, CH_4 (methane) and N_2O (nitrous oxide) increased, but with the industrial revolutions, the emissions growth rate was higher. In the 20th century, emissions increased exponentially, and the growth was slightly higher than in the previous periods. CO_2 emissions are the biggest cause of pollution.

Fowler et al. [40] confirmed that CO_2 emissions represent a problem, but the level of concentration significantly increased during the industrial revolutions. The global level increased, but there are differences among different groups of countries. Countries with a better industrial structure and a higher standard and level of industrial development are the frontrunners in reducing CO_2 emissions, while the pollution level increases in economies such as India, where the standard and industrialization level is lower. A higher level of institutional quality and rule of law impact the reduction in CO_2 emissions.

Li, Ma and Wei [41] state that technological progress, upgrading industrial structure, innovation activity and institutional quality have positive effects on the reduction in emission levels; meanwhile, GDP growth does not have quantitatively large effects, although its effects are positive and statistically significant. They recommend focusing on new technologies and the development of an industrial structure of higher quality.

Hill and Magnani [42] found that there are vague impacts regarding income and industrialization levels on CO_2 emissions, but low-income countries, with a lower level of technological progress, are faced with an increased pollution level. The same was found with the quality of human capital, while providing education services in these countries increases pollution due to a higher energy intensity.

Xu, Li and Huang [43] state that studies confirm the importance of transferring credits to the private sector because they enhance industrial development and advance industrial structure, thus reducing level of CO_2 emissions; they confirmed this based on examples in China and the EU. They recommend a transformation toward innovative industries and green innovative solutions.

Olah et al. [44] examined the impact of the fourth industrial revolution and its technologies on pollution. They state that it provides a great opportunity to reduce pollution levels and mitigate emissions, and can be a foundation for environmental policies and the harmonization of economic and industrial policies with environmental protection. They state there are benefits of the fourth industrial revolution and its technologies in mitigating emission levels, but the impacts will differ in countries with different levels of economic and technological development, thus, again confirming the necessity for upgrading industrial structure. Institutions and innovation activity will be necessary to enable these technologies to mitigate emission levels. The fourth industrial revolution implies upgrading industrial structure through innovation activity, better infrastructure and a transformation toward green energy.

Bonilla et al. [45] state that impacts will differ and there are different scenarios. The fourth industrial revolution will change business models, require higher digitization levels, and therefore, can contribute to the reduction in emission levels. However, there is a possibility that with a higher industrialization level, digitization will increase emissions through increasing car use, traditional energy sources, raw material usage and energy intensity, but there is also a possibility that these technologies will enable the tracking of environmental data and provide the necessary information to reduce pollution levels. The reorganization of business processes can reduce energy intensity, waste creation and usage of raw materials and durability of products. It is expected that through time, the fourth industrial revolution will bring more positive than negative effects.

Kahia and Ben Jebli [46] state that the industrial revolutions caused higher pollution levels due to the usage of non-renewable energy sources. They found that industrial upgrading has different effects in different national economies in the long and short term. In certain economies, it reduces emissions, while in others, it can increase emission levels in the long term, while in the short term, it reduces in all economies. Green energy reduces pollution levels, and they consider that industrial development based on innovative solutions can contribute towards mitigating CO_2 emissions. The same situation was observed with income per capita level, where effects differ in various economies.

Han and Chatterjee [47] state that poor economies with low levels of industrialization are bigger polluters then high income and industrialized economies. They found that industrial development in less-developed economies causes higher pollution levels, and in industrialized economies, further development of industrial structure and transition from traditional toward innovative industries with low energy intensity causes lower pollution levels.

According to Zhou, Zhang, and Li [48], improving industrial structure and technological development lowers pollution levels. Technologically advanced industries contribute to lower CO_2 emissions. The share of public companies, fixed capital formation, and FDI reduce CO_2 emissions, while the total and urban populations increase them.

Wang et al. [49] state that industrial development, urbanization, energy consumption and income level increase GDP per capita in the panel of 14 countries, while effects differ per each country. They suggest to improve the industrial structure and enhance innovation activities in order to reduce the pollution level.

Kofi Adom et al. [50] found that shifting industrial structure toward low energy intensity sectors centered on technological development and innovation can reduce CO_2 emissions. Economic growth can be affected by reshaped industrial structures. Lower CO_2 emissions can be a barrier to economic growth, whereas higher growth rates imply lower emissions. Reduced pollution levels are influenced by technological advancements, green energy, and innovative solutions.

According to Aiginger [51], decision makers in the EU and industrialized countries must continue to develop strategies and policies for industrial development in order to achieve the sustainable development goals. One of the objectives should be to restructure the industry in order to reduce CO_2 emissions. Technological advancement, innovation activity, human capital creation and institutional quality are important drivers. These industrial strategies and policies complement environmental policies. More developed and industrialized economies that implement these ideas are more likely to achieve long-term development goals. Technological advancement, which includes reindustrialization with a different structure, as well as the transition to new technologies, all contribute to lower emission levels. Such industrial policies, which are already in place in Europe, have yielded some early results, as absolute and relative (per unit of GDP) pollution levels today are lower than in the last decade of the twentieth century, and countries with a higher level of industrialization and greener industrial structure outperform those with a lower level of industrialization.

Canal Vieira, Longo and Mura [52] examined impacts of the EU-ETS (European Union Environmental Trading System) and industrial policy in mitigating CO_2 emissions from

2005 to 2017 in EU members. They found that different production sectors have different performances—the same as in different economies. Sectors that are more successful in the transformation toward new technologies and industrial structure reshaping processes perform better in mitigating emissions.

Muûls et al. [53] confirmed that industrial development toward new technologies that were innovation-driven resulted in a nearly 5% reduction in pollution levels between 2005 and 2017. Developed EU economies with higher levels of industrialization and a diverse industrial structure outperform new members in terms of pollution reduction. It was the result of the EU-ETS and ideas about industrial and environmental policy harmonization.

