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The role of Innovation on Economic Growth and Climate Change

Dissertation submitted

by

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Abstract

This study is investigating and contributing to the hypothesis of the relationship between economic growth and climate change, which the significance of both concepts being accepted by the Environmental Kuznets Curve hypothesis and going a step forward to examine the role of innovation, which as it had been stressed by Stern (2006) it is needed in order to reduce environmental degradation coming from economic activities as well as human activities. Even though there are only few studies that have examined the effects of innovation on climate change as it is stated, and this study is a contribution to that literature as well.

The results of this study came from the use of panel data quantitative analysis, including 76 countries from 1990 to 2019 using the method of Least Square Dummy Variable (LSDV) and controlling for cross sectional effects and time variant effects, borrowing the Environmental Kuznets curve methodology, are suggesting that the hypothesis of the literature that innovation reduces the environmental pollution is accepted. Additionally, the hypothesis of EKC has been accepted in the study, as the results show that economic growth has an inverted U-shaped relationship with climate change.

Keywords: Environmental Innovation, Environmental Pollution, Environmental Kuznets Curve (EKC) Hypothesis, Quantitative analysis, Panel data regression analysis.

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Summary

The initial influence of this study came from the importance of the three factors that have been analyzed, having on one side the factor of economic growth which as it has been stated by Mokyr (2005) it was a concept that have raised awareness centuries back, and leading to the creation of many theories and coming to the more recent ones, the neoclassical theories of economic growth. On the other side the significance of environmental condition and quality have raised awareness in the 20th century as it is state by , which led many researchers to examine the relationship between these two phenomena, leading to the creation of the Environmental Kuznets Curve hypothesis. And based on the significance of the relationship of economic growth and climate change as it been described by the hypothesis of EKC which examines the relationship between economic growth and environmental degradation and climate change, this study is a contribution to the literature of Environmental Kuznets Curve Hypothesis, where its origins go back to the 1990s.

The first studies that have examined this relationship conducted by Grossman and Krueger (1991), World Development Report (1992) and Panayiotou (1992) and the hypothesis is that there is an inverted U-shaped curve between economic growth and environmental degradation. The first studies mentioned above, have found that the relationship that the relationship that exist between these two phenomena, accepts the hypothesis of EKC, and from then on, they have launched a new methodology and hypothesis for the examination of environmental degradation in regards to economic growth. By following the same steps, using a panel data quantitative analysis for 76 country and annually observed from 1990 to 2019, using the method of Least Square Dummy Variable controlling for country effects and time variant effects, borrowing the EKC methodology, this study has examined this relationship and as it is shown by

`the results, it is consistent with the results that the researchers that are mentioned in the chapter of the literature review have found.

Going a step forward, this study examines the effects of innovation in the literature of economic growth and climate change, influenced by its significant role in the economic activity and quality of life in general. As it is stated by Rubinstein, innovation is the process whereby new and improved products, processes, material, and services are developed and transferred to a plant and/or market where they are appropriate and based on what Nicolas Stern stressed, that innovation is needed for the reduction of environmental degradation and face the climate change phenomenon. Thus, it can be understood that it is important to examine its effects on climate change phenomenon having in mind the hypothesis of Environmental Kuznets Curve and by using this methodology and the quantitative analysis mentioned above, the results are indicating that innovation can reduce the environmental pollution and climate change.

Although the role of innovation seems important to be examined in the relationship of economic growth and climate change the availability of studies in this topic are limited as it is stated in the literature by Fethi and Rahuma (2018) and Mohd Saudi et al (2018). Nevertheless, the results from the quantitative analysis it is consistent with those of the studies in the literature and going a step forward and following the same steps as EKC did with economic growth and climate change relationship, the results suggest that there is a U-shaped relationship between innovation and climate change.

As Panayiotou (1992) did, providing recommendations regarding the policy makers and countries to avoid or reduce the negative consequences of the economic growth on environment, the same it is done in the discussion part of this study making recommendations on the management of innovation and knowledge to get the most out of it in order to reduce the negative consequences of environmental pollution and climate change.

1. Introduction

This study examines the relationship between economic growth and climate change, as well as the role of innovation, regarding the phenomenon of climate change. The concept of economic growth and development has been examined and its significance was accepted centuries back, from the era of Adam Smith coming to the 20th century where great growth theories such as the Sollow – Swan (1956) and Ramsey (1965) have arisen. On the other hand, the phenomenon of climate change hasn't raised awareness since its discovery in 1951, and its cause can be described by V. Ramanathan and Y. Feng (2009), stating that environmental pollution that leads to environmental degradation is causing increased warming of the surface leading to climate change phenomenon.

Despite the significance of both concepts, the first studies examining their relationship were conducted in the 1990s by Grossman and Krueger (1991), World Development Report (1992) and Panayiotou (1992) , introducing the Environmental Kuznets methodology and hypothesis, which indicates that there is an inverted U-shaped relationship between economic growth and environmental degradation. And in Stern's study, there is a figure illustrating the relationship of these phenomena, indicating that there is a vicious cycle, while positive economic growth leads to environmental pollution and then environmental pollution leads to limited economic growth.

Going to the concept of innovation, the concept of Sollow – Swan (1956) and Ramsey's (1965) both can give insight of the role of technical change on economic growth, but more focused theories have arisen on the relationship between economic growth and innovation, one of which, is the Romer (1990). An example of the importance of innovation has been given with the statement of Rubinstein that "Innovation is the process whereby new and improved products, processes, material, and services are developed and transferred to a plant and/or market where they are appropriate", and even though innovation is perceived as important and Nicolas Stern stressed out that innovation is needed to reduce the negative consequences on the environment, given that the main sources of environmental degradation and greenhouse emissions are coming from the economic and human activities, there are limited studies that are focused on the effects of it on economic growth - climate change relationship as it is mentioned in the literature.

Thus the importance of this topic has driven this study to conduct a research, using a panel data analysis, for 76 countries and for 29 years annually observed from 1990 to 2019 deriving results following the Environmental Kuznets methodology because it is used to explain the relationship between economic growth and climate change as it is shown in the literature, as well as explaining the effects of innovation when a variable of it is added to the model. The empirical analysis follows the Least Squared Dummy Variable method, controlling for country effects as well as time effects, as it is shown in the study that it is more suited in this case using various comparisons between regression methods and tests indicating the process that should be followed. Nevertheless, the results indicated that there is an inverted U-shaped curve for economic growth and climate change, thus in this study the hypothesis of EKC is accepted, but more importantly, is indicated that innovation reduces the environmental pollution, by decreasing the emissions per capita of Carbon Dioxide (CO_2), ceteris paribus, thus the phenomenon of climate change is reducing when innovation is increasing.

Following the same steps as EKC with income per capita and its exponential variable, and going a step forward regarding the available literature, an additional test was conducted, by using the exponential variable of innovation, to examine whether innovation leads to reduction of environmental pollution only, or it is exhibiting a curved shaped relationship. Surprisingly, the results from the empirical analysis of this study, show that innovation and environmental pollution have a U-shaped curve, thus innovation is decreasing emissions per capita of CO2, up to a point, where then it starts to increase the pollution. So, the results suggest that environmental related innovation does decrease the phenomenon of climate change but up to a point, where then it starts positively contributing to.

An important note that should be made here, is that for the indicator innovation, the variable of environmental related patents have been used, which as it is mentioned in the handbook of Economics of Innovation (Ch.8) (2010), M.P. Feldman and D.F. Kogle , it is not a very good proxy, and can lead to misleading results when making inferences and that the studies such as this should be careful when doing so.

Having in mind the note made in the paragraph above, and based on the results of the empirical analysis, this study has made suggestions to countries and policy makers regarding the environmental pollution and climate change reduction methods, influenced by Panayiotou (1992) study that did the same. Those suggestions are focused on how to utilize the knowledge management to deliver better results regarding the climate change phenomenon, as well as the policies that will be implemented by countries to give incentives to organizations that are innovative and leading them to cooperate with others that lack the ability to contribute to the solution of this phenomenon.

2. Literature Review

2.1 Economic Growth – Climate change Literature

The significance of economic growth has been examined and accepted centuries back, as it is stated the concept of economic growth by Mokyr (2005) was not a novelty 1800's where the industrial revolution and enlightenment began, but it is going back to Adam Smith's findings where he was examining the production of land and labour in Britain. The theory of economic growth, has led many important economists to contribute to the examination of this phenomenon, coming up to the point where the growth theory has come to two main stages, the first stage originated with the Sollow – Swan model in 1956, and the second stage emerging in 1980's.

The importance of climate change phenomenon has raised awareness in more recent years, and the discovery of its effects are originated back to 1951 where British hydrologist H.E. Hurst was examining the presence of cycles over a multitude of scales as it is mentioned by Bloschl and Montanari (2009). The explanation of this issue regarding its origins, is described by World Development Report (1992), mentioning that, climate change is caused by the build-up of carbon dioxide and other greenhouse gases can lead to increased climate temperatures, and by V. Ramanathan and Y. Feng 2009, stating that, the environmental degradation from air pollutants comes from increased warming of the surface and the atmosphere as well as an increase in the tropospheric ozone, which leads to climate change as well as other phenomena such as ice melting, rising sea levels etc.

Having knowledge on the causes that lead to climate change, led to further investigation and in later years the effects of this phenomenon on environment were examined, especially when awareness was raised on the development led to further discoveries regarding the problems that will be occurred and the irreversibility of the environmental damage that will limit the quality of future generations (WDR 1992).

The jointly examination of the relationship between economic growth and climate change has begun in the 70s, raising awareness since then, because as it is stated above, both phenomena are important to the quality of human life, On one hand the economic development and growth is improving the well-being of people, but can also lead to damages to the environment such as water pollution, water scarcity, deforestation, air pollution from greenhouse gases and on the other hand climate change that comes from environmental degradation-pollution from greenhouse gases, The outcomes of which can have serious consequences on people's health, productivity and amenity, harming the well-being of future generations World Development Report (1992). This relationship can be described by Lin and Zhu (2018), mentioning that the use of fossil fuels to generate energy that it is use for manufacturing, transportation and for the economic activity in general, and in Stern's (2006) study a figure used to show the impact of human activity on the environment, leading to environmental pollution. The graph indicates that, the pollution to the environment due to greenhouse gas emissions, will eventually lead to climate change and clearly stating that economic growth and climate change are highly inter-related. Thus, these effects can be described as a two-way relationship between those concepts, where economic growth can lead to environmental degradation by pollution, eventually leading to the climate change phenomenon, where then the future generations will have lower quality of life, as well as limited economic activity and limited economic growth, thus it is a vicious circle.

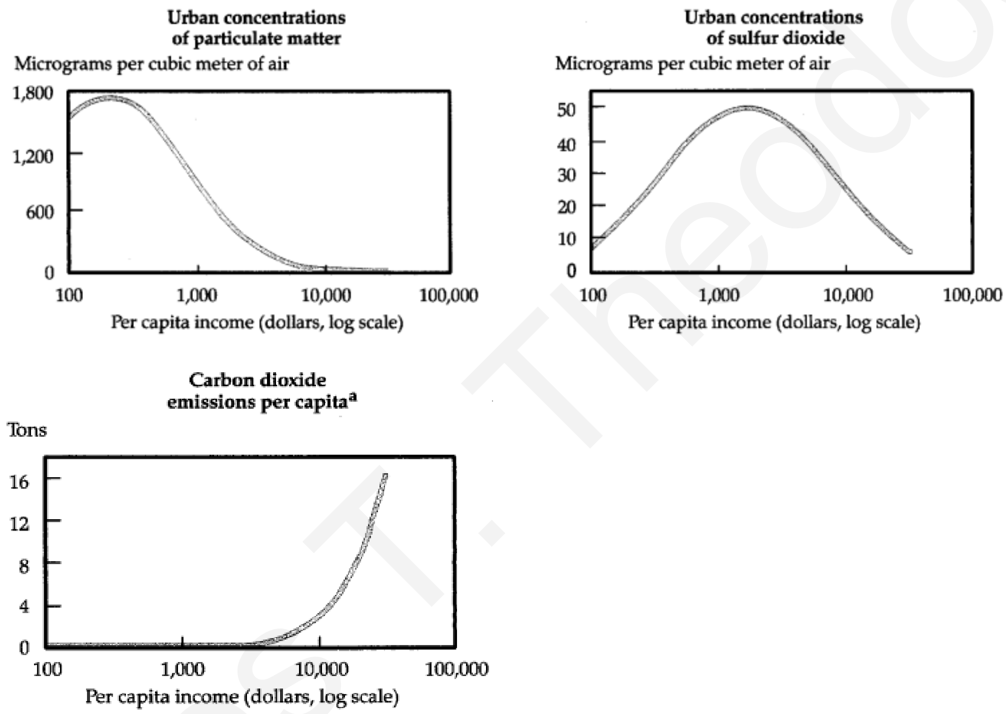
Since the awareness of the relationship between economic growth and climate change many scientists and economists have contributed to the examination of the outcomes, as of today, there has been a lot of improvement in the available literature regarding the relationship between economic growth and climate change, a relationship that has been researched for nearly 50 years, but the most tested methodology delivering results on these effects is the Environmental Kuznets Curve hypothesis, M. Bhattacharya (2019). The origins of the hypothesis of which are unclear, but nevertheless there were three studies that firstly introduced the hypothesis, one study was conducted by Grossman and Krueger (1991), the other by World Development (1992) and by Panayiotou (1993), using the methodology of the original Kuznets Curve on income inequality. (Simon Kuznets, 1955).

