ERASMUS UNIVERSITY ROTTERDAM

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Master Thesis [Economics and Business – International Economics]

The Environmental Kuznets Curve in the EU: A Study Focusing on CO2, N2O, and the Environmental Footprint

Name student: Swen Spee

Student ID number: 450813

Supervisor: dr. J. Emami Namini

Second assessor: dr. A. Erbahar

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Abstract

This thesis contributes to the existing literature focused on the Environmental Kuznets Curve hypothesis. This hypothesis states that the relationship between income per capita and environmental degradation is that of an inverted U-shaped curve. Existing literature on this topic is rich, but it is still not a clear case whether the traditional hypothesis holds around the world. Three measures of environmental degradation (CO2, N2O, and the environmental footprint) is being used in this thesis as dependent variables. The polynomial approximations include cubic functions of income per capita and numerous control variables. Both the dependent variables and independent variables have been transformed into natural logarithmic values. The EKC is being tested with the use of data from 28 European Union countries for the period 1970-2018. The regressions have been performed with the use of fixed effects and random effects models. The results show evidence in support of an N-shaped EKC for all three measures of environmental degradation. However, these results slightly change after the addition of time fixed effects. An implication of the traditional inverted U-shaped curve is that a higher level of income per capita is all that a country needs to reduce its strain on the environment. However, this thesis shows that this may not be the case and other measures must be taken as well in order to decrease environmental degradation in the future.

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1. Introduction

In the past, industrialization has led to the rise of new products and markets (Medina, 2020). As a result, the products and raw materials needed to reach consumers around the world, which caused an expansion in global trading markets (Medina, 2020). However, international trade is associated with negative environmental consequences due to the generation of greenhouse gasses through the production of traded goods and the transportation between trading partners (Cristea et al., 2013). These environmental consequences—which include rising global warming, pollution, and extincition of species—have gained a rising interest from people worldwide (Lampert et al., 2019). However, debates around this topic often reach a level of polarization, which could problematize meaningful dialogues and problem solving (Hoffman, 2011). One question that poses a challenge in the debate around global warming is whether the potential positive impact on the environment will weigh up to the economic costs. In order to evaluate this, we need to examine the relationship between international trade, economic growth, and the environment. One way to do this is with the help of the environmental Kuznets curve (EKC). The EKC shows the relationship between various indicators of environmental degradation and income per capita (Dinda, 2004). It is named after Simon Kuznets, and often shows an inverted U-shaped relationship between environmental quality and income per capita. This means that an increase in income per capita initially causes environmental degradation, but this relation turns around with a higher level of income per capita, thus leading to environmental improvements. An explanation for this phenomenon could be that developing countries with a fast rising economy focus more on producing at a large scale, which increases pollution and other environmental degradation, while other more wealthy countries experience slower economic growth and focus more on reducing pollution (Stern, 2004).

Most of the existing literature uses carbon dioxide (CO_2) as a measurement for environmental degradation and often focus on countries that should be in the middle of the curve. Recent papers that provide evidence in support of the EKC hypothesis in those countries include studies on India (Sinha & Shahbaz, 2018), Indonesia (Shahbaz et al., 2013), and Asia as a whole (Apergis & Ozturk, 2015). However, there are also recent papers that focus on countries that should be at the end of their EKC, like Scandinavia (Urban & Nordensvärd, 2018), France (Iwata, Okada, & Samreth, 2010), and the USA (Bulut, 2019). Other measures for environmental degradation have also been used recently in existing literature, such as SO_2 levels (Wang et al., 2016; Fosten et al., 2012; Sinha & Bhattacharya, 2017), the ecological footprint (Al-mulalia et al., 2015; Altintas and Kassouri, 2020), and the level of water pollution (Thompson, 2014).

Overall, there is plenty of existing literature that provides evidence for the environmental Kuznets curve hypothesis. However, Stern (2004) stated in his infamous paper that most of the EKC literature is econometrically weak. He states that papers often pay little to no attention to the statistical properties of the data and to the model adequacy. Also, many studies use simple quadratic functions of levels of income while a cubic EKC may result in a different conclusion. This thesis contributes to existing literature by taking multiple environmental measures into account, using recent data points and including a cubic variable for income per capita.