Kaivo-oja et al. [54] compared CO_2 emission reduction determinants in the EU, China, and the United States. Industrial structure and industrial development, which imply technological advancement, were important factors in pollution reduction. Innovations, particularly in green technology, fueled industrial development and technological advancement.

2.3. Innovation Activity and CO_2 Emissions

One of the primary drivers of societal development is innovation activity. Innovations improved life quality by making everyday tasks and communication easier, and they enabled higher levels of development by increasing productivity and creating new paradigms. In this chapter, the role of innovation in reducing CO_2 emissions will be discussed. In the fourth industrial revolution era, innovation, particularly in the fields of green energy and technological advancement, should be a key to reducing pollution levels.

Ali et al. [55] found that innovation activity reduced pollution levels, while investment activity, an increasing GDP and higher energy consumption caused higher pollution levels. Results regarding the effects of innovation on environmental pollution agree with [8,11,14,24,26,35,40,43,48–50,52,53]. Wang et al. [56] examined the effects of economic policy uncertainty on pollution levels on a panel of 137 economies. They found that the uncertainty level increased emissions, but the effects were lower in developed and industrialized countries with an upgraded industrialized structure. Innovation activity, a higher average population age and rising population reduce the pollution level, while economic growth and added manufacturing value increase it. Carrion-Flores and Innes [57] state that innovation activity—expressed with investments in R&D and an increased number of patents—reduces pollution levels in 127 manufacturing sectors across the USA, and reduced pollution levels enhance innovation activity. Mensah et al. [58] examined OECD economies and found that innovation activity expressed in patent application have different effects in different economies. In certain economies, it reduces pollution levels, while in others, it increases pollution; the reason for this might be that patents are not related to the innovation activity that mitigates CO_2 emissions. However, they emphasized that innovation activity is a key driver in reducing emission levels. R&D and green energy are also key drivers in reducing emission levels, while GDP growth can have vague effects. Khan et al. [59] examined the determinants of CO_2 emissions in 176 countries, and the EU member states was among these economies. Innovation measured with patent applications resulted in economic growth and a short-term increase in FDI, while it decreased pollution levels in the long term. FDI affects technological development and industrial structure, and can confirm that industrial development and structure reduce CO_2 emissions. Trade openness is a significant driver of the reduction in CO_2 emissions because it enhances technology and innovation transfer across the world. Institutional quality measured with different indicators—including the rule of law and corruption, and the transition to green energy that also represents innovation activity—contribute to decreasing pollution levels. Institutional quality is important because quality institutions can create a macroeconomic environment that enhances investment activity, technology transfer, and consequently, the advancement of industrial structure in certain economies. Welmin et al. [60] found that CO_2 emissions are major source of environmental pollution compared to SO_2, NO_2 or other polluters. They found that an increase in innovation activity reduces CO_2 emissions since it develops green energy solutions and affects the technological upgrading of industry.

The transition to green energy is another determinant of pollution reduction—the same as the globalization level. Economic growth, FDI and traditional energy sources increase CO_2 emissions. Choi and Han [61] state that innovation activity and an increase in patent applications, especially in green technologies, should play a key role in mitigating pollution levels, and FDI as a main technology transfer channel that reshapes industrial structure and upgrades industry could reduce pollution. They examined developed and developing economies and found that innovation activity expressed through patent applications in the field of green technology and involvement in global trade flows reduce pollution levels in developed economies, while this is not always the case in developing countries. In the end, economic development level reduces CO_2 emissions in both groups, while in the short term, it increases pollution levels in developing economies. FDI and institutional quality reduce pollution levels.

Grosso et al. [62] state that R&D and innovation activity are key drivers in reaching EU goals related to the zero-emission rate, especially because they enable technological development and the reshaping of industrial structure. The main finding of the paper is that all types of innovations should reduce pollution levels in the EU. Such types of innovations include technological innovations, but also the innovation of business models. Gilli, Mancinelli and Mazzanti [63] found that innovation activity represents and will represent key determinants in mitigating the pollution level, but it will be necessary to complement green innovation with other types of innovation, such as business model innovation, process, product or service. Despite developed EU members outperforming the less-developed part, the major differences are among manufacturing sectors; however, in all sectors, innovation activity reduces the pollution level. Balsalobre-Lorente [64], when analyzing five EU countries, stated that investments in innovation and transition to green energy reduced CO_2 emissions, while EKC was confirmed in the long term, but not in the short term. FDI increased the pollution level.

According to Wolf et al. [65], several factors influence the achievement of zero emissions. Innovation, industrial development and the transformation of industrial structures through digitization processes should reduce pollution levels. The EU will need to shift its economic policy paradigms, reshape its innovation policy by ensuring a high-quality institutional and regulatory framework, and increase and improve spending on such activities. Innovation should help the EU compete with its main global competitors, such as the United States and East Asia, by lowering pollution and increasing economic growth. Human capital and education quality are also important drivers of lower emission levels.

Constantin et al. [66] observed that overall innovation activity, capacity, and R&D are the major drivers of sustainable development in the EU, allowing it to achieve higher GDP growth rates while lowering pollution levels. They noticed that developed and highly industrialized EU economies outperform new Europe economies in industrial structure, development, and innovation capacity, and thus, in pollution reduction.

According to Vollenbroek [67], innovation activities and their outcomes enabled the highest development and growth rates ever by increasing productivity levels and changing industrial structure, and they should now be the key in balancing economic growth and pollution levels in the EU and the rest of the world.

Mazzanti and Rizzi [68] investigated the factors that contribute to lower CO_2 emissions in the EU and its manufacturing sector. Innovations such as new products, services, processes, and business models geared toward sustainable development should be a key driver in reducing CO_2 emissions. Such innovations reshape industrial structure, accelerate technological and industrial development, and facilitate the transition to renewable energy sources.