Starting with one of the first studies, the study of Grossman and Krueger (1991), which empirically investigates the relationship between economic growth and environmental pollution by using the available literature at the time, as well as borrowing the Kuznets Curve Methodology (1955), and eventually introducing the methodology of Environmental Kuznets Curve. The study was focused on the environmental impacts of NAFTA agreement, using panel data set, with the dependent variable being sulfur dioxide (SO2) emissions and independent variables GDP per capita as well as dummy variables controlling for cross sectional effects.

Their findings suggest that there is an inverted U-shaped relationship between income per capita and environmental pollution, thus when GDP per capita increases leads to increase in the amount of air pollutants, thus increasing environmental degradation, up to a point of a value of GDP per capita where the environmental pollution from greenhouse gases it reaches the highest point and then it starts improving-reducing while the income per capita increases, where the curve shapes down.

Additional research that was done at the earliest stages of this topic, was done by Panayiotou (1992), with the initial purpose of his study as he mentions is to empirically test the hypothesis of the inverted U-shaped curve, as well as explaining the reasons that the curve has this shape. His empirical analysis used cross-section data, focusing on 50 developing and developed countries, using three models for which the dependent variable is a different variable for emissions per capita of air pollutants (SO2 , NOx, SPM), and for independent variables income per capita and squared income per capita. The results of his analysis indicate that there is an inverted U-shaped relationship between economic growth and environmental degradation, and as it is mentioned in the study, the shape of the curve between income per capita and environmental pollution is analogous to the already existing at the time relationship between inequality and growth that the results of Simon Kuznets and the Kuznets Curve. The explanation given in the study regarding the shape of the EKC, is that at low levels of development the environmental degradation is caused by the impacts of resources used for the economic activity and the limited quantities of wastes produced, and when the economic development increases more resources are used in order to maintain the economic activity and industrialization starting to grow leading to generating more pollutants. When economic growth reaches higher levels of development, awareness is raised regarding the environmental condition, thus measures are taken to improve the quality of the environment. By going a step forward, Panayiotou (1992) concludes that developing countries should take consideration of the relationship that is described by EKC and take measures that help to limit the negative effects of increasing economic development on environment.

Among the first studies on the economic growth and environmental degradation-climate change relationship is the World Development Report (1992), pointing out that countries with lack of economic development are facing environmental quality issues such as water sanitation, air pollution from the usage of biomass burning and land degradation and that there are significant negative consequences on the environmental quality that come from economic growth as well. Those consequences are closely related to the economic expansion of the country due to industrial and energy related pollution, deforestation, and overuse of water. This study mainly focuses on the illustration of the relationship that exists between income per capita and air pollutants, as well as other environmental degrading factors, by using figures shown below.



As it is mentioned in the study, on the section that discusses the relationship between economic growth and environment, indicators of environmental stress are getting worse when the income per capita increases, and in case of air pollutants while growth keeps increasing the pollution is starting to decrease, and the responsibility of this decrease is the implementation of policies that improve environmental quality.

In D.H. Eakin and T.M. Selden (1995) the relationship between economic growth and CO_2 emissions per capita is empirically tested using a panel data set and follows the EKC methodology, with dependent variable the emissions per capita of carbon dioxide (CO_2) and independent variables GDP per capita and exponential GDP per capita, also controlling for country effects and year effects. The results of their analysis follow the hypothesis of EKC, finding that emissions initially rise while per capita GDP increases and eventually are falling having an inverted U-shaped curve. Going a step forward, they used the forecasting method, to examine the marginal propensity to emit in regards to the economic growth, finding that the existence of positive economic growth leads to diminishing marginal propensity to emit. Despite these results the other tests that they conducted indicated that CO_2 emissions will keep growing, the source of that being the middle- and lower-income countries.

The studies that examined the relationship between economic growth and environmental pollution, using the methodology of EKC, have accepted the hypothesis that there is an inverted U shaped relationship between income per capita and emissions of air pollutants, while some of the authors going a step forward are pointing out that developing countries are mainly the cause that environmental pollution is kept increasing, see Panayiotou (1992) D.H. Eakin and T.M. Selden (1995), and as it is mentioned in Panayiotou (1992) those countries should be more eager to implement policies to reduce the effects of economic growth to environmental pollution.

2.2 Role of Innovation

As it is mentioned above, economic, and human activities are posing a threat to environmental quality, as N. Stern (2006) in his study presents, the main sources of greenhouse gas emissions are coming from agriculture, energy, land use changes, transportation as well as industrial, these effects will eventually lead future generations to have lower quality of life, such as water pollution, water scarcity, air pollution and the phenomenon of climate change that will eventually limit the productivity, WDR (1992) and thus economic growth will face major setbacks.

Romer (1990) has initiated one of the innovation-growth based theories which in this case innovation causes productivity growth by creating new, but not necessarily improved, varieties of products. Also, there is another version of this relationship which is called Schumpeterian theory developed by Aghion and Howitt (1992) and Grossman and Helpman (1991) focuses on quality-improving innovations that render old products obsolete, through the process of “creative destruction” P. Howitt (2010), which is the process where new innovative products replace old. And as for the importance of innovation, a good reference is what Rubinstein have stated, that Innovation is the process whereby new and improved products, processes, material, and services are developed and transferred to a plant and/or market where they are appropriate and Stern (2006) stressed out that innovation is needed to reduce the negative consequences on the environment, given that the main sources of environmental degradation and greenhouse emissions are coming from the economic and human activities.

Given the statement of Nicholas Stern, we can understand that this topic seems important and investigation of the relationship between innovation and climate change is needed. Despite the significance of the role that innovation might have on the climate change phenomenon that is caused by economic activities and human activities that both can be better off when innovation is present, Fethi and Rahuma (2018) and Mohd Saudi et al. (2018) on their studies have stated that, at that time were they have conducted their research, there were few studies that examined the impact of eco-innovation on climate change thus it hasn’t raised that much of attention in comparison to the topic of economic growth, energy consumption impacts on climate change.

Of course, for innovation in the field of environmental quality improvements must be accompanied by complimentary improvements that will positively impact its effects, as it is mentioned in the handbook of economics of innovation (2010) (Ch.2) by J. Mokyr (2005) and quoted, "Improvements in technological capabilities will only improve economic performance if and when they are accompanied by complementary changes in institutions, governance, and ideology". Also equally important is the management of innovation, because an industry's evolution starts with new product ideas establishing market positions and then the dominant design emerges by then the process innovation must take place as it is referred by W.M. Cohen (Ch.4) in Handbook of Economics of Innovation, thus it is equally important to focus on the products relevant to economic activity that negatively affect environmental quality to innovate as well as the process that are used regarding the activity to be innovative.

Starting with the Fethi and Rahuma (2018) a study that is empirically investigating the role of innovation in economic growth and climate change relationship, and as it is mentioned in the study there are limited studies that are focused on this topic. For the analysis, the study is using panel data, and it uses the EKC methodology, adding to the model as an independent variable eco-innovation, using data for R&D spending on carbon emissions, as well as the income per capita and squared income per capita and controlling variables, and for dependent variable of the CO_2 emissions are used. Their results suggest that there is an inverted U-shaped relationship between income per capita and environmental pollution, contributing to the EKC hypothesis by confirming its existence and confirming the available literature on economic growth relationship between climate change and their results indicate that eco-innovation reduces the carbon dioxide emissions, ceteris paribus, as well.

The study of Mohd Saudi et al. (2018) is focusing on the impact of renewable energy, non-renewable energy and technology innovation on CO_2 emissions, and uses annual data for Malaysia. Their methodology follows the methodology of EKC and hypothesis, trying to examine the existence of that hypothesis. The model has as a dependent variable the CO_2 emissions and for independent variables, indicator of economic growth which is income per capita and squared income per capita, as well as a variable of innovation and renewable energy usage. Their results indicating that technology innovations indeed reduce the CO_2 emissions and support the hypothesis of EKC, that an inverted U-shaped relationship exists between economic growth and environmental pollution.

Another study that focuses on the role of innovation in technology on renewable energy on CO_2 emissions, is that of Lin and Zhu (2018), using again the EKC model and methodology, with data on China. They have also stated on their study that this topic hasn't been given much of attention by researchers, and that the current literature available at the time was the research focused on the role of economic growth on CO_2 emissions ignoring the role of renewable energy technological innovation. Given that, their research adds to the literature of innovation's role on CO_2 emissions, providing empirical research using panel data analysis for China and other countries, using panel regression analysis, having as a dependent variable the emissions of CO_2 and for independent variables the income per capita and income per capita squared, as well as environmental related patents, and controlling variables. Their results conclude that there is a significant and negative effect of innovation on CO_2 emissions, meaning that innovation can reduce the environmental pollution when it is increased, and adding that it would be beneficial for the societies to have innovative methods in energy usage on the environment and climate.

The literature on the role of innovation on climate change and specifically on Environmental Kuznets methodology and hypothesis, suggest that it is important to examine that role of innovation in the field of environmental economics and despite that, the available literature is limited, based on Lin and Zhu (2018) Mohd Saudi et al. (2018). Even though it is limited, the available literature suggests that the same effects are present when examining the relationship between economic growth and environmental degradation, that is, the hypothesis of EKC that there is an inverted U shaped relationship between income per capita and environmental degradation is accepted, but provide insights on the effects of innovation to environmental pollution as well, that is, innovation can reduce the emissions of pollutants, thus can reduce the effects of the climate change phenomenon. Thus, based on the findings available on the literature, and the methodology, the analysis in this paper will follow the same footsteps as the previous researchers did, utilizing the Environmental Kuznets methodology, and examining the hypothesis of inverted U-shaped relationship between economic growth and climate change as well as providing insights to the role of innovation regarding that relationship.

3. Theoretical and Operational background

When discussing and examining the concept of economic growth, there are several theories that come to mind, this is due to its significant role in the quality of life for people, and thus the examination of its origins and effects is extensive going back to Adam Smith's era Mokyr (2005), and leading to the more complete theories such as the neoclassical growth theories provided by Sollow – Swan (1956), examining the role of technology as well, where it is assumed to be exogenous and later years where technology is assumed to be endogenous to the concept of economic growth, such as the Ramsey models A. Xepapadeas (2005).Based on this, as Mokyr (2005) mentioned, the progress of technology has been explained by both concepts of the growth theories, the internalist such as Sollow – Swan (1956) which perceive innovation autonomous, and externalist as driven by economic needs. Also, more focused theories on innovation-growth were derived from Romer (1990) and the Schumpeterian Theory (1991) describing the process that innovation can affect economic growth.