This paper starts with a literature review in Chapter 2, followed by an overview of the dataset and their sources in Chapter 3. Then, the methodology is presented in Chapter 4, followed by the results in Chapter 5. Finally, this paper ends in Chapter 6 with its conclusion.

2. Literature review

2.1 The environmental Kuznets curve

In 1954, Simon Kuznets delivered his presidential address to the American Economic Association about income inequality. Kuznets found evidence for a trend in the equalization of income distribution with the help of data from Germany, the United Kingdom, and the United States. The trend followed an increase in inequality in the early phases of industrialization, followed by a decline in the more advanced stages. Kuznets extended his research by focusing on developing countries and found that income inequality is higher there than in the more advanced countries. A possible explanation for this trend, according to Kuznets (1955), could be that industrialization causes a higher concentration of money to be in the hands of the less wealthy. However, Grossman and Krueger (1991) were the first to extend this idea towards environmental impact. The paper by Grossman and Krueger (1991) focuses on the NAFTA and its impact on the environment by studying the relationship between air quality and economic growth. Evidence had been found that some of the pollutants concentration increased with per capita GDP at low levels, but decrease with higher levels of per capita GDP. Therefore, Kuznets' hypothesis of an inverted U-shaped curve seemed to not only hold for income distribution, but also for environmental impact.

Grossman and Krueger (1991) focused on three types of air pollutants: SO2, dark matter, and suspended particles. The paper presented evidence for SO2 and dark matter to follow an inverted U-shaped curve. They also present three possible mechanisms through which a change in national income can affect the level of pollution. The first mechanism is a scale effect, which captures the fact that the total amount of pollution will increase if there is an expansion of economic activity and the nature of the activities remain unchanged. The second mechanism is a composition effect, which captures the effect of specialization in sectors where the country has a competitive advantage. This could also be in terms of environmental regulations, so that each country will specialize in sectors where its government has no strict regulations in place in terms of pollution. However, a traditional comparative advantage in terms of technology and differences in factor abundance could counter these effects. The third mechanism is a technique effect, which captures the effect of a change in the method of production. It is believed that this mechanism contributes towards a potential decrease in pollution per unit of output. Especially in developing countries, since modern technologies from foreign investors are often cleaner than the technology used in those countries. Besides that, an increase in national income could also change the focus of a country towards more stringent pollution standards. As a result, the country will be more motivated to use technologies that reduce pollution.

2.2 EKC and developing countries

2.2.1 Individual country studies

An example of existing literature that focused on countries that should be in the middle of their EKC is the paper by Shahbaz et al. (2013). This paper focused on Indonesia with CO2 emissions as a measure of environmental impact. The authors used quarterly data in the period 1975-2011. The authors used an ARDL bounds testing approach, which is often used to identify long run relationships between series with different order of integration (Pesaran et al., 2001). The results suggested that economic growth and the level of energy consumption increases CO2 emissions, while financial development and trade openness temper it.

Och (2017) studied the EKC hypothesis for nitrous oxide levels in Mongolia. Data for the period 1981-2012 was used and processed with the help of an ARDL bounds testing approach. The results showed an U-shaped relationship between nitrous oxide emissions and income, which means that the traditional EKC hypothesis has been rejected.

Sinha and Shahbaz (2018) found a significant negative relationship between renewable energy and CO2 emissions in India. This paper used annual data for the period of 1971-2015 and provides evidence, with the help of the ARDL approach, in support of an inverted U-shaped EKC for India. The turnaround point of this EKC was shown to be at 2937.77 US dollars.

2.2.2 Multiple country studies

Tamazian et al. (2009) focused on examining the EKC in the so-called BRIC countries (Brazil, Russia, India, and China). Panel data on these emerging countries was used for the period 1992-2004 and processed with the help of a random effect specification. CO2 levels were used as a measure for environmental impact and the results provided evidence in support of the traditional EKC hypothesis. Besides that, the results also showed that the level of financial development is negatively related to CO2 levels.

Apergis and Ozturk (2015) extended the paper by Shahbaz et al. (2013) by including 13 other countries in their dataset as well in order to test the EKC hypothesis for a total of 14 Asian countries. The authors used annual data in the period 1990-2011 on CO2 emissions. This paper uses the panel fixed effects methodology with the employment of the generalized method of moments (GMM) by Arellano and Bond (1991). The results show evidence in support of the traditional EKC hypothesis among the 14 Asian countries.