According to Aghion, Veugelers and Serre [69], innovation and R&D are major deterrents to reducing pollution levels in the EU. Policymakers must increase both private and public investment in such activities.

2.4. Human Capital and CO_2 Emissions

Human capital determines the productivity of all other resources, making it a critical driver of not only economic growth, but also overall societal development. Previous chapters emphasized and confirmed that innovation drives economic growth. Innovation is the inexorable result of human activity that adds to human capital. This section will focus on the role of human capital quality in reducing CO_2 emissions. Human capital is expected to contribute to lower pollution levels. Different reasons are given, such as the negative effects on life quality and health, as well as work productivity. Because innovation activity and the transition to green energy reduce pollution, human capital becomes more important, and all of these solutions will be the result of quality human capital.

Kwon [70] emphasized that human capital is a key driver of overall societal development, including a reduced pollution level through innovative solutions in the transition toward green energy and industry. It is necessary for national economies to find as many as possible indicators to determine its quality; in addition, they should increase investments in human capital. This is in accordance with the findings of [14,23,50] and [58].

Wang and Xu [71] examined the drivers of CO_2 emissions in developed, developing and emerging economies. They found that the quality of human capital reduces the pollution level. A higher percentage of people that use the internet, economic growth, developed industrial structure and financing enterprises through credit activity reduce the pollution level. A higher number of people that live in the cities and investment activity increase the pollution level. Their findings also show different results in different groups of countries. In developed economies, human capital and internet penetration have higher effects on pollution reduction.

Khan [72], when analyzing 122 economies, found that the quality of human capital is essential to mitigate CO_2 emissions—the same as financial development. He confirmed EKC in the long term. The involvement in global trade flows, FDI and an increasing population increase the pollution level. Salahodjaev [73] stated that human capital is necessary in mitigating pollution—the same as institutional quality. He confirmed EKC in the long term. Population, level of globalization and bio-capacity increase pollution levels. Iqbal, Majeed and Luni [74] found that quality human capital is an important driver in reducing pollution levels, while the increasing number of people that live in cities and a higher level of involvement in global trade increase it. However, the effects differ in developed than in developing and transition economies; developed economies have advanced industries and manufacturing, and their products and services are environmentally friendly; thus, in their case, inclusion in global trade flows reduces CO_2 emissions. Lin et al. [75] examined the correlation among human capital and pollution in Chinese regions. Human capital is an important driver of the decline in pollution levels, but the most important is that human capital is innovative, and the personnel involved in R&D, science and engineering must apply as many patents as possible; the number of patents per applied researcher reveals their innovativeness. Such human capital will be the driver of innovative ideas and solutions for technological and industrial development, and the transition toward green energy. They recommend to all types of economies: high, middle, upper-middle and low-income to increase investments in human capital, but especially in innovative human capital. Economic growth in the short term increases pollution levels, while decreasing it in the long term, thus, confirming the EKC hypothesis. Investment activity, which is the main channel of technology transfer and industrial development, reduces the pollution level. The increasing population, manufacturing and energy usage are drivers of higher emissions.

Mance, Krunić and Mance [25] conjecture that in the 21st century, the HDI is a more comprehensive measure of societal development, since it includes not only economic, but also other social components. Nadeem et al. [76] found that human capital is an important driver in reducing pollution levels—the same as the transition toward renewable energy sources. A higher level of economic complexity, export, involvement in global trade flows, economic development and urbanization lead to higher emission rates. They suggest that it is necessary to transfer knowledge across the world to reduce pollution levels, since it can increase the quality of human capital. Ali, Akram and Burhan [77] found that there are different drivers of pollution levels in various national economies by creating three groups of economies by pollution convergence levels. Human capital is the most important driver of CO_2 emissions, while economic complexity, investment activity, inclusion in global trade flows and total factor productivity have different effects. The effects of each variable—especially the economic complexity level, since it regards the indices level of industrial development—depend on the level of technological upgrading of industry toward green technologies. It is necessary to technologically upgrade industrial structure with eco-friendly technologies, products, services, organization and business models.

Chen and Wang [78] analyzed EU economies in a 30-year period. They found that human capital—which encompasses knowledge, education levels and general health conditions—is an important driver of pollution reduction and economic growth, especially because human capital is a driver of innovation activity and technology upgrading in industry, of which are very important for lower emission rates. Flores Chamba et al. [79] found that European economies that perform best in the quality of human capital and its knowledge level reach lower pollution levels. They conjecture that human capital and knowledge level are key drivers of lower energy usage and pollution reduction in EU member states and the rest of Europe. Increasing the price of fossil fuels reduce pollution and energy intensity in the EU, but increase it in the rest of Europe.

Alsaleh, Oluwaseyi Zubair, and Abdul-Rahim [80] investigated what factors influence higher levels of bioenergy usage in the EU, because shifting to such sources is one of the key enablers of lower emission rates and meeting the EU's zero-carbon emission targets. A lack of knowledge can be a significant impediment to a successful transition to such sources. Their main discovery is that high-quality human capital with a higher knowledge level, institutional quality, innovation activity and capacity, and economic development are the most important drivers of the transition to bioenergy sources and, as a result, lower emission rates. The EU must invest in these factors and increase private investments in people and innovative solutions. One of the major tasks of the EU is to create a regulatory and institutional environment that will allow for the development of human capital and the enhancement of innovation, as well as to invest in infrastructure that will allow for the transition to bioenergy sources.

According to Braun [81], human capital and increasing its knowledge level through knowledge diffusion were and continue to be important determinants of lower pollution levels. EU-ETS, which is now one of the EU's top priorities, necessitates a higher level of knowledge about the environment, technology (particularly green solutions and energy) and innovation. For the EU, it is necessary to encourage all stakeholders, including the public, academic and educational sectors, as well as the business sector, to invest in human capital and knowledge about EU-ETS and pollution reduction.