Even though there was an evolution to the economic growth theory, as well as innovation-economic growth theories as it is shown above, it is assumed that by neglecting the environmental pollution effects, those theories can be observed as biased (William Brock, 1973) A. Xepapadeas (2005) and according to Paul Romer (1994) there are five basic factors that economic growth theorists are taking for granted and A. Xepapadeas (2005) adds another factor to that, which is the environmental quality stating that individuals are positively valuing this aspect. This can be confirmed by Panayiotou (1992) which focuses on the relationship between economic growth and environmental pollution, finding that there is an inverted U-shaped relationship and explaining that, when economic growth reaches higher levels of development, awareness is raised regarding the environmental condition, thus measures are taken to improve the quality of the environment.

As it is mentioned above, there is extensive studies on economic growth and that many theories have been derived, the effects on environmental pollution and climate change haven't been included, since the arrival of Environmental Kuznets hypothesis, and as it is mention by Fethi and Rahuma (2018) and Mohd Saudi et al. (2018), that even though the relationship of economic growth and environmental degradation raised awareness and the hypothesis of EKC has been delivered, the effects of innovation haven't been included in , despite its significant role in the growth theory and not only. Nevertheless, studies that have examined the hypothesis of economic growth and climate change with the role of innovation have followed the methodology of Environmental Kuznets Curve, thus this analysis is following the same footsteps, and the theoretical and operational framework that we follow for is the Environmental Kuznets Curve (EKC) that was derived from the original Kuznets Curve, addressing the income inequality, delivered by Simon Kuznets (1954). The nobel awarded theory of Simon Kuznets suggests that there is an inverted U relationship between income per capita and income inequality, and following the same theoretical background, the studies of Grossman and Krueger (1991), Panayiotou (1993), World Development Report (1992), have given insights to the effects of economic growth to environmental pollution delivering the EKC theory and empirical analysis.

The methodology of Environmental Kuznets Curve is created by using as a dependent variable an indicator of the environmental degradation coming from air pollution of SO2 emissions, see Grossman and Krueger (1991), World Development Report (1992), Panayiotou (1993), NOx emissions (World Development Report (1992), Panayiotou (1993)), as well as SPM emissions (Panayiotou (1993)).Later studies have used CO2 emissions as an indicator of environmental pollution and following the methodology of Environmental Kuznets Curve, they have used that indicator as a dependent variable (D.H.Eakin and Selden (1995), Cole (2004), Martínez-Zarzoso and Morancho (2004)). The selection of the dependent variable being air pollutants came from the logic that those pollutants increase environmental stress leading to increased warming of the surface and the atmosphere as well as an increase in the tropospheric ozone, which leads to climate change as it is described by V. Ramanathan and Y. Feng (2009).

Because we are examining the relationship between economic growth and climate change, an outcome of environmental pollution, in the model must be included the indicator of economic growth which is interpreted by income per capita. The widely used indicator for income per capita in the EKC analysis is the GDP per capita, firstly used by Grossman and Krueger (1991) and then many studies have been influenced by, and in case of Panayiotou (1993) the GNP per capita is used, influencing other studies such as the study of Cole (2004).

The original methodology of Simon Kuznets on his analysis of income inequality, the exponential income per capita is used as well, thus in the methodology of Environmental Kuznets Curve it is also used and can be showed in the earliest studies of Grossman and Krueger (1991), World Development Report (1992), Panayiotou (1993). Because it was used in the empirical analysis of the first studies that have focused on the relationship between economic growth and environmental pollution, and they are these studies that have introduced the EKC model, now it is a part of the methodology.

EKC model in general form:

1. $ED_{i,t} = \alpha_0 + \beta_1 Y_{i,t} + \beta_2 Y_{i,t}^2 + \varepsilon_{i,t}$

2. $lnED_{i,t} = \alpha_0 + \beta_1 lnY_{i,t} + \beta_2 lnY_{i,t}^2 + \varepsilon_{i,t}$

The model (1) above indicates the first model that Grossman and Krueger(1991), Panayiotou(1993) and World Development Report (1992) have used in their studies to measure the effects of income per capita to environmental degradation. As the model shows, the dependent variable is the indicator of environmental degradation($ED_{i,t}$), which they have used data of greenhouse gases, and the independent variables is income per capita ($Y_{i,t}$) and exponential income per capita ($Y_{i,t}^2$), using data of GDP per capita (Grossman and Krueger (1991) and World Development Report (1992)) and GNP per capita (Panayiotou (1993)). Additionally, they have used the EKC model as a log-log model because it deals with nonlinear relationship between the variables.

The theoretical analysis of the EKC hypothesis suggests that there is an inverted U relationship between economic growth and environmental degradation, meaning that an increase in income per capita leads to an increase in environmental degradation, up to a point, and then followed by a decrease of environmental degradation income per capita continues to increase.

In a more explanatory form, by taking the derivatives of equation (1) must be:

1. $\frac{dy}{dx} = \beta_1 + 2\,\beta_2\, x > 0$

2. $\frac{d_2 y}{dx_2} = 2\,\beta_2 < 0$

3. $\frac{dy}{dx} = 0,\ x = -\frac{\beta_1}{2\,\beta_2}$

Where:

$y = environmental\ degradation$

$x = income\ per\ capita$

$\beta_i = coefficients$

By following the results of the derivatives above (1,2) the curve is going to be inverted U shaped, showing that at first there is a positive relationship between economic growth and environmental degradation coming to the highest point given by (3), where then the relationship becomes negative.

Except from the relationship of economic growth and climate change, this study is going a step forward by trying to examine the effects of innovation on this topic as well. Similar studies on this topic have added to the EKC model not only a variable of innovation but of energy consumption as well (Fethi and Rahuma (2018), Mohd Saudi et al (2018) Lin and Zhu (2019)). And in the case of the indicator of innovation to determine its effects on environmental pollution, having in mind that innovation is difficult to measure, there is a variety of options but most of the studies are using the indicators of R&D and patents. Both indicators of innovation have added to the Environmental Kuznets Curve model and in case of R&D as an indicator of innovation, was used by the authors already mentioned.

The model below is the models that have been used in the studies that examine the effects of innovation on environmental degradation, which adds an independent variable of innovation $(INN_{i,t})$ to the EKC model and a variable of energy consumption $(EC_{i,t})$. In the literature have been used two kinds of indicators of innovation, the environmental related R&D spending see, Mohd Saudi et al. (2018) and Fethi and Rahuma (2018)) and environmental related patents, see Lin and Zhu (2018)). In the same sense as before, they have used the EKC model as a log-log model, dealing with nonlinear relationship between the dependent and independent variables.

1. $ED_{i,t} = \alpha_0 + \beta_1 Y_{i,t} + \beta_2 Y_{i,t}^2 + \beta_3 EC_{i,t} + \beta_4 INN_{i,t} + \varepsilon_{i,t}$

2. $lnED_{i,t} = \alpha_0 + \beta_1 lnY_{i,t} + \beta_2 lnY_{i,t}^2 + \beta_3 lnEC_{i,t} + \beta_4 lnINN_{i,t} + \varepsilon_{i,t}$

Despite that there is limited studies available in the literature that examine the influence of innovation on environmental degradation using the empirical methodology of Environmental Kuznets Curve, as it is mentioned by Mohd Saudi et al (2018) and Fethi and Rahuma (2018) the theoretical analysis of the literature suggests that when the environmental related innovation increases, it reduces the environmental pollution, and thus the phenomenon of climate change, keeping all others constant.

In a more explanatory form, by taking the derivatives of equation (1) must be:

1. $\frac{dy}{dx} = \beta_4 < 0$

Where:

$y = environmental\ degradation$

$x = innovation$

$\beta_4 = coefficient$

By following the results of the derivatives above (1) the relationship of innovation with environmental pollution should be negative, thus when environmental related innovation increases, the environmental pollution decreases, ceteris paribus.

Based on the available literature on the topic of investigating the effects of innovation on environmental degradation, influenced by the researchers mentioned above, it has been chosen to follow the empirical methodology of Environmental Kuznets Curve, examining the hypothesis of the relationship between economic growth and climate change as well as adding an indicator of innovation to the EKC model to examine its effects.

4. Empirical and analytical methodology

4.1 Model specifications

As it is mentioned in the previous part, the model that will be used for our methodology under econometric approach to get our results for the research and help us make our conclusions, is the Environmental Kuznets model.

The model's specifications are, the dependent variable that is indicating the environmental degradation that eventually leads to climate change, independent variables indicating economic growth which are income per capita and exponential income per capita, as well as independent variable indicating innovation and other independent variables for controlling purposes as it is commonly used in the available literature on this specific topic.

The model:

1) $$CO_{2_{i,t}} = \alpha_0 + \beta_1 GDP_{i,t} + \beta_2 GDP_{i,t}^2 + \beta_3 EC_{i,t} + \beta_4 POP_{i,t} + \beta_5 ENVPAT_{i,t} + C_i + Y_t + \varepsilon_{i,t}$$

2) $$lnCO_{2_{i,t}} = \alpha_0 + \beta_1 lnGDP_{i,t} + \beta_2 lnGDP_{i,t}^2 + \beta_3 lnEC_{i,t} + \beta_4 POP_{i,t} + \beta_5 ENVPAT_{i,t} + C_i + Y_t + \varepsilon_{i,t}$$

3) $$CO_{2_{i,t}} = \alpha_0 + \beta_1 GDP_{i,t} + \beta_2 GDP_{i,t}^2 + \beta_3 EC_{i,t} + \beta_4 POP_{i,t} + \beta_5 ENVPAT_{i,t} + \beta_5 ENVPAT_{i,t}{}^2 + C_i + Y_t + \varepsilon_{i,t}$$

Where:

$CO_{2_{i,t}}$= *Carbon Dioxide emissions per capita*

$GDP_{i,t}$ = *Income per capita*

$EC_{i,t}$ = *Energy consumption per capita*

$POP_{i,t}$ = *Population*

$ENVPAT_{i,t}$ = *Environmental Related Patents*

C_i = *Country individual characteristics*

Y_t = *Time effects*

$i = 1, 2, \dots 76$, *Countries denoted by number*

t = *1990, 1991, … 2019 , Years observed*

4.2 Data Sample

The data set we use for our methodology to deliver the results for our approach contains observations of multiple countries for multiple time periods (cross sectional and time series), thus it is panel data. In detail, there are data of 76 countries both OECD members and non-OECD that were selected, for time the time-period of year 1990 to 2019, annually observed. (see section (4.3.3) table (1))

4.2.1 Dependent Variable ($CO_{2_{i,t}}$)

The data that are used for the dependent variable, are data for CO_2 emissions per capita, as it is described by Manabe and Wetherald (1979), it is a factor that is closely related to climate change, and the data are obtained by obtained by a data set from GitHub, which is a researchers' site uploading compiled lists of data sets gathered from different data sources. Specifically, the data set that is used for the dependent variable, as it is referred in the description of the site, was compiled from data sources of Statistical review of world energy (BP), International energy data (EIA), Our World in Data.

Initially the data set contained observations of 247 countries , islands, and regional integrated organizations of countries for over 60 years, annually observed, but the reason that the data set was restricted to 76 countries and 29 years was the inconsistency of available observations either in the data set of CO_2 emissions or the data sets used for the other variables.

4.2.2 Independent variables

1. Income per capita (GDP per capita)

The data set for GDP per capita was obtained from United Nation's statistical division of the Department of Economics and Social Affairs, having observations for more than 240 countries , islands, and regional integrated organizations of countries and annually for 50 years.

As before the data set was restricted to, having observations for the same countries and years, due to inconsistencies between data sets and missing observations making our panel data set being unbalanced.

2. Exponential income per capita (GDP per capita squared)

The data set is the same that was used for GDP per capita, obtained from United Nation's statistical division of the Department of Economics and Social Affairs, restricted to the same size as before.

3. Environmental Innovation (ENVPAT)

As it is mentioned in the previous chapters of this study, innovation is difficult to measure, and there are different methods that researchers are using to measure innovation. Nevertheless, in this case a data set of environmental related patents per capita has been used, obtained by OECD statistics department for green growth indicators. In the data set was observations of 111 countries, regional integration organizations of countries, and islands, annually for the time – period of year 1977 – 2020. The data set was limited to the same 76 countries as the previous data sets and for the same period, 1990-2019.

4. Energy Consumption (EC)

For this variable, a data set of primary energy consumption per capita was used and it was obtained from Our World in Data having nearly the same number of countries that the other data sets have, but again it has been restricted to 76 countries. The data set for energy consumption has annual data from 1980 to 2019, and as before it has been restricted to number of years from 1990 to 2019, for the same reasons.