Lin et al. (2016) focused on CO2 emission as measure of environmental degradation in five African countries. The authors used the STIRPAT empirical model, panel cointegration, and fully modified ordinary least squares (FMOLS). The STIRPAT model is based on the impact, population, affluence, technology (IPAT) formula and often used to estimate human impacts on the environment. The paper shows no evidence of an inverted U-shaped EKC in these African countries. Besides that, evidence showed that population growth and urbanization are negatively related to CO2 emissions.

2.3 EKC and developed countries

2.3.1 Individual country studies

Existing literature have often focused on developing countries that should be in the midst of their environmental Kuznets curve. However, some papers have also studied the Kuznets curve hypothesis on countries that should be at the end of the inverted U-shaped curve. Once again, these individual country studies often use the ARDL approach to cointegration as their estimation method.

An example is the paper by Iwata et al. (2010) in which the EKC in France is studied by taking the role of nuclear energy into account. This paper uses the ARDL approach and provides evidence in support of the traditional EKC hypothesis. It also provides evidence of a negative causal relationship between nuclear energy and CO2 emissions.

Fosten et al. (2012) focused on data on CO2 and SO2 for the period 1830-2003 in the United Kingdom. This study also uses an autoregressive cointegration method to estimate the EKC hypothesis. The paper provides evidence in favour of the traditional EKC hypothesis for both CO2 and SO2 emissions. Additionally, the turning point for SO2 and CO2 in the UK were respectively 8167 and 7691 dollar.

Baek (2015) studies the EKC in the arctic countries. The paper used annual time series data at individual country levels for the period 1960-2010 and focused on CO2 emissions as measure of environmental impact. The data was processed using an autoregressive distributed lag (ARDL) cointegration technique. The results showed little support for the existence of the traditional EKC hypothesis in the case of the Arctic countries.

One of the papers that use N2O as a measure for environmental degradation is the paper by Zambrano-Monserrate & Fernandez (2017). This paper studies the EKC in Germany for the period 1970-2012. The authors use an ARDL methodology in order to find a long term relationship. The results showed evidence in support of the traditional EKC hypothesis and a turning point was found of 27.880 dollars.

2.3.2 Multiple country studies

Martínez-Zarzoso and Bengochea-Morancho (2004) tested the existence of an environmental Kuznets curve for CO2 emissions in 22 OECD countries for the period 1975 to 1998. The authors used a pooled mean group estimator (PMG) including cubic terms for GDP per capita. The results showed evidence in support of a N-shaped EKC for most of the countries.

López-Menéndez et al. (2014) studied the relationship between CO2 emissions and per capita GDP for 27 countries of the European Union in the period 1996-2010. The paper used both the fixed effects and random effects method to estimate the models. At first, the Hausman was performed to select the most suitable option. The results showed that the parameters show an inverted N-shaped curve. However, with the inclusion of a new variable that proxies for renewable energy intensity, the traditional EKC hypothesis is supported for countries with a high level of renewable energy intensity.

Besides CO2 and N2O, there have also been studies that took the ecological/environmental footprint in consideration. For example, Aydin et al. (2019) used data of 26 European Union countries for the period 1990-2013. The authors found no evidence in support of the EKC with the use of the environmental footprint as measure of environmental degradation. Another paper that used data on the ecological footprint is the study by Altintas & Kassouri (2020).

This study has the most resemblance with this thesis, since the authors also use multiple measures of environmental degradation. They include both the CO2 emissions and the ecological footprint as measures. Data on 14 European countries for the period 1990-2014 was used and resulted in the conclusion that there was no evidence of an inverted U-shaped EKC for CO2 emission and that there was only little evidence in support of the traditional EKC hypothesis for the ecological footprint dependable on the indicators used to form the ecological footprint. Finally, Adedoyin et al. (2020) provides evidence in support of the traditional EKC hypothesis by using data from 16 EU countries in the period 1997-2014.