Cakar et al. [82] identified human capital as one of the most important drivers of lower emission rates; however, this does not have to be the case in less-developed EU members. Increasing the number of patent applications is a similar situation because it depends on whether the patents are environmentally friendly and committed to pollution reduction. One of the main findings is that increasing the quality and knowledge of human capital reduces pollution levels, as increased knowledge leads to patents and innovations that can help reduce emissions.

Alsarayreh et al. [83] stated that human capital—through increased knowledge and quality—contributes to lower pollution levels, while an increase in the general and urban population increases pollution. They recommend investments in human capital and innovation activity that will create new technologies necessary for green transition.

2.5. Institutional Quality and CO_2 Emissions

National economies must build high-quality institutions that are resilient to corruption because this is the only way to create a quality regulatory and macroeconomic framework. Such a framework enhances innovation activity, economic and social development, technological progress, the creation of high-quality human capital, and therefore, is one of the major drivers of mitigating pollution. It can be measured with a variety of indicators such as the rule of law, corruption level, government effectiveness of integrity, regulatory quality, political stability and level of democracy.

Gani [84] found that institutional quality—measured with various indicators, such as the rule of law or corruption levels—reduces pollution levels. Such findings agree with [12,17,24,27,40,41,51,59,60,65,73,80]. He confirmed EKC in the long term, but in the short period, he stated that a higher economic growth increases the pollution level—the same as the industrial and trade-to-GDP ratio. Muhammad and Long [85] found that institutional quality measured through the rule of law, corruption and political stability levels contributes to lower emission rates in developed, developing and transition economies. The trade-to-GDP ratio and FDI have different effects in different group of economies, while energy usage causes higher emission rates. Results of their research emphasize the importance of building high-quality institutional frameworks through enhancing the rule of law and reducing the corruption level.

Lisciandra and Migliardo [86] found that institutional quality is inversely associated with emission rates—the same as energy usage—while industrial development in the long term reduces emissions, and increases it in the short term. Economic growth represents an important driver of reduced pollution.

Runar, Amin and Patrik [87], when examining 124 developed, developing, and transition economies, found that institutional framework is an important driver for reducing emission levels. They emphasized the importance of innovations and technological progress in the transition toward environmentally friendly business and growth models.

Eskander and Fankhauser [88] found on a panel of 133 national economies that institutional quality, quality of legal framework related to emission levels, new laws related to pollution, economic growth in the long term and service-based economy reduce pollution levels, while economic growth in the initial stages and higher trade levels increase emission rates.

Li, Rishi and Bae [89] examined economies that receive Official Development Aid (ODA). Not only is institutional quality in these economies an important driver of pollution reduction, but it also affects it indirectly, because a higher level of institutional quality effectiveness of ODA programs increases pollution reduction in terms of economic development and increasing the environmental quality. With a low level of institutional quality, ODA programs could contribute to higher pollution levels.

Stef and Ben Jabeur [90] examined 83 economies and found that institutional quality is a key driver in lowering CO_2 emissions and that they are key determinants of the effectiveness of environmental legislation. Regarding poor institutions, new regulations related to the environment will not contribute to a lower pollution level. Human capital and the share of territory covered by forests contribute to reduced pollution, while urbanization, higher energy intensity and investments increase it. Jian et al. [91] found that institutional quality indicators are important determinants in reducing the pollution level in China—the same as human capital and globalization—while an increasing population and energy intensity affects higher emission rates. Strengthening domestic institutions, a higher globalization level, increasing the quality of human capital, having a sustainable population growth and transitioning toward green energy are recommendations for China to reduce pollution levels.

Galeotti [92] stated that institutional quality and legal frameworks are key drivers in implementing any type of policy, including those related to the reduction in pollution levels in each economy, including the EU. Another important driver of lower emission rates is technological and industrial progress, because it enables the harmonizing of objectives related to higher economic growth and lower pollution levels.

Castiglione, Infante, and Smirnova [93] investigated the links between fiscal policy and taxes, environmental protection, economic growth and institutional quality. They classified EU economies as developed or developing: Scandinavian countries, Benelux, Austria, Germany, France, and the United Kingdom. The second group consisted of Mediterranean EU economies that were old EU members. The third group consisted of ex-communist economies. Their main finding is that institutional quality and legal framework quality are critical in achieving environmental tax efficiency and balancing higher levels of environmental tax burden with economic growth. This effect was stronger in developed and more industrialized EU economies, whereas in the other two groups, where institutional quality was lower, the effect of institutional quality on lower emission rate was weaker.

The United Nations Environmental Program research [94] stated that institutional quality is key for successful and effective environmental protection policies and programs in the EU and the rest of the world. Corruption is one of key indicators of institutional quality, and therefore, it will affect all programs and policies related to pollution reduction.

Haring [95] found that institutional quality is a very important driver for effective environmental policies in the EU. Countries with lower corruption and inequality levels are more successful in pollution reduction because people are more likely to believe in benefits of such policies; the reason for this is a higher level of trust in public institutions.

Fan [96] stated that the EU is a pioneer in forming policies and programs related to environmental pollution. The EU enhances the rule of law and strengthens its institutions to reach objectives of lower emissions and economic growth. Such institutions enhance innovation activity and technological and industrial upgrading. The EU adapts its regulatory framework to challenges of the 21st century, and one of them is pollution. The legal framework and quality institutions are factors of success of environment protection policies. The problems in pollution reduction are disparities among member states, where developed and highly industrialized economies outperform the rest of the EU. The author suggests to Chinese authorities to set the EU as a benchmark for their environmental policies that will be harmonized with economic growth policies.

Chang and Hu [97] found that institutional quality plays an important role in environmental protection in the EU, but different indicators have different effects. Reducing the corruption level is essential to reduce the pollution level. Higher political involvement can always represent a problem for reduction of pollution level.