5. Population (POP)

The dataset for the variable of population, is the same as the one that has been used for the dependent variable (CO_2), that has been obtained by a researchers' site, GitHub ,with compiled lists of datasets. In this case of population variable, they have gathered data from Our World in Data.

4.3 Empirical Analysis:

Starting with the empirical analysis which follows quantitative analysis, the first step was to declare the data set to be panel data. At first, we had an unbalanced panel data set, that is why it has been decided to restrict the data set to T=29 and N=76 eventually made it to be strongly balanced, thus we can have more accurate results and our inferences made easier.

Since the study is focused on the relationship between economic growth and climate change as well as the examination of the role of innovation, it has been decided that it needs to follow statistical analysis by doing regression analysis and since the data set is a panel data the study excludes the time series regressions.

4.3.1 Diagnostic Tests for the regression model

1. Multicollinearity Test

To determine the final form of the population model, that will be used for the empirical analysis, a correlation test between the variables was used, and the results can be shown on the table (2) as well as the Variance Inflation Factor (VIF) test, table (3) in order to avoid multicollinearity, a phenomenon that occurs when an explanatory variable is strongly related to a linear combination of the other independent variables and if it doesn't taken care of can inflate regression coefficients and make the estimations unreliable (Ronald N. Forthofer, Eun Sul Lee and Mike Hernandez).

2. Heteroskedasticity and Autocorrelation

To examine whether the regression model suffers from heteroskedasticity, a phenomenon where the variance of the residuals is not constant across the range of measured values, and there is relationship between the variables with the residuals which can cause the standard errors of the regression to be inflated. Therefore, the White Test was used where the null hypothesis is that there is no relationship between the variables with the error term and the alternative hypothesis is that there is relationship, and the results can be shown in the section (5.1.2) table (4). Also, the Breusch-Pagan / Cook-Weisberg test was conducted, with the null hypothesis that the error variances are all equal versus the alternative that the error variances are a multiplicative function of one or more variables R.Williams (2020), table (4). An additional test for heteroskedasticity is the Modified Wald test for groupwise heteroskedasticity in fixed effect regression model, where it has null hypothesis of homoskedasticity and the alternative hypothesis that it does not follow homoskedasticity. Table(4) .

For autocorrelation or serial correlation, which is the case where there is correlation of a series or a variable with its own lagged values, can lead to incorrect inferences of the results of the regression even though the estimated coefficients are correct the standard errors are not (Ján Palguta,2016). Thus, to examine the presence of serial correlation the Lagram – Multiplier Test (Wooldridge test) was used, having as the null hypothesis of no serial correlation and for the alternative hypothesis that there is first order serial correlation. The results of the test are shown in the section (5.1.3) table (4).

Based on the results of the heteroskedasticity tests and autocorrelation test, the regression analysis should follow either the robust standard errors method if there are presence of heteroskedasticity and autocorrelation, or not if there is no presence of those phenomena.

4.3.2 Regression Models

Starting with the first method of the regression analysis, the Pooled OLS method, that is the most restrictive model in regards to the other options in panel data analysis, because it does not take into account any time variant or cross sectional effects, comparing it with help of Wald test, with the second method which is the Least Squared Dummy Variable (LSDV1), which refers to the method of derivation using explicit dummy variables (Steve Pudney) and in this case a cross sectional dummy variable was added, and the third method Least Squared Dummy Variable (LSDV2) a time variant dummy variable was added.

Additionally, the two methods of LSDV cannot be compared due to the lack of basis of variant effects of the dummy variables. The results of the comparison are shown in the appendix (8.2) and table (13) , indicating that the LSDV1 is more preferable.

After comparing the three methods above (Pooled OLS, LSDV1, LSDV2), two more regressions were ran, the Fixed-Effects (FE), which takes into account the individual time-invariant characteristics of the panel model that might impact or bias the predictor or outcome variables, thus this method controls for those effects by removing them (Oscar Torres-Reyna), in order to avoid biasedness of the estimated coefficients of the fixed-effects due to omitted time-invariant characteristic (Kohler, Ulrich, Frauke Kreuter), thus taking into account cross sectional effects coming from individual characteristics of countries, and the results of this regression are shown in the section (8.2), table (11).

The other method is the Random Effects (RE) regression model which assumes that the variation across entities to be random and uncorrelated with the predictor or independent variables included in the model (Oscar Torres-Reyna), and the results of the methods are shown in the appendix, table (12). Moreover, to decide whether Fixed – Effects or Random-Effects is suited for our analysis, the Hausman Test was used, where the null hypothesis (H_0) is that the preferred model is random effects vs. the alternative the fixed effects (H_1), section (8.2) table (13)., indicating that the Fixed Effects (FE) regression model is better than Random Effects (RE).

The comparison between Least Squared Dummy Variable with added cross sectional dummy variable (LSDV1), and Fixed-Effects (FE) method shows that they are the same, due to their specifications, by considering the effects of time-invariant effects, section (8.2) table (13), and having in mind that LSDV2 cannot be compared with Fixed-Effect (FE) due to the same reasons that LSDV1 and LSDV2 can't.

The final method is the Least Squared Dummy Variable (LSDV3) with cross-sectional and time-variant dummy variables, comparing it with the Pooled OLS method, LSDV1 and LSDV2, using Wald test, the results of the comparison are shown in the appendix table (10). Also, by comparing it with LSDV1 which is basically the same with Fixed-Effects (FE), we can get more complete opinion which model from above is more suitable for this study's empirical analysis.

An additional method that was used, regarding the model (1) that it is used for the empirical analysis, is by transforming it from linear regression model to a log-log regression model (2) shown in the section (4.1) . This method of logarithmically transforming variables it is used to handle situations where a non-linear relationship exists between the independent and dependent variables as well as transforming a highly skewed variable into one that is more approximately normal(Kenneth Benoit).

4.3.3 Descriptive Statistics

The table (1) is a summary of the panel data that is used for the analysis in this study, indicating the variables that are used. The descriptive statistics give the mean of the data for each variable, the Standard Deviation, the minimum and the maximum value that the data are taking. Also, the table shows the number of total observations of the sample, the number of cross-sectional data and the years that are observed, and the measurements in the table are taken for the total observation for the data sample, as well as for each cluster of countries and years, as it can be seen in the last column.

Table 1: Summary Statistics

Variable		Mean	Std. Dev.	Min	Max	Observations
co2	overall	7.743804	7.67928	0.04	68.724	N = 2280
	between		7.436051	0.0784667	49.20227	n = 76
	within		2.092868	-17.49946	27.26554	T = 30
gdp	overall	19821.05	20375.41	208.1115	113574.2	N = 2280
	between		19986.9	381.7301	94780.12	n = 76
	within		4556.773	-8948.34	51199.45	T = 30
ec	overall	39993.55	39345.56	193.4671	308704.3	N = 2280
	between		38488.5	445.6364	226797	n = 76
	within		9249.773	-42165.92	121900.8	T = 30
pop	overall	7.11E+07	1.99E+08	362017	1.43E+09	N = 2280
	between		1.99E+08	4.03E+05	1.32E+09	n = 76
	within		2.06E+07	-1.87E+08	3.06E+08	T = 30
envpat	overall	7.089158	13.92928	0	100.03	N = 2280
	between		11.99065	0.0053333	51.54233	n = 76
	within		7.216555	-33.98451	64.81549	T = 30

The graphs below are histograms for the variables that are used to indicate the distribution of the variables, with the first graph (figure 1) indicating that the distribution of the CO2 emissions per capita variable, have high concentration on one side and it is highly skewed to the right. The same can be said for the graph 3 that shows the distribution of the variable of innovation, having high concentration of observations on the left side and there is high skewness in the right side. The figure 2 that is the histogram for the income per capita variable, have many observations concentrated on the left side and have right side skewness but in comparison with the distribution of innovation, it is not that much.

Figure 1: Histogram for CO2 emissions per capita variable

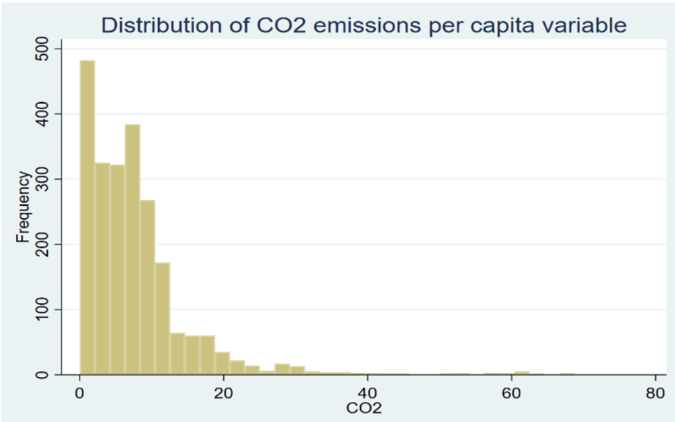


Figure 2: Histogram for income per capita variable

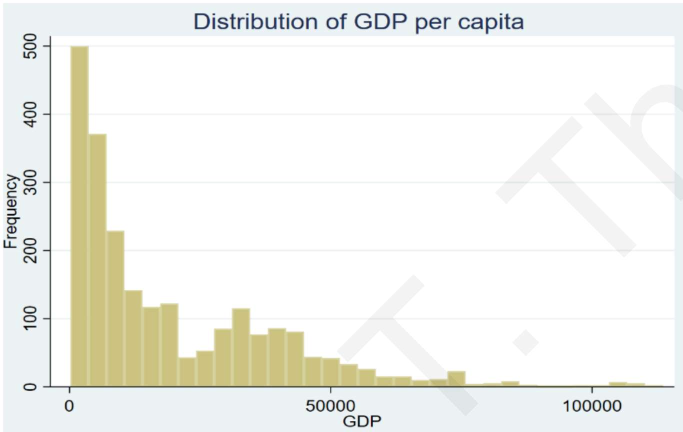
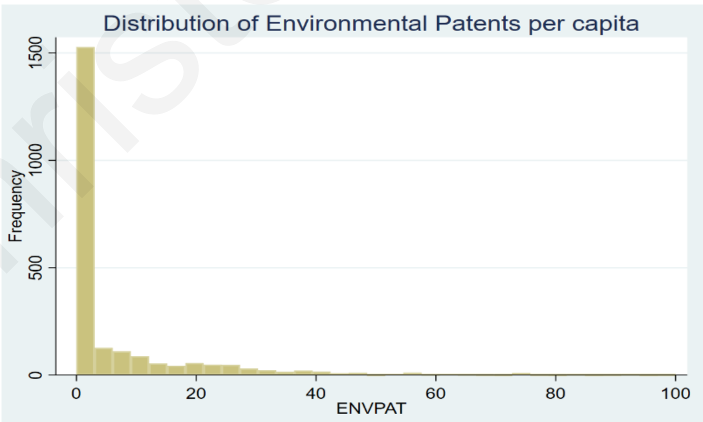


Figure 3: Histogram for environmental patents per capita variable



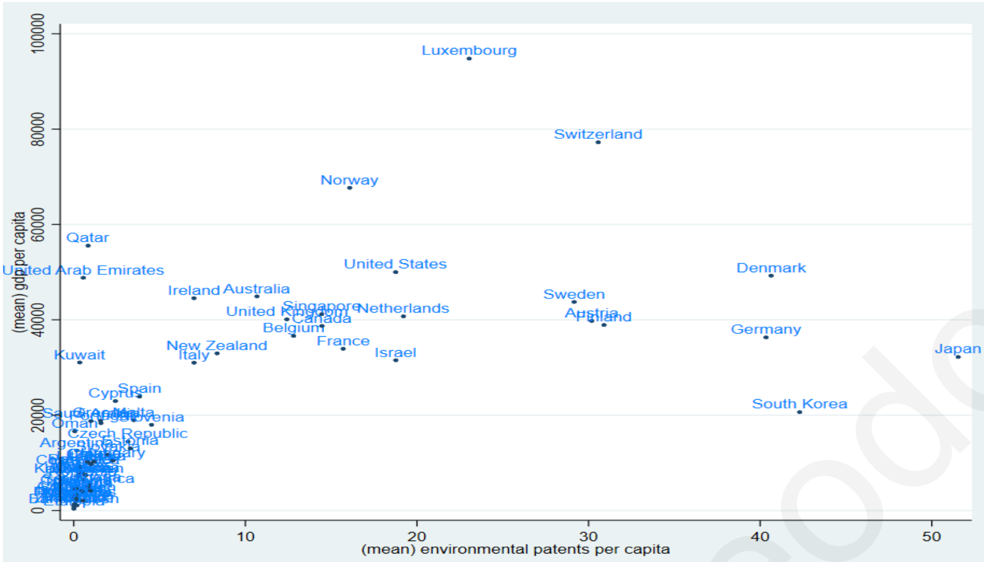
There are also histograms constructed for illustrational purposes indicating the distribution of the variables and as for example, the graphs in the appendix (figure 8) show the distribution of the data using histograms for two of the variables (CO2 and GDP per capita) before and after the logarithmic transformation. As it can be seen, the variables are highly skewed to the right side before the transformation and after logarithmically transforming them, they seem that they are more normally distributed.