Dogan and Inglesi-Lotz (2020) used CO2 emissions to study the EKC. The authors used data from 7 European countries in the period 1980-2014. The methodology starts by multiple panel unit root tests, then panel cointegration tests, and eventually estimators are constructed with a long-run OLS (FMOLS) technique. The results showed evidence in support of the EKC hypothesis.

Madaleno and Moutinho (2021) is an example of a paper that studied the EKC for N2O emissions. The authors also collected data on CO2, CH4 (methane gas), and total GHG emissions. The data included the 27 countries from the EU for the period 2008-2018, which was processed with the help of fixed effects and OLS techniques. The results supported mostly a U-shaped curve, which is not in line with the traditional EKC hypothesis. However, the authors also divided the 27 EU countries into two groups based on oldest to newest addition into the EU. In this analysis the “new” group of 12 EU countries showed an inverted U-shaped curve, therefore, supporting the traditional EKC hypothesis.

2.4 Worldwide studies

Al-mulali et al. (2015) is another paper that does not focus on CO2 emissions as measure of environmental impact, instead it focuses on the ecological footprint. The authors used annual panel data on 93 countries, and categorized them on income. The methodology is specified using a standard panel model including fixed country and time effects. The results showed support for the EKC hypothesis between GDP growth and the ecological footprint for upper middle- and high-income countries, but not for low- and lower middle-income countries.

Özokcu and Özdemir (2017) presented two models in their paper based on CO2 emissions data for the period 1980-2010. The first model analyzed 26 OECD countries with high income levels, while the second model analyzed 52 emerging countries. The results of both models show no support of the EKC hypothesis, since the high income OECD countries show an inverted N-shaped curve and the emerging countries show an N-shaped curve. However, Bibi & Jamil (2021) also focused on CO_2 emissions and came to a different conclusion. The authors used data on six different regions around the world for the period 2000 to 2018. The random effect and fixed effect models in this paper showed support of the EKC hypothesis in every region except in the Sub-Saharan African region.

Sinha and Sengupta (2019) focused solely on N_2O emissions as dependent variable. The authors analyzed the EKC hypothesis for APEC countries over the period of 1990-2015. The results showed evidence of an N-shaped EKC, and therefore, the traditional EKC hypothesis was not supported.

The main consideration that can be extracted from above studies is that the EKC literature is extensive with different outcomes. It seems that a substantial amount of studies provide evidence in support of the traditional EKC hypothesis (i.e. the inverted U-shaped EKC). However, there are also a number of studies that find evidence of other forms of EKC (e.g. the N-shaped EKC) or find little to no evidence in support of an EKC whatsoever. Additionally, most of the existing literature focuses solely on CO_2 as measurement for environmental degradation. This thesis contributes to existing literature in studying multiple measures of environmental degradation with a unique combination of independent variables. To my knowledge, there are no other papers that compare CO_2, N_2O, and the environmental footprint as measures of environmental degradation in multiple countries.

3. Data and methodology

The data used in this thesis consists of annual data between 1971-2018. In total, 28 European countries that form the European Union (as of 2018) will be included in the dataset. The countries included are: Austria, Belgium, Denmark, Croatia, Cyprus, Czech Republic, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovenia, Slovak Republic, Spain, Sweden, and the United Kingdom. However, ecological footprint data on Bulgaria, Cyprus, Finland, Hungary, Ireland, and Malta is not available. Therefore, this regression only includes 22 of the 28 EU countries and only includes data between 1971-2017.

3.1 Dependent variables

This thesis focuses on CO_2, N_2O, and the ecological footprint as measures of environmental degradation. Therefore, these are the three dependent variables in this thesis. CO_2 emissions are one of the biggest causes of rising temperatures globally out of all the greenhouse gasses.