According to Apergis and Garcia [98], institutional and governance quality, as well as a regulatory framework, are critical in lowering emission rates in the EU because they reduce corruption, ensure that public funds are distributed fairly, and increase investments in appropriate technologies and programs. In such cases, government policies enable not only business sector development, but also investment in environmental programs and solutions. In highly developed and highly industrialized EU members, emission rates are lower. Their level of industrialization and welfare allows them to invest in innovations, technological and industrial structure upgrades, and green energy.

Ojonugwa, Osama and Osama [99] found that public institutions and their quality in the EU increase the level of environmental protection in the EU when regulatory frameworks and judicial systems are characterized with the rule of law, the corruption level is reduced and controlled, authorities are effective, the political situation is stable and threats related to terrorist or criminal activities are on a low level. It also enables economic development, while economic growth and tourist activity increase CO_2 emissions.

Based on the theoretical background acquired from the literature review, the following research hypotheses regarding statistical associations were formulated:

1. The change in innovation activity is negatively associated with the level of CO_2 emissions.
2. The improvement in industrial structure is negatively associated with the level of CO_2 emissions.
3. The quality of human capital is negatively associated with the level of CO_2 emissions.
4. Higher institutional quality is negatively associated with the level of CO_2 emissions.

For research hypotheses 1, 3 and 4, besides the usual statistical significance, they are also expected to bear a negative sign in the statistical association. Research hypothesis 2 only expresses an expectation regarding the statistical significance regardless of the sign since it is a purely qualitative variable.

3. Material and Methods

3.1. Model Explanation

CO_2 emissions are very harmful for society and cause negative effects, such as endangering human capital, causing health issues, reducing education performance, global warming, climate changes and various problems in the functioning of society—which agrees with the findings of [8–10,16] and [22]. The majority of pollution comes from CO_2 emissions—which agrees with [8]—while [11,15] and [17] consider it as a major issue for global society. The EU tends to reduce emission rates to zero, which agrees with [13,61,64] and [80]. The existing literature found various determinants of lower emission rates, such as institutions, human capital, innovation activity, transition to green energy solutions, environmental taxes and investments in R&D, while there are vague effects of industrial development and GDP growth.

$$CO_2 = f(CPI_{i,t}; CIP_{i,t}; know_{i,t}; pat_{it}; law_{it}) \tag{1}$$

The dynamic panel model in this paper is made from 123 observations from the period 2012 to 2019 and is based on the EU. Equation (2) describes a dynamic model with a single time-changeable lagged variable based on Galović and Bezić [100].

$$y_{it} = \beta y_{it-1} + u_i + v_{it},\ |\beta| < 1 \tag{2}$$

where y_{it} is the dependent variable in period t; y_{t-1} is the dependent variable with lag for one period from t; u_i represents individual time-invariant effects. Value v_{it} is the random error. Individual effects are taken as stochastic. Additional significant assumptions about stability of the model are errors v_{it}, which are serially uncorrelated. Individual time-invariant effects are mostly related to the previous effect of the dependent variable in the model, which resolves the problem of endogenity.

Subsequently, the following model is tested (Equation 3):

$$dCO_{2it} = \beta_0 + \beta_1 CPI_{i,t} + \beta_2 CIP_{i,t} + \beta_3 know_{i,t} + \beta_4 pat_{i,t} + \beta_5 law_{i,t} + u_{i,t} + v_{i,t} \tag{3}$$

Generalised Method of Moments (GMM), two-step dynamic panel is chosen to be the appropriate estimator for this study because it is useful for both hypothesis testing and coefficient estimation, and has many other useful properties, as shown in more detail in Piper [101]. Accounting for autoregression by the use of a lagged dependent variable is also one these useful properties described in more detail in Baum [102]. Hall [103] states that GMM is an appropriate method to get precise and asymptotically normally distributed estimators of variables, and agrees with [102] about the increasing use of GMM in economic research. GMM sets two types of restrictions. The identifying restrictions include data that are employed for estimations, and the overidentifying restrictions are related to the rest of the data and are the key driver in relation to the reliability of a dynamic panel. Hansen [104] agrees with [101] about the accuracy of the method regarding the asymptotic distribution of normality, and states that GMM ensures the reliability of the model under certain restricting conditions. Hansen [105] points out that the GMM estimator is applicable to large samples and eases comparisons. It enables calibration verification because it chooses the best linear combination between the variety of moment restrictions.

The Panel GMM is an often-used method when the variables are non-stationary, when the dependent variable is dynamic i.e., when it depends on the previous values of itself. Panel GMM allows econometric models to be specified while avoiding unwanted or unnecessary assumptions and heteroscedasticity of unknown origins. When the number of cross-sections is greater than the number of time periods, GMM provides better predictions of coefficients in terms of a lower standard error.

For the appropriate decision on the method, one should take a careful look at the data. Data begets the method.