Additional graphs are used to illustrate the relationship between the dependent variable and independent variables and the graph 4 in the appendix show the scatterplots that are used for an example of the relationship between dependant variable (CO2) and the independent variable (GDP) before and after the logarithmic transformation. As it can be seen, after the transformation there is a more clear linear relationship between the dependant variable and the independent variable. Thus, the logarithmic transformation as it is mentioned by K. Benoit (2011) resolve the situation of the non-linear relationship.

The logarithmic transformed model, model (2), was analysed following the Least Square Dummy Variable (3) regression method, as the non-logarithmic model, model (1) because as it is mentioned in the section (4.3.2) it is the most complete method of regression, by considering the cross-sectional effects and time variant characteristics and it is proven by the comparison of the methods that was conducted for the model (1), it is more suited for the study. The results of the regression analysis of the logarithmic transformed model, are shown on the table (6) in the section (5.2.7) and should be considered that the interpretation of those results is different compared to the linear regression model.

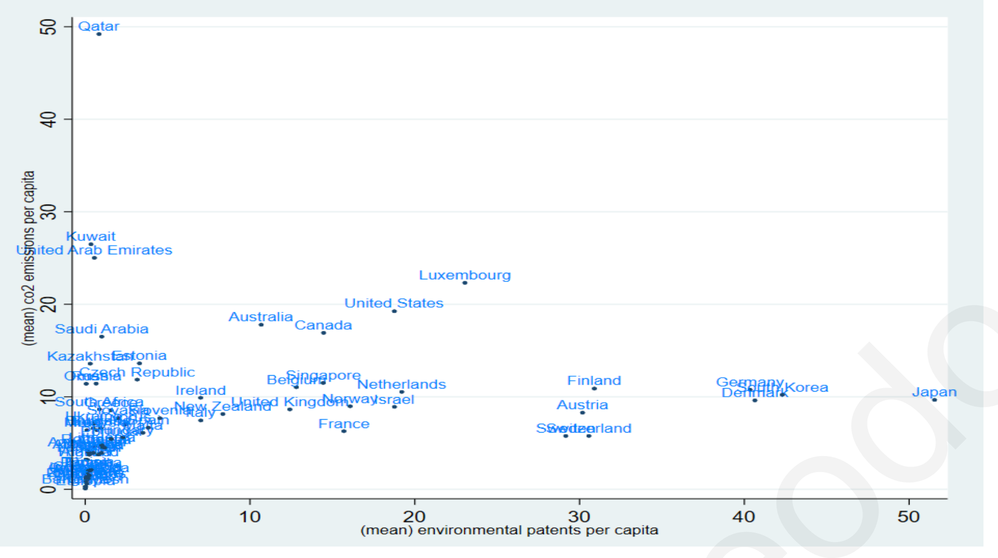
The figure 4 is a two-way scatter plot between the mean of income per capita of countries and the mean of environmental related patents per capita of countries. This graph indicates that income per capita is not a decisive factor whether a country is environmentally innovative, because as it can be seen Luxembourg has the highest mean of income per capita although it is positioned in the middle of the indicator of environmental innovation, also Qatar with high income per capita has very little environmental innovative activity. In comparison Japan is located below the mean of the mean of income per capita although it is located at the highest position of the mean of environmental related patents. Despite that, many of the countries in the sample with low income per capita are less environmentally innovative and it can be seen from the distribution of the scatter plot at the point of low mean of environmental patents per capita. Additionally, the concept of the concentration of innovation, that is distributed geographically, the graph indicates that many European countries are environmentally innovative, as well as countries that are cooperating with those countries, and even benefitted from outsourcing such as South Korea. Nevertheless, this data sample, indicates that a country with higher income per capita is not de facto more environmentally innovative, but in many cases the country with higher income per capita can be environmentally friendly and innovative.

Figure 4: Scatterplot indicating the relationship between Income per capita and innovation



The figure 5 is a two-way scatter plot between the mean of emissions per capita of Carbon Dioxide, the indicator that is used for environmental pollution and climate change in the analysis, and the environmental patents per capita which is the indicator for the environmental innovation. The graph indicates that a country that is environmentally innovative can have lower environmental pollution, as it can be seen with the case of Japan, Denmark, Korea etc. in comparison with UAE, Kuwait, Qatar, that have high emissions per capita and very small environmental innovative activity. Despite that environmental innovation is not a decisive factor, as it can be seen at the point of the graph where are countries with low environmental innovation activity, have small environmental pollution. Nevertheless, it is a good example that, environmental innovative countries have lower emissions of air pollutants per capita, but having any other factor kept constant (ceteris paribus).

Figure 5: Scatterplot indicating the relationship between CO2 emissions per capita and innovation



5. Results

5.1 Diagnostic Tests for the regression model

5.1.1 Multicollinearity tests

1. Correlation test results

The correlation test results, shown in the table (2) indicate that there is high correlation between the independent variable used for energy consumption (EC) and the dependent variable CO_2, and in order to avoid misleading results of the regression analysis it has been decided to remove the independent variable of energy consumption. Thus, the model (1,2,3) has been modified and the one that will be utilized for the regression analysis won't be including the control-independent variable of energy consumption, neither the other tests that were conducted.

Table 2 : Correlation test results

Variable	co2	ec	gdp	envpat	pop
co2	1	0	0	0	0
ec	0.886688	1	0	0	0
gdp	0.5741261	0.6890974	1	0	0
envpat	0.1614355	0.2576226	0.5945318	1	0
pop	0.1324706	0.1658412	0.1740358	0.0640447	1

2. Variance Inflation Factor (VIF) test results

Moving on, the Variance Inflation Factor (VIF) test which measures the strength of the correlation between independent variables that was conducted and the table (3) shows that all the values of the test are relatively low, regarding the reference of R. N. Forthofer et al. (2005) that it is a rough rule of thumb that if the VIF is greater than 10 give some cause for concern, thus it can be said that there is no high multicollinearity among the independent variables. As it is shown the independent variable of energy consumption was excluded from the test and from the overall analysis, due to high correlation with the dependent variable and it is no need to examine its effects. Also, the variable of exponential income per capita was excluded due to high correlation with the variable of income per capita to avoid inflated test results.

Table 3: VIF test results

Variable	VIF	1/VIF
gdp	1.59	0.627971
envpat	1.55	0.644929
pop	1.03	0.967307
Mean VIF	1.39	

5.1.2 Heteroskedasticity test results

As the tests results suggest, the regression suffers from heteroskedasticity, with the three results having as the null hypothesis of homoskedasticity being rejected with p-value=0 < 0.05, for both OLS methods and Fixed Effects. Based on these results, the methodology must also take into account heteroskedasticity in order to avoid incorrect and biased standard errors (SE) of the regression. Thus, a good way of correcting this issue is by running a robust regression having more trustworthy results of standard errors (SE) (Richard Williams, 2020) and more importantly the coefficients won't be affected.

5.1.3 Autocorrelation Test

The results on the table (4) for autocorrelation's presence in the analysis suggest that there is serial correlation, meaning that the results of the regression will have misleading values of Standard Errors (SE). In the same sense of heteroskedasticity the analysis must consider this effect, thus a robust regression is more suited in this case.

Based on the results of the tests of heteroskedasticity and autocorrelation, it is found that the approach suffers from both phenomena, and as a result, a regression without taking into account these issues will lead to incorrect results of Standard Errors, thus the inferences won't be correct. And as it is mentioned in the sections (4.3.1) (2) the way to make the regression's results of standard errors to be more trustworthy, is to follow the robust method of regression.

Table 4 : Heteroskedasticity and Autocorrelation test results

Heteroskedasticity and Autocorrelation Tests	Results of P-value
White's test	p-value = 0.0000
Breusch – Pagan / Cook – Weisberg test	p-value = 0.0000
Modified Wald test	p-value = 0.0000
Wooldridge test for Autocorrelation in panel data	p-value= 0.0000

5.2 Regression results of various methods and Comparison Results

5.2.1 Pooled OLS method

The table of the results of the robust Standard Errors (SE) Pooled OLS regression (table 7) shows that that there is an inverted U-shaped relationship between income per capita (gdp) with environmental degradation-climate change, a result that can be showed by Jeroen Weesie Analysis of the turning point of a quadratic specification as well, thus we can accept the hypothesis of Environmental Kuznets Curve. More importantly, in the results' table of the regression we can see that there is a significant negative relationship between innovation and climate change for all significant levels, and an increase of one environmental related patent per capita leads to a decrease of 0.1874789 units of emissions per capita of CO_2, ceteris paribus.

5.2.2 Least Squared Dummy Variable (1) (Country Dummy variable)

The regression has utilized a dummy variable for cross sectional effects, but for the purpose of ease the table of the results shown below has been modified to fit in the study's page, thus only main variables and their results are shown (table 8). Specifically, we can see that there is again an inverted U-shaped relationship between income per capita and climate change, leading to the acceptance of the Environmental Kuznets Curve hypothesis, having a positive value coefficient of income per capita and negative coefficient of squared income per capita. The hypothesis of Environmental

Kuznets Curve for the relationship between income per capita and environmental pollution can be also confirmed by Jeroen Weesie Analysis of the turning point of a quadratic specification. Additionally, we can see that innovation is significant for 90%, 95% , 99% significant levels, and an increase of one environmental patent per capita leads to 0.0370661 units of emissions of CO2 per capita, ceteris paribus.

Wald Test results

Afterwards, the Wald test was conducted to determine whether Pooled OLS is preferable or Least Squared Dummy Variable (1), and the results are shown below, having as the null hypothesis that country dummy variables are not significant and the alternative hypothesis that null hypothesis does not hold. As it can be seen from the results, the p-value is less than 0.05 ($p\text{-value} < 0.05$), thus we reject the null hypothesis, and we must include cross sectional effects with binary variables. As a result, the LSDV (1) regression model is preferable compared to Pooled OLS regression model.

5.2.3 Least Squared Dummy Variable (2) (Year Dummy variable)

This method of regression adds time variant effects as binary variables, and the results shown on the table (9), which has been modified as the table (8) to fit in the page, indicating that there is the same relationship for income per capita and climate change as the previous methods (Pooled OLS, LSDV1), and the effects are statistically significant for all significant levels (p-value=0).

In the case of innovation's effect on climate change, it is shown that there is a negative relationship between environmental related patents and CO2, with an increase of one environmental patent per capita leading to a decrease of 0.181204 units of emissions of CO2 per capita, being statistically significant for all significant levels.

Wald Test results

The results of the Wald test, when the Least Squared Dummy Variable (2) regression with time variant binary variables was compared with the Pooled OLS regression, with the null hypothesis being that time variant effects are not significant and the alternative hypothesis being that those effects are significant, show that we cannot reject the null hypothesis, with the p-value being higher than the significant level of 0.05 (p-value= 0.3538 > 0.05). Even though the Pooled OLS is indicated that is preferable than LSDV2 we cannot utilize it, because the LSDV1 is more suited as it is shown in the section (8.2) table (13).

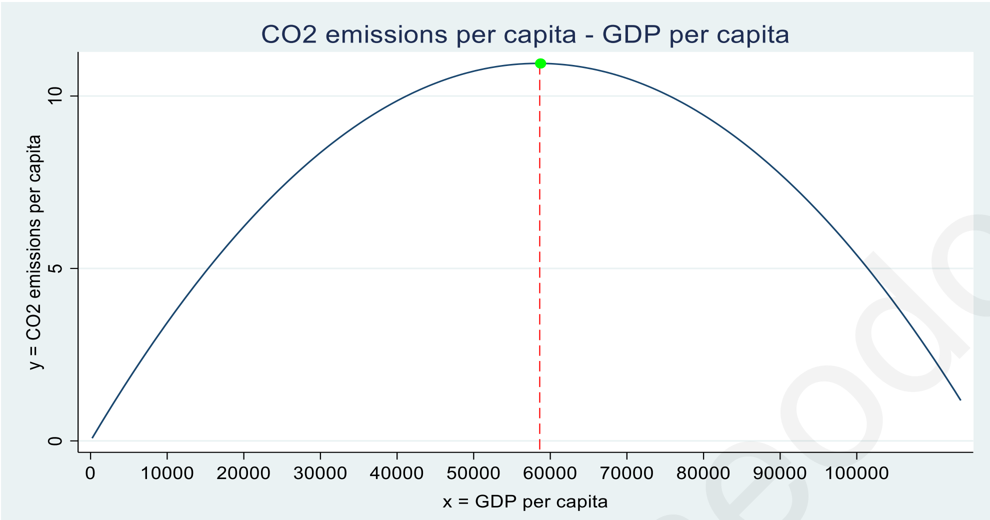
5.2.4 Least Squared Dummy Variable (3) (Dummies Country and Years)

5.2.4.1 Regression Model 1

The Least Squared Dummy Variable (LSDV3) method is the most complete compared to the previous because it includes both time variant and cross-sectional effects to the model. As before there is shown to be an inverted U-shaped relationship between income per capita and climate change, and the effects of income per capita are statistically significant for all significant levels.

The results from the Jeroen Weesie Analysis of the turning point of a quadratic specification, indicating that the relational concave curve of income per capita and CO2 has a maximum point equal to $58318.97 of annual income per capita, that means before reaching that amount of annual income per capita, any unit of increase of income per capita leads to increase of units of CO2 emissions per capita, and when that point is reached which is the maximum, any increase in unit of income per capita leads to a unit of CO2 emissions per capita decrease. These findings can also be confirmed by the function graph of the, showed below (figure 1) using the estimated coefficients from the results of the estimated regression model.

Figure 6: Relationship of Environmental pollution with Income per capita



Going forward, the effects of innovation to climate change are negative and statistically significant for 90%, 95% ,99% significant levels, and an increase of one environmental related patent per capita leads to a decrease of 0.0288248 units of emissions of CO_2 per capita, ceteris paribus.

Table 5 : Regression results of LSDV3

co2	Coef.	Robust Std. Err.	t	P>t	[95% Conf.	Interval]
gdp	0.000375	5.74E-05	6.53	0	0.0002623	0.0004874
gdp2	-3.21E-09	4.30E-10	-7.48	0	-4.06E-09	-2.37E-09
pop	1.30E-08	1.57E-09	8.32	0	9.96E-09	1.61E-08
envpat	-0.02882	0.0099	-2.91	0.004	-0.0482389	-0.009411
_Iyear_1991	-0.00963	0.569803	-0.02	0.987	-1.127048	1.107786
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
_Ic_id_76	-1.19707	0.205441	-5.83	0	-1.599951	-0.794189
_cons	2.428931	0.453364	5.36	0	1.539859	3.318003

Wald Test results

The Wald test in this case is conducted to determine whether the first model of Least Squared Dummy Variable (1) that includes only cross-sectional dummy variables, is preferable than the more complete model of LSDV (3) that includes time variant effects as well. There is no reason to compare this model with the other two previous models because as it is referred above the LSDV(1) is better than them.

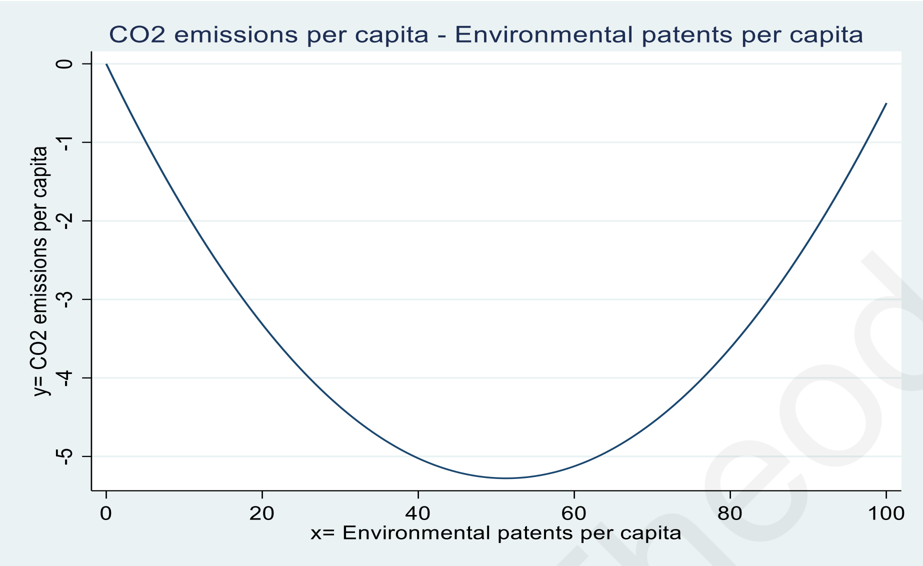
Nevertheless, the results of the test shown below, with the null hypothesis of time variant effects (year dummy variables) are not significant and the alternative hypothesis that they are significant indicate that, the null hypothesis is rejected for all significant levels, with the p-value=0.00 < 0.05. Thus, the Least Squared Dummy Variable (3) with the inclusion of binaries of both cross sectional and time variant effects is more suited for our analysis.

5.2.4.2 Regression Model 2

Another model was used to determine the monotonicity of innovation – environmental pollution curve, the model (3), which adds the exponential independent variable of environmental related patents, as to examine the relational curve between CO2 and innovation. The regression analysis follows the Least Square Dummy Variable (3) method, and the results indicate that there is a U-shaped relationship between innovation and climate change and an increase of one unit of environmental related patents per capita decreases CO2 emissions per capita by 0.2059565 units, and these effects are statistically significant for all significance levels.

The function graph (figure 7) indicates the relationship that exists between climate change and innovation, and it is a U-shaped relationship. This means that as environmental innovation progresses, it reduces the phenomenon of climate change but up to a certain point, which is the minimum point, and after that it seems that innovation positively contributes to climate change phenomenon.

Figure 7: Relationship of Environmental pollution with innovation



5.2.5 Fixed-Effects (FE)

The fixed effects regression model takes into account the individual time invariant characteristics of the panel model that might impact or bias the predictor or outcome variables and controls for those effects by removing them (Oscar Torres-Reyna). Also, the Fixed Effects (FE) model assumes that the individual time invariant characteristics are unique to each individual thus should not be correlated with other individual characteristics (Oscar Torres-Reyna).

The results of the Fixed Effects (FE) regression model are shown in the table (11), indicating that there is an inverted U-shaped relationship between income per capita and climate change, and the effects are statistically significant for all significant levels. Additionally, innovation it is shown that its effect is statistically significant for all significant levels, and it reduces environmental pollution by 0.0370659 units for an increase of one per capita environmental related patent, ceteris paribus.

5.2.6 Random Effects (RE)

The Random Effects (RE) regression model assume that the entity's error term is not correlated with the predictors which allows for time-invariant variables to play a role as explanatory variables (Oscar Torres-Reyna). Having the model ran, the results indicate that there is the same relationship between income per capita and climate change indicator as the previous models and innovation has negative relationship with climate change and both independent variables are statistically significant for all significant levels. Thus, the effect of innovation is that by an increase in one environmental patent per capita leads to a decrease in per capita emissions of co2 by 0.0435922, ceteris paribus. (table 12)

5.2.6.1 Hausman Test

To determine whether Random Effects (RE) model is preferable than Fixed Effects (FE), the Hausman test was utilized, having as the null hypothesis (H_0) that random model is more suitable for the analysis versus the alternative hypothesis (H_1) that it is not suitable.

The results of the test indicate that the null hypothesis is rejected for all significance levels with p-value=0 < 0.05, thus for the analysis it is more suited to follow the Fixed Effects (FE) regression model.

Even though the Hausmann test indicates that the preferred method is Fixed Effects which takes into account and controls for the cross sectional effects, but the method that this analysis focuses on is the Least Square Dummy Variable (3) method that controls for both individual characteristics of the countries by utilize binary variables for the countries , because as it is shown above (5.2.2), the cross-sectional effects are statistically significant, as well as controlling the time variant effects which are also statistically significant in the regression analysis. Thus, the results that the study is considering are those shown in the section (8.2) table (13).

5.2.7 Log-Log transformation model

As it is mentioned in the section (4.3.2), the logarithmic transformations are used whenever there is not linear relationship between the dependent variable and independent variables, as well as when the variables are not normally distributed having highly skewed distributions. And it is shown from the examples given in the section (8.1) graphs (figure 8;10;11) that indeed the distribution of the variables are right skewed before the transformation, and the relationship between the dependent variable and independent variable is non-linear.

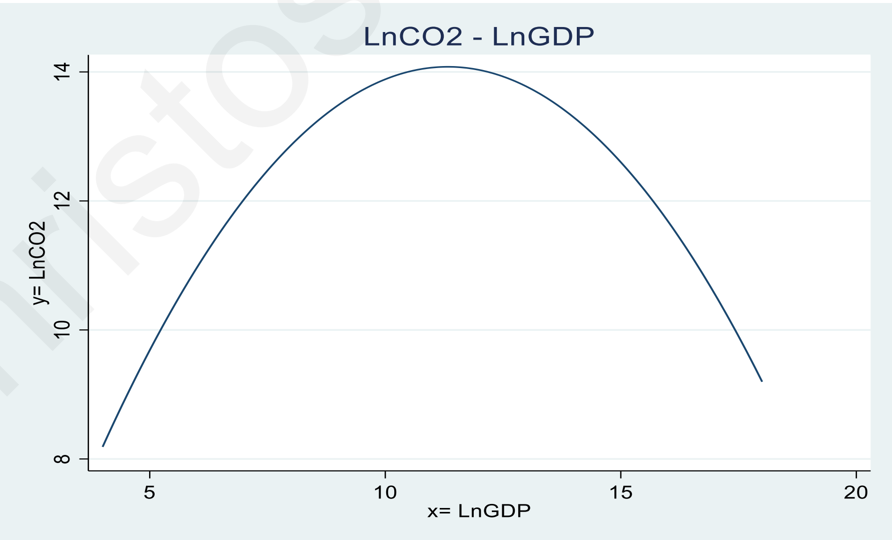
The results of the logarithmic transformed model (2), a log-log model where both dependent and independent variables are logarithmically transformed is shown in the table (6) and having in mind that the interpretation of those results is different in comparison with the other regressions' results due to the specifications of this model. Nevertheless, the results indicate that the hypothesis of Environmental Kuznets Curve, that the climate change has an inverted U-shaped relationship between income per capita and can be shown that a 1% of increase in income per capita increases CO2 emissions per capita by 0.0225%, and an increase of 1% in squared income per capita reduces the CO2 emissions per capita by 0.0011% and the effects are statistically significant for all significance levels. Additionally, the effects of the innovation on the climate change, are not statistically significant for the significance levels of 90%, 95%, 99%, even though it is shown that it has negative effects on emissions of CO2 per capita.