3.2. Data and Variables

This research measures the effects of institutional quality, technological and industrial development, innovation activity and human capital on CO_2 emissions. For the purposes of this paper, 27 EU economies for the period 2012–2019 are observed. UK is not included in the model due to Brexit. As a proxy for pollution levels, CO_2 emissions are most consistent in providing stable datasets. All CO_2 emission data are in 2015 USD per kg taken from the World Bank [106] World Development Indicators. It agrees with the relevant literature that states how CO_2 emissions are a major cause of pollution levels. Two measures of institutional quality are used. The World Bank [106] rule of law estimation measures the perception of inhabitants in relation to the state of rule of law in their country. It measures the quality of contract enforcement, property rights, policing, and the courts, as well as the likelihood of crime and violence. The estimate gives the country's score on the aggregate indicator in units of a standard normal distribution, i.e., ranging from approximately 2.5 to 2.5. Data are taken from World Bank, Worldwide Governance Indicators [107]. Another indicator is the corruption perception index that estimates the rate of institutional corruption in public administration. Data are taken from Transparency International [108]. The literature review found that institutional quality is measured with these two indicators, and it represents one of the key determinants in lowering emission rates. Institutional quality ensures equal framework and a fair distribution of public funds. As a proxy for technological and industrial development, CIP or competitive industrial performance index is chosen and is measured by the United Nations Industrial Development Organization [109], which states how measuring this index is important in the period of the fourth industrial revolution, where the industrial sector is a driver of innovation and transition toward the fourth industrial revolution. This index measures the level of technological advancement in the industrial sector of certain national economies, the ability of industry of certain economies to produce products that are competitive on the global market and its share in global exports. As a proxy for human capital, the knowledge and technology output variable is chosen, which is an indicator of global innovation index and is measured by WIPO [110]. It measures the results of knowledge processes and investments in human capital. Human capital determines the productive capacity of all resources and is a major driver of development, especially in the knowledge economy. Educated people are more aware of the pollution problem and will have more capacity to find solutions to mitigate CO_2 emissions. As a proxy for innovation capacity, the indicator of patents per capita is used, which is taken from World Bank [106], World Development Indicators database. Calculation of this indicator is shown in the formula in Equation (4).

$$Patents\ per\ capita = \frac{Total\ number\ of\ patents}{Total\ population} \tag{4}$$

This indicator for the innovation activity variable is also in accordance with the relevant literature. Innovation activity is essential for reducing pollution, since the transition to renewable energy requests innovative solutions and patents that will enable industries to accept environmentally friendly solutions. The variables are shown in Table 1.

Table 1. Explanation of the variables.

Symbol	Variable	Explanation	Database
d_CO_2	Pollution	CO_2 emissions (kg per 2015 USD of GDP)	World Bank–World Development Indicators
d_CPI	Institutional quality	Corruption perception index	Transparency International
d_CIP	Technological and industrial progress	Competitive industrial performance index	United Nations–United Nations Industrial Development organization
d_know	Human capital	Knowledge and technology output	Global innovation index database
d_pat	Innovation activity	Patents per capita	World Bank–World Development Indicators
d_law	Institutional quality	Rule of law	World Bank–Worldwide governance indicators

3.3. Correlation Matrix

For the purpose of testing for multicollinearities, a correlation matrix shown in Table 2 was calculated.

Table 2. Correlation matrix.

d_CO_2	d_CPI	d_CIP	d_law	d_know	d_Pat	
1.0000	−0.1977	−0.1189	−0.0942	−0.2185	−0.0056	d_CO_2
	1.0000	−0.0858	0.0809	0.0564	0.0188	d_CPI
		1.0000	0.877	0.1061	0.0259	d_CIP
			1.0000	0.0107	−0.0975	d_law
				1.0000	−0.0577	d_know
					1.0000	d_Pat

The correlation matrix in Table 2 shows no multicollinearity between variables. None of the coefficients are higher than the critical 0.5 value. Moreover, all of the variables are below 0.22. There are three instances of non-expected signs, i.e., where the signs are not strictly commensurate with the theory. Firstly, there is a positive relationship between the changes in the corruption perception index and the competitive industrial performance index. Instead, negative but close-to-zero values were found. Secondly, negative signs but with values close to zero were also found for the changes in the patents per capita and the changes in the rule of law. Lastly, changes in patents per capita and changes in the knowledge and technology output also have a negative sign, although small in magnitude. None of the coefficients are close to the critical value of 0.5.

3.4. Descriptive Statistics

The descriptive statistics of the used variables' first differences are shown in Table 3.

Table 3. Descriptive statistics.

Variable	Mean	Median	S.D.	Min	Max
d_CO_2	−0.0113	−0.00867	0.0231	−0.122	0.0993
d_CPI	0.175	0.000	3.99	−34.0	34.0
d_CIP	−0.00117	0.000153	0.00820	−0.0362	0.0620
d_law	−0.00404	−0.00449	0.0785	−0.319	0.209
d_know	−0.818	−0.700	5.10	−20.1	18.8
d_Patent	0.000000621	−0.00000187	0.000054	−0.000470	0.000357

3.5. Panel Unit-Root Test

The unit-root test results are shown in Table 4.

Table 4. Results of unit-root tests.

Test	Variable	Level	First Difference
KPSS	CO_2	0.0103	0.6792
	CPI	0.0023	0.6393
	CIP	0.0077	0.5419
	know	0.1323	0.9446
	pat	0.0006	0.3418
	law	0.7920	0.8743
Levin, Lin and Chu	CO_2	0.0000	0.0000
	CPI	0.3936	0.0000
	CIP	0.0128	0.0000
	know	0.1456	0.0000
	pat	0.0000	0.0000
	law	0.4540	0.0000
Augmented Dickey–Fuller	CO_2	0.8745	0.0000
	CPI	0.9709	0.0000
	CIP	0.2687	0.0000
	know	0.7997	0.0000
	pat	0.0004	0.0000
	law	0.7573	0.0000
Phillips and Perron	CO_2	0.0003	0.0000
	CPI	0.4374	0.0000
	CIP	0.0000	0.0000
	know	0.0070	0.0000
	pat	0.0000	0.0000
	law	0.1265	0.0000

The unit roots were tested with the Kwiatkowski–Phillips–Schmidt–Shin (KPSS); Augmented Dickey–Fuller (ADF); Im, Pesaran, and Shin; Levin Liu; and Chu and Phillips Perron test. The null hypothesis of the KPSS test assumes the non-existence of unit roots, i.e., that the time series is stationary around the trend, whereas all other tests assume non-stationarities, i.e., the existence of unit roots in their null hypotheses. Table 4 confirms that all variables are stationary in the first differences, but the variable *pat* is stationary in levels in all tests except in the KPSS test. According to Arltova and Fedorova [111], the KPSS test is reliable and applicable for shorter periods of time and provides very accurate test results. By making the data stationary, one avoids a spurious correlation due to data dynamics. The results of the stationarity tests confirm the model's robustness. The results of the stationarity tests confirm the need to difference the variables. All variables are stationary after first differencing. Thus, this research is determined toward statistical associations between the changes in variables.