Table 6 : Log-Log model regression results

lco2	Coef.	Robust Std. Err.	t	P>t	[95% Conf.	Interval]
lgdp	2.485666	0.162468	15.3	0	2.167057	2.804276
lgdp2	-0.10971	0.010029	-10.94	0	-0.1293742	-0.090039
lpop	0.283682	0.052819	5.37	0	0.1801012	0.3872618
lenvp01	-0.00213	0.002644	-0.8	0.422	-0.0073103	0.0030602
_lyear_1991	-0.00327	0.043259	-0.08	0.94	-0.088103	0.081563
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
_Ic_id_76	-0.06794	0.111486	-0.61	0.542	-0.2865682	0.1506931
_cons	-16.4423	0.963635	-17.06	0	-18.332	-14.55252

The relationship between income per capita and CO2 emissions per capita, can be shown in the function graph below, which also indicates that there is an inverted U-shaped relationship between them thus the inferences are correct.

Figure 8: Log-Log results of the relationship between Environmental Pollution and Income per capita



Additionally, the model (3) was logarithmically transformed to a Log-Log model, and the results in the appendix, table (14) suggest that environmental innovation reduces the climate change phenomenon. Specifically, a 1% of increase on environmental related patents per capita leads to 0.020661% of decrease in CO_2 emissions per capita, ceteris paribus, and the effects are statistically significant at the significance levels of $\alpha= 0.1$, $\alpha= 0.05$, $\alpha=0.01$.

6. Discussion

The analysis as it is mentioned in the section (3) follows the theoretical and empirical approach of Environmental Kuznets Curve, that was firstly used by Grossman and Krueger (1991), World Development Report (1992) and Panayiotou (1992), with the hypothesis that economic growth and environmental pollution have an inverted U-shaped relationship, as well as following the footsteps of , that have examined the effects of innovation in the economic growth and climate change relationship, focusing on the effects that might have on the environmental pollution. The models in the section () were used for the regression analysis, following the EKC methodology.

The first step for the analysis as it is mentioned in the section (4.3) was to determine whether the model suffers from multicollinearity (correlation test, VIF test), heteroskedasticity (White's test, Breusch – Pagan / Cook-Weisberg test, Modified Wald test) and autocorrelation (Lagram – Multiplier Test / Wooldridge test), the results of which indicating that the there is high correlation between Energy Consumption and CO_2 emissions, and as it is mentioned above the variable is excluded creating a new form for the model, and then the results for heteroskedasticity and autocorrelation suggest that measures should be taken due to their present in the model, thus as it is mentioned in the section (5.1.3) the robust Standard Error (SE) method for should be followed in the regression analysis.

To determine the effects of innovation on the economic growth – climate change relationship, mainly to determine the impacts on climate change, different regression methods were used, firstly to examine the initial hypothesis of the EKC literature on the relationship between income per capita and environmental pollution, with the results indicating that there is an inverted U-shaped relationship between income per capita and CO2 emissions per capita and the Jeroen Weesie Analysis of the turning point of a quadratic specification, that was done for the Least Square Dummy Variable (3) regression, had as a result that the curve for CO2 and GDP has a maximum point of $58318.97 and the function graph that illustrates the relationship, which indeed is an inverted U shaped, indicating that the hypothesis of Environmental Kuznets Curve, that it is examined and accepted firstly by Grossman and Krueger (1991), World Development Report (1992) and Panayiotou (1993) and later by others, is accepted in this research as well.

Afterwards, when the EKC hypothesis had been tested, the innovation effects on this topic are examined by analysing the impacts on climate change, integrating the variable of environmental related patents per capita to the regression models. At first, running the models where the exponential variable of innovation is excluded (model 1, model2), the results are indicating that innovation has negative effect on environmental pollution, which are consistent with the findings available by the studies of the literature. Specifically, the regression analysis of LSDV(3) non-logarithmic transformed model (model 1) show that an increase of one environmental related patent per capita leads to a decrease of 0.0288248 units of emissions of CO2 per capita, ceteris paribus, with statistical significance for 90% 95% 99% significance levels, and based on these results

, the climate change phenomenon is reduced when there is an increase in environmental related innovation. Furthermore, by looking at the results of the log-log transformed model with the exponential log variable of innovation excluded, model (2) even though innovation seems to decrease climate change, when the significance test is conducted with the null hypothesis that the innovation's effect is not statistically significant $\beta=0$ and the alternative hypothesis is that the effect is statistically significant, the null hypothesis can not be rejected with p-value=0.42 < 0.05.

Also, additional models were constructed, including the squared variable of environmental related patents, by following the same methods as the model 1 and model 2 had followed, to examine the relationship between innovation and environmental pollution whether it exhibits the same as income per capita and environmental pollution (inverted U-shaped). As the results (table 10) indicate, for the non-logarithmic model, model (3), that there is a U-shaped relationship between innovation and climate change (figure 7) and an increase of one unit of environmental related patents per capita decreases CO_2 emissions per capita by 0.2059565 units, and when it reaches the minimum point, the effects of innovation are changed and an increase of one unit of the squared environmental related patents per capita increases the environmental pollution, and these effects are statistically significant for all significance levels. The log-log model (4) indicates that environmental related patents have negative statistically significant effects on CO_2 emissions for significance levels of 90% 95%, by 0.020661% of decrease when there is an increase of 1% on per capita environmental related patents.

As it is shown in the analysis of the regression models and methods, the hypothesis of the EKC on the relationship between income per capita and environmental pollution, it is accepted in the study, illustrated by the graphs (figure 6;8) and by the results of the regressions, see table(5;6), . In the case of the effects of innovation on climate change, when the Environmental Kuznets methodology was utilized, the regression results indicating that by increasing the per capita environmental related patents the CO2 emissions are decreasing, thus there is negative relationship between innovation and climate change phenomenon.

Also, the additional test was conducted to illustrate the relational curve of innovation and environmental pollution, by using an additional variable, the squared environmental related patents per capita to the non-logarithmic transformed model, model (3) and to the logarithmic transformed model, model (4), having as results, that innovation negatively affects climate change phenomenon up to a point and then positively affect that phenomenon by increasing the per capita emissions of CO2 (graph (7)). Thus, if it is to follow the results of this test, the optimum point where the environmental pollution is at the minimum level is at the level where the environmental patents per capita equals to 51. In contrast, the regression of the log-log transformed model indicates that innovation has only negative effects on CO2 per capita emissions.

The hypothesis that the effects of innovation to climate change are significant cannot be accepted or rejected due to contrasting results of the two regression models (1,2) and to accept or reject the significance of the effects of innovation to environmental pollution, with the null hypothesis being that these effects are statistically significant and the alternative hypothesis that they are not statistically significant, we have to look what model is better in explaining the relationship between the dependent variable and independent variables. Even though the log-log transformed regression model is used to handle situations like this study's, where there is no linear relationship between the dependent and independent variables, it is better to compare the value of R squared of both regression models, indicating that the logarithmic transformed model has higher R squared = 0.9792 than the non-logarithmic model R squared = 0.9358.

Despite that the logarithmic transformed regression model is assumed to be better than the linear regressed model by the theory that is preferable when non linear relationship exists between the dependent and independent variables and by the results of the comparison between the R squared of the regressions, to avoid type I or type II errors, it is better not to make conclusions whether the effects of innovation to climate change are statistically significant or not. This is due to the statement made above, section () , that innovation is difficult to measure, and in handbook of Economics of Innovation (Ch.8) (2010), M.P. Feldman and D.F. Kogle, it is stressed that Studies that draw inferences about innovation by focusing on invention should be interpreted with caution because patents and inventions are only a part of innovation, and as Griliches (1990) and Scherer (1984) discussed there are limitations of patents when used as an indicator for innovation.

Moving on, and having in mind what Nicolas Stern stressed out, that innovation is needed to reduce the negative consequences on the environment, and as the results from the regression analysis suggest, that indeed innovation reduces the CO_2 emissions, thus the climate change phenomenon is restricted, and following the same path as Panayiotou (1992) that discusses what should be done by countries that face the negative effects on the environment when they have positive economic growth, this study can argue that, when countries are at the point where the EK- curve hasn't reached the turning point, thus the economic growth leads to environmental degradation, should follow environmental quality improving innovative products and processes for their development. Also, countries that have already reached the turning point of EK-curve should implement environmentally friendly innovative procedures and products, and in both country situations should go through the process of "creative destruction".

Another important note that countries should take into consideration, is what it is mentioned in the handbook of economics of innovation (2010) (Ch.2) by Mokyr that, "Improvements in technological capabilities will only improve economic performance if and when they are accompanied by complementary changes in institutions, governance, and ideology", meaning that they should create an environmental innovation friendly eco-system that will boost the innovation process and the outcomes of it. One way of doing it is by countries being aware of the issues that environmental pollution can lead to and the phenomenon of climate change, they can implement policies that give the incentives to their organizations to become more environmentally innovative. Also, by countries being aware, they can raise awareness for organizations about the issues that might occur when they are not using environmentally friendly methods and delivering environmentally friendly products, and this may lead organizations to join forces to deliver environmentally friendly innovations, and a great example of organizations that joint forces when there was a global hazard, is when there was the covid-19 pandemic, when pharmaceuticals joint forces to deliver the vaccine, and as of today we can say that they have made a good work by delivering it in a short time where it was needed the most, saving many people's lives.

Adding to the procedures that will help improve innovative activity of countries, an important role is that of knowledge, which is an important part of human capital, and as the Sollow model with the interpretation of knowledge per capita suggests, increased of knowledge leads to higher growth rates. Thus, the acquisition of new knowledge and managing it to provide outcomes it is important for innovation, and in this case knowledge for eco-friendly products and processes will help reduce the outcomes of environmental pollution and climate change. In this case it is important for organizations within countries to manage knowledge better, as well as sharing it with other organizations oversees because, climate change is a global problem and knowledge spillover is not enough as it is geographically concentrated. As this might be seen as a paradox because we live in an era of an infinite number of available resources and data online, there is a distinction on where the knowledge comes from, one being explicit that comes from data, documents, files etc. that can be found, but that only accounts for a small percentage of knowledge that can lead to innovation. The biggest asset in knowledge is the tacit knowledge that comes from the capabilities of individuals (handbook of Economics of Innovation (Ch.8) (2010), M.P. Feldman and D.F. Kogle). Thus, sharing knowledge and managing it correctly can lead to innovative products and processes regarding the environmental pollution reduction and the concept of that innovative activity is concentrated in space (Feldman, 1994, 1999; Moreno et al., 2005), will be faced and countries will increase their innovative activity, and climate change will be globally jointly faced.

While countries may implement policies that force organizations to be more environmentally innovative, or give them incentives to become, a problem might arise due to that Many corporations and organizations do utilize Intellectual Property Rights, which can be seen as a method of management tool that businesses have in order to protect their innovative discoveries, and their processes, and give them advantage over others, while this is not an issue in many cases, in this case can be seen as a moral hazard. The reason is that, by discovering new eco-friendly and environmental quality improving product or process of doing business, and strategically implement IPRs to restrict others from acquiring and using it, can lead to further stressing the environment and inducing the phenomenon of climate change, because less eco-innovative organizations and organizations with limited resources and knowledge on environmental quality improving products and processes will keep following the method of doing business as usual.

As it can be understood, this situation is tough because, on the one hand the use of IPRs from organizations help them to get benefitted from their innovations by getting revenues from renting out their discoveries, or even ruling out competitors from the industry, thus their share of pie in the industry becoming bigger, but on the other hand there is the case that monopolies might arise in industries.

So, in order to avoid on one hand to create monopolies or on the other hand to limit the incentives that organizations have to become more eco-friendly innovative, the policies should be implemented by considering both cases, providing incentives but avoiding the creation of monopolies, and to do that policy makers should have in mind that this is a global issue and that innovative corporations should join forces to deliver the best results possible.

7. Conclusion

This study contributes to the hypothesis of Environmental Kuznets curve by being tested, with the hypothesis being that economic growth and environmental pollution have an inverted U-shaped relationship, meaning that while a country having positive economic growth the environmental degradation increases, up to a point, where then increasing economic growth leads to improving the environmental condition. By using the methodology of Environmental Kuznets Curve that was introduced by Grossman and Krueger (1991), World Development Report (1992), and Panayiotou (1992) the results indicate, that there is an inverted U shaped relationship between income per capita (the indicator of economic growth) with Carbon Dioxide emissions per capita (indicator of environmental pollution and climate change) accepting the hypothesis of EKC.

Also, this study contributes to the literature that examining the effects of environmentally related innovation to the Environmental Kuznets hypothesis, although it is limited as it is mentioned by, with the hypothesis of the literature being that innovation reduces the environmental pollution and negatively contributes to the phenomenon of climate change. With the use of Environmental Kuznets methodology, and the empirical analysis follows the Least Square Dummy Variable method that controls for country individual effects and time variant effects, which the tests indicate that it is more suited for this study, the results show that indeed innovation reduces the environmental pollution by reducing the emissions per capita of CO2, that it is the indicator used for environmental pollution and climate change. Similar finding have been shown by the studies of Fethi and Rahuma (2018), Lin and Zhu (2018) using panel data regression analysis, and using the EKC methodology, and both studies have accepted the hypothesis that innovation decreases the environmental pollution and negatively contributes to the phenomenon of climate change. Another study that examined this hypothesis was done by M.H Mohd Saudi et al. (2018) but in this case they had used a time series regression model for Malaysia, having the same results.

Thus, the results of this study, accepts both hypotheses, on one hand that economic growth has inverted U shaped relationship with environmental pollution and climate change, and on the other hand that environmental innovation reduces the environmental pollution and climate change. The results are going hand in hand with the results of the studies of Fethi and Rahuma (2018), Lin and Zhu (2018) and M.H Mohd Saudi et al. (2018)), that have examined and accepted both hypotheses.

While this study contributes to the literatures results, there were difficulties, starting with the empirical analysis of the regression models, as it is mentioned in the section , the regression model suffered from heteroskedasticity and autocorrelation thus the method of robust Standard Errors should be implemented, in order to get more trustworthy results and make more correct inferences. Also, there is difficulty when innovation is to be measured and get a proxy, and the study had used for the variable of innovation the environmental related patents, which as M.P. Feldman and D.F. Kogle refer, the studies that follow this path should be careful when making inferences, and that is what this study have done. Additionally, and in this case, the results from the regression of the model (3) that tests the curve that innovation and climate change exhibit might have been different if a different proxy for innovation would have been used.

8. Appendix

8.1 Descriptive statistics

Figure 9: Scatterplot for CO_2 emissions per capita – GDP per capita

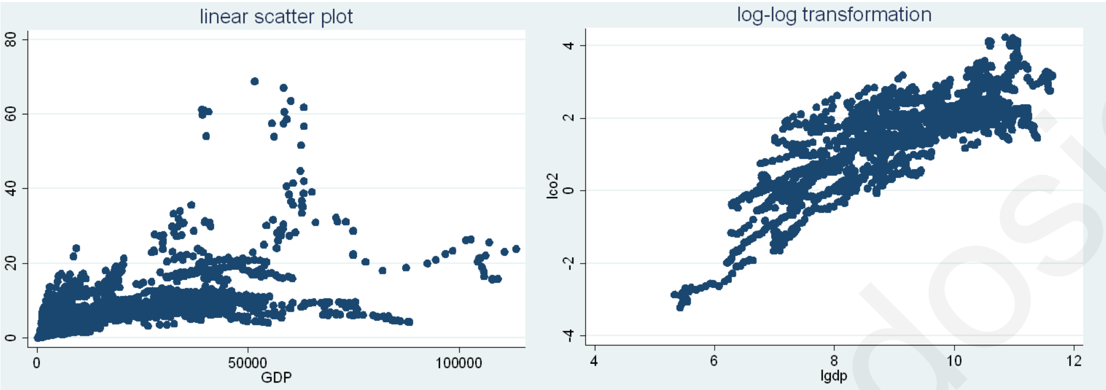


Figure 10: Histogram for Carbon Dioxide distribution before and after logarithmic transformation

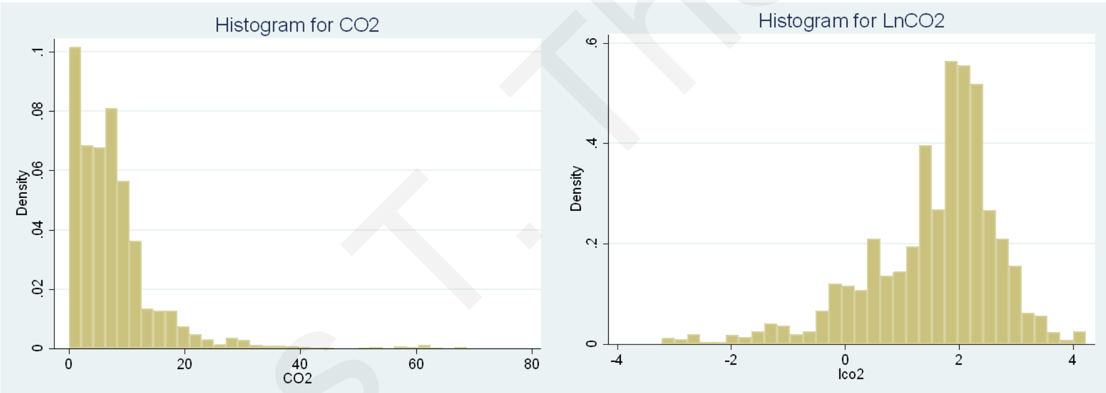
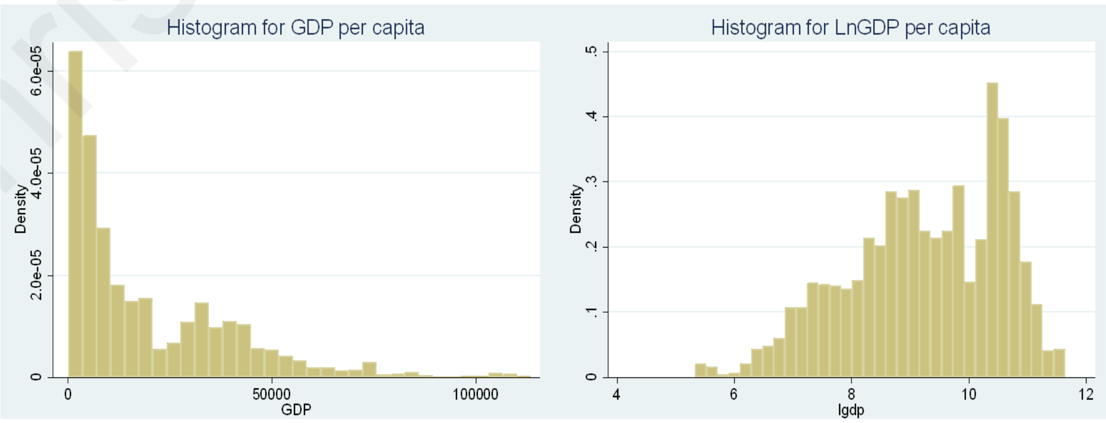


Figure 11: Histogram for Carbon Dioxide distribution before and after logarithmic transformation



8.2 Regression Results

Table 7: Pooled OLS regression results

		Robust				
co2	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
gdp	0.00051	2.55E-05	19.97	0	0.00046	0.0005602
gdp2	-3.12E-09	2.51E-10	-12.46	0	-3.61E-09	-2.63E-09
pop	3.75E-10	1.96E-10	1.91	0.056	-9.04E-12	7.59E-10
envpat	-0.18748	0.022413	-8.36	0	-0.2314315	-0.143526
_cons	1.459016	0.184104	7.92	0	1.097987	1.820044

Table 8: Least Square Dummy Variable (1) regression results

		Robust				
co2	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
gdp	0.000207	4.54E-05	4.56	0	0.0001181	0.0002961
gdp2	-2.27E-09	3.88E-10	-5.86	0	-3.03E-09	-1.51E-09
pop	4.93E-09	9.64E-10	5.11	0	3.04E-09	6.82E-09
envpat	-0.03707	0.01075	-3.45	0.001	-0.0581471	-0.015985
_Ic_id_2	-0.82344	0.385985	-2.13	0.033	-1.580369	-0.066503
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
_Ic_id_76	-1.7086	0.115209	-14.83	0	-1.934524	-1.482665
_cons	2.434876	0.133074	18.3	0	2.173913	2.69584

Table 9: Least Square Dummy Variable (2) regression results

		Robust				
co2	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
gdp	0.000511	2.54E-05	20.09	0	0.0004608	0.0005605
gdp2	-3.11E-09	2.45E-10	-12.71	0	-3.59E-09	-2.63E-09
pop	5.17E-10	2.15E-10	2.4	0.016	9.52E-11	9.38E-10
envpat	-0.1812	0.022444	-8.07	0	-0.2252166	-0.137191
_Iyear_1991	0.011626	0.827552	0.01	0.989	-1.611221	1.634472
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
_Iyear_2019	-2.35816	0.849968	-2.77	0.006	-4.024965	-0.691356
_cons	1.982634	0.625744	3.17	0.002	0.7555376	3.20973

Table 10: Least Square Dummy Variable (3) regression results with quadratic innovation variable

		Robust				
co2	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
gdp	0.00042	5.76E-05	7.29	0	0.0003071	0.000533
gdp2	-3.24E-09	4.01E-10	-8.07	0	-4.03E-09	-2.45E-09
pop	1.25E-08	1.56E-09	8.03	0	9.47E-09	1.56E-08
envpat	-0.20596	0.032327	-6.37	0	-0.2693511	-0.142562
envpat2	0.002009	0.000291	6.9	0	0.0014383	0.0025799
_Iyear_1991	-0.00732	0.548691	-0.01	0.989	-1.083334	1.068696
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
_Ic_id_76	-1.11588	0.201696	-5.53	0	-1.511418	-0.720345
_cons	2.130494	0.454482	4.69	0	1.239228	3.021761

Table 11: Fixed Effects regression results

co2	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
gdp	0.000207	2.29E-05	9.04	0	0.0001621	0.000252
gdp2	-2.27E-09	2.07E-10	-10.99	0	-2.68E-09	-1.87E-09
pop	4.93E-09	2.11E-09	2.33	0.02	7.87E-10	9.07E-09
envpat	-0.03707	0.00699	-5.3	0	-0.0507731	-0.0233592
_cons	5.387556	0.317839	16.95	0	4.76426	6.010852
sigma_u	6.973935					
sigma_e	2.058236					
rho	0.919876	(fraction of variance due to u_i)				

Table 12: Random Effects regression results

co2	Coef.	Std. Err.	z	P>z	[95% Conf.	Interval]
gdp	0.00025	2.18E-05	11.48	0	0.0002074	0.0002928
gdp2	-2.50E-09	2.02E-10	-12.4	0	-2.90E-09	-2.11E-09
pop	2.06E-09	1.76E-09	1.17	0.243	-1.39E-09	5.51E-09
envpat	-0.04359	0.006975	-6.25	0	-0.0572631	-0.029922
_cons	4.970679	0.69815	7.12	0	3.602331	6.339027
sigma_u	5.435604					
sigma_e	2.058236					
rho	0.874598	(fraction of variance due to u_i)				

Table 13: Comparison tests results

Wald Test	**Results**
POOLED OLS VS LSDV1 (COUNTRY DUMMY)	**p-value = 0.0000**
POOLED OLS VS LSDV2 (TIME DUMMY)	**p-value= 0.3538**
LSDV1 (COUNTRY DUMMY) VS LSDV3 (COUNTRY & TIME DUMMY)	**p-value= 0.0000**
Hausman Test	
RANDOM EFFECTS (RE) VS FIXED EFFECTS (FE)	**p-value= 0.0000**

Table 14: Log-Log regression model with exponential variable of innovation results

		Robust				
lco2	**Coef.**	**Std. Err.**	**t**	**P>t**	**[95% Conf.**	**Interval]**
lgdp	2.348278	0.166765	14.08	0	2.021243	2.675313
lgdp2	-0.10119	0.010389	-9.74	0	-0.1215611	-0.080813
lpop	0.279128	0.05195	5.37	0	0.1772511	0.3810054
lenvp01	-0.02066	0.007707	-2.68	0.007	-0.0357753	-0.005547
lenvpat2	-0.00181	0.000726	-2.5	0.013	-0.0032376	-0.00039
_lyear_1991	-0.0027	0.04274	-0.06	0.95	-0.0865186	0.0811124
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
_Ic_id_76	-0.07396	0.11216	-0.66	0.51	-0.2939075	0.1459974
_cons	-15.8569	0.969539	-16.36	0	-17.75819	-13.95554

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