4. Results

The test results of the Panel GMM dynamic model are shown in Table 5.

Variable $d\_CO_2(-1)$ represents the lagged dependent variable and is measured in kilograms per USD. All other variables show negative signs. CPI—corruption perception index—is measured from 0–100, where 0 is the highest and 100 is the lowest level of corruption. The results show that increasing the index value by one point will reduce CO_2 emissions by 0.002 kg. The competitive industrial performance index (CIP), measured by UNIDO, is a measure of industrial structure "quality" and technological development, with values ranging from 0 to 1—where lower values that are closer to zero imply a lower quality of industrial structure and technological advancement. Increasing the value of CIP by 1% will reduce CO_2 emissions by 0.577%. The knowledge output as an indicator of the global innovation index is measured from 0 to 100, where the higher indicator values imply better results of knowledge processes and investments in human capital. The results indicate that increasing the value of this indicator by 1% coincides with the reduction in

CO_2 emissions by 0.00034%. Patents per capita represent the result of the formula patent applications/total population. Results indicate that an increase by 1% in the number of patents per capita will reduce CO_2 emissions by 13.14%. The rule of law is measured on a scale ranging from −2,5 to +2,5, where higher values imply higher levels of the rule of law. The results indicate that a 1% increase in this value is commensurate with the reduction in CO_2 emissions by 0.032%.

Table 5. Results of the model (dependent variable: d_CO_2).

	Coefficient	*Std. Error*	*z*	*p-Value*	*Significancy*
d_CO_2(−1)	0.0809932	0.0136867	5.918	< 0.0001	***
d_CPI	−0.00185476	8.38444×10^{-5}	−22.12	< 0.0001	***
d_CIP	−0.577332	0.140301	−4.115	< 0.0001	***
d_know	−0.000347782	0.000172190	−2.020	0.0434	**
d_pat	−13.1497	2.97081	−4.426	< 0.0001	***
d_law	−0.0321677	0.00671299	−4.792	< 0.0001	***
T3	−0.00737523	0.00111335	−6.624	< 0.0001	***
T4	−0.0148437	0.00295451	−5.024	< 0.0001	***
T5	−0.00821629	0.00123617	−6.647	< 0.0001	***
T6	−0.00331857	0.00100970	−3.287	0.0010	***
T7	−0.0114142	0.00116085	−9.833	< 0.0001	***

Note: In the last column *Significancy* is explained p-value, where *p* value labeled ***, indicate the level up to 1% significance, and *p* value labeled **, indicate the level up to 5% significance. Sum-squared resid = 0.044741, S.E. of regression = 0.019987, Number of instruments = 24, Test for AR(1) errors: z = −2,07249 [0.0382], Test for AR(2) errors: z = −0.589242 [0.5557], Sargan over-identification test: Chi-square(13) = 14.8812 [0.3148], Wald (joint) test: Chi-square(6) = 1089.05 [0.0000], Wald (time dummies): Chi-square(5) = 213.349 [0.0000].

All variables, including time dummies, are statistically significant at $p < 0.01$. Only the variable d_know is significant at the level $p < 0.05$. The Arellano–Bond test's null hypothesis asserts that autocorrelation does not exist in the first differences of the errors. If the errors are not serially correlated, the test may show a first-order correlation but not second- and higher-order correlations. The presence of first-order autocorrelation is frequently overlooked because the parameter estimates are consistent with the presence of autocorrelation among the first differences of the residuals. The test reveals that the first-order AR(1) statistic is statistically significant, but not the second-order AR(2) statistic. The results of the Arellano–Bond test statistics thus reject the existence of second-order autocorrelation since the AR(2) probability value is above 0.5. We conclude there is no residual autocorrelation. The results of the Sargan test, 0.3148 > 0.05, indicate the accuracy of the models, while the results of the Wald test imply that the variables in the model show an adequate level of explanatory power.

5. Discussion

The empirical findings imply that institutional factors, defined as rules and regulations that guide human behavior, provide future guidance towards greener production and are just as important as technological progress in guiding economies toward the green economy goal.

In other words, the hypothesis testing part of the analysis confirmed the conjectured research hypotheses. The second part of expected results was concerned in gaining some new information about the strength of those associations: the coefficient estimation.

For various reasons, ranging from the presence of unit roots in the panel time series to the differences in the idiosyncratic effects of the cross sections, the optimal hypotheses test and coefficient estimation method was GMM. This method, combined with the necessary first differencing of the underlying variables, allowed us to answer the hypotheses about relationships between the changes in variables. In a model with many variables and the risk of multicollinearity among variables—i.e., how much does a change in one variable correlate with a change in another variable? The findings do not contradict predictions regarding the signs and directions of causality.

CIP (competitive industrial performance) index, a variable used in the model as a proxy for technological and industrial development, is a sign of technological advancement and the transformation of an industrial sector in a particular national economy toward the fourth industrial revolution. The results show that changes in CO_2 emissions are inversely related to changes in industrial and technological development. It is statistically significantly ($p < 0.05$) associated with the CO_2 emissions reduction. Not every industry is the same in producing CO_2 emissions. Moving upwards on the competitive industrial performance (CIP) scale significantly reduces CO_2 emissions, since industrialized countries are able to cherry-pick the industries or their clean sectors and outsource "dirty" industries or their "dirty" sectors to industrializing countries, not least because of the introduction of the EU-ETS that monetizes CO_2 emissions.

Human capital quality, essential for social development and represented by the knowledge output indicator variable, is inversely correlated with CO_2 emissions. The EU must be focused on creating its own human capital and attracting quality human capital from different parts of the world. Patents p.c. are a proxy variable for innovation activity. Patents are one of the results of human capital, and both variables resulted in not being multicollinear with one another. The negative sign in the coefficient estimation output confirms the importance of innovation activity as a factor in pollution reduction. Pollution is of anthropogenic origin. Its reduction will also necessarily be the consequence of innovative anthropogenic activity. Innovations drive industrial development and technological improvements, including the ones in the field of pollution reduction. This means that a higher level of innovation activity in combination with institutional arrangements, such as the EU-ETS, should lead to new green solutions, technological development and industrial structures that are more environmentally friendly.

Finally, yet importantly, the positive changes in institutional quality represented by the rule of law and CPI are also inversely correlated to changes in CO_2 emissions. The higher a country stands on a rule of law ladder, the more it takes care about the environment, since the rule of law includes the institutionalization of property rights and rules on environmental protection. This is commensurate with the ordo-liberal idea and the Coaseian theorem that well-defined property rights and other institutional forms about resources, also including environmental commons, create incentives for their most appropriate use. For this incentive structure to work, there is the need to dampen the negative effects of institutional corruption. The combination of the rule of law index and the CPI that are not multicollinear, but commensurate, gives us the more complete picture.

6. Conclusions

The paper examines many factors that contribute to CO_2 emissions and estimates the coefficients with the ultimate objective of reducing environmental pollution. A total of 27 EU nations are included in the dataset, spanning the years from 2012 to 2019. This dataset necessitates the use of a dynamic panel inferential statistical approach due to the dataset's non-stationarities, heteroscedasticities and autoregression. The dynamic panel Generalized Method of Moments (GMM)'s two-step estimator has produced coefficients with the lowest standard errors and greatest stability. Following a detailed description of the factors that contribute to CO_2 emissions in the literature review, hypothesis testing and coefficient estimation modelling come next. According to the results, CO_2 emissions are negatively related to innovation, industrial structure and development, human capital and institutional framework. The results of the econometric model confirm the intuitively expected statistical relationships and may provide the EU and other policymakers with guidelines on the drivers of pollution reduction, while also confirming the fundamental idea that technology, industry and the economy should be developed in an environmentally friendly direction. The results of this study support the conjecture that technological development and lower CO_2 emissions are commensurable. The paper's most important theoretical contribution is a thorough study of the effects of several variables in tackling environmental pollution and providing us with new cognitions about the indicators, factors and determinants necessary for pollution reduction policies in the EU.

Reduced CO_2 emissions are a result of factors associated with the fourth industrial revolution, such as human capital, which powers each technical advancement and innovation activity. With these insights, this research adds to the theory and discourse around the consequences and advantages of the fourth industrial revolution, particularly in the area of its contribution to reducing climate change and attaining carbon neutrality. Particularly given that it measures CO_2 emissions, which, in comparison to NO_2 or SO_2 emissions, are, according to pertinent research, the most significant.

The results of the econometric model are commensurate with the literature review, providing important guidelines for policy makers, not only in the EU, but also in other regional and national economies. The fourth industrial revolution was a strategy to increase the European competitiveness and economic growth, but also to reach sustainable development goals and contribute to lower pollution levels. The results of our model may provide guidelines to the EU and other policy makers, since the results clearly point towards the variables that are statistically associated with pollution.

The EU industrial policy should be based on innovation and technology and a higher level of digitization and automation. Focus should be given to green innovations that contribute to pollution level reduction. The EU policy framework has to be focused on creating an innovation-enhancing environment that implies the necessity of investments in R&D by private and public sectors simultaneously.

One of the EU goals is to increase investments in R&D to 3% of GDP. To increase innovation activity, it is necessary to create macroeconomic environments that encourage business activity, including starting new domestic businesses, start-ups and FDI. Innovation activity and technological shifts are driven by high-quality human capital, especially in today's era of knowledge economy. Human capital determines the productivity of all other resources. The results of the model confirm the importance of human capital in pollution level reduction. It is highly important for EU policymakers to focus on creating and attracting quality human capital from different fields.

Creating high-quality human capital implies the necessity for investment, as well as educational system reforms that are adapted to the needs and requests of the job market in the 21st century. EU policy should continue with the integration between the business, scientific, education and public sector, and focus on their previously set goals to increase higher education levels including lifelong learning. Attracting foreign workforce is necessary, since the battle for high-quality workers is happening at a global level.

The results of the model confirm the importance of the institutional framework quality, where lower corruption and higher levels of the rule of law are commensurate with the reduction in the pollution level. The EU should continue strengthening its institutions that are on a supranational level, but should also encourage member states on strengthening institutions on their national, county or municipal level. Regulatory frameworks should encourage business activity, but should also focus on reducing pollution levels. This is why it is highly important to continue fighting corruption and strengthening the judicial system. To achieve these goals, it is necessary to continue with the cohesion policy that will reduce not only economic, but also technological, institutional and educational gaps between developed and less-developed member states.

This study has its limitations. Firstly, there is a relatively short time period of analysis of only 8 years. This is due to the fact that the fourth industrial revolution started only in 2011. Another limitation is the problem of missing variables. We tried to address this problem by focusing the study on the correlation between the technological advancement and human capital as drivers of the fourth industrial revolution, on the institutional framework encouraging technological shifts, pollution reduction and CO_2 emission levels.

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Abbreviations

CEE	Central and Eastern European
CH_4	Methane
CO_2	Carbon dioxide
EKC	Environmental Kuznets Curve
EU-ETS	European Union – Environmental Trading Scheme (System)
FD	First Differences
GMM	Generalized Method of Moments
HDI	Human Development Index
N_2O	Nitrous Oxide
ODA	Official Development Aid
PPM	parts per million
R&D	Research and development
ROI	Return on investments
WB	World Bank

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