This is mainly due to the use of fossil fuels and deforestation. CO_2 and N_2O are able to absorb and emit infrared radiation. However, the rising levels of CO_2 and N_2O in the atmosphere over the last 100 years have caused more infrared radiation to be trapped near the surface of the earth instead of the upper atmosphere. Therefore, the surface of the earth experiences higher temperatures while the upper atmosphere is relatively cooler since less energy reaches that far into the atmosphere (UCAR, 2012). The CO_2 and N_2O emissions data have been retrieved from the World Bank (2021) and cover the period 1971-2018. Figure 3.1 shows the logarithmic function of CO_2 emissions on the y axis and the logarithmic function of GDP on the x axis. The outlier in this figure is Luxembourg, with a maximum of 40.59 (3.70 in logarithmic form) metric tons per capita CO_2 emission in 1974. However, this number gradually declines up to 2018. An explanation for these large values is that Luxembourg is a country with relatively high GDP per capita and relatively few inhabitants, and therefore, the total level of CO_2 emission is divided by a smaller number resulting in high per capita values. At first sight, Figure 3.1 does show a resemblance of an inverted U-shaped curve relationship for certain countries. However, it is not clear from the graph and further tests are necessary.

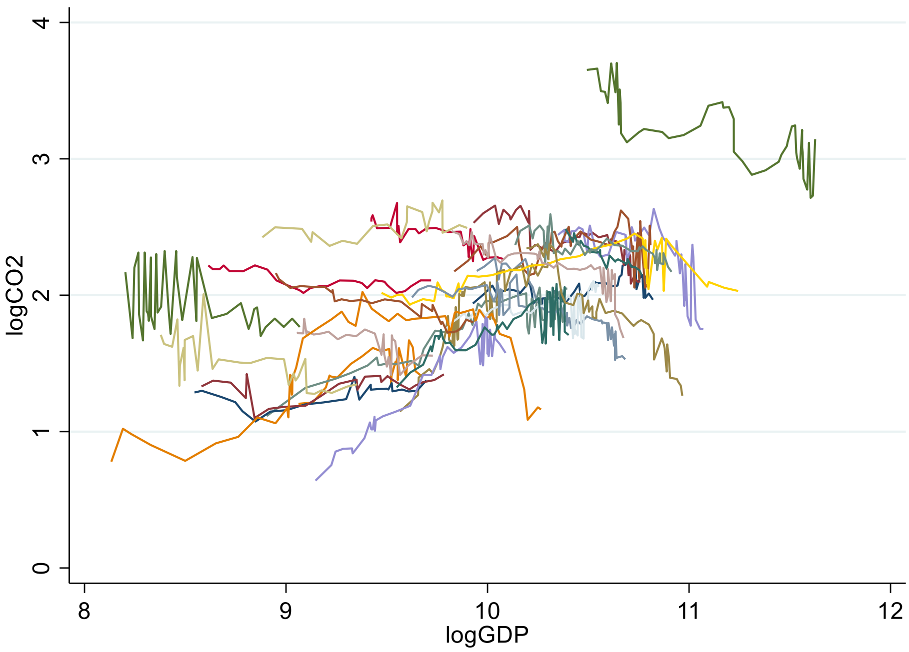

Figure 3.1 Logarithmic function of CO_2 emissions over the logarithmic function of GDP

Notes: Data in this Figure are drawn from The World Bank (2021). Out of the 28 countries, some recorded missing values before 1990. These countries include Croatia, Czech Republic, Estonia, Germany, Latvia, Lithuania, Slovak Republic, Slovenia.

Figure 3.2 shows the logarithmic function of N2O emissions on the y axis and the logarithmic function of GDP on the x axis. The three outliers in this figure are respectively Cyprus, Luxembourg, and Malta. Cyprus reported a minimum of 159.97 (5.07 in logarithmic form) N2O emission in 1977, Luxembourg a minimum of 210.00 (5.35 in logarithmic form) N2O emission in 2000, and Malta a minimum of 37.55 (3.63 in logarithmic form) N2O emission in 1974. Unlike the per capita definition of CO2 emissions, the N2O emissions are being defined as thousand metric tons of CO2 equivalent. Therefore, it is no surprise that these three countries have the lowest level of N2O emissions since they are also relative small countries. At first sight, it is hard to see any pattern in the data since the variation in logN2O values are quite high between the different countries. In fact, looking at the countries individually, a wide range of relationships can be seen. Some countries show a resemblance of an increasing or decreasing function, while others seem to have no relationship at all. Some other countries have increasing N2O values at first and decreasing N2O values with higher values of GDP, or the other way around. This means that Figure 3.2 shows no clear relationship. Therefore, an inverted U-shaped curve relationship is still possible and further tests are necessary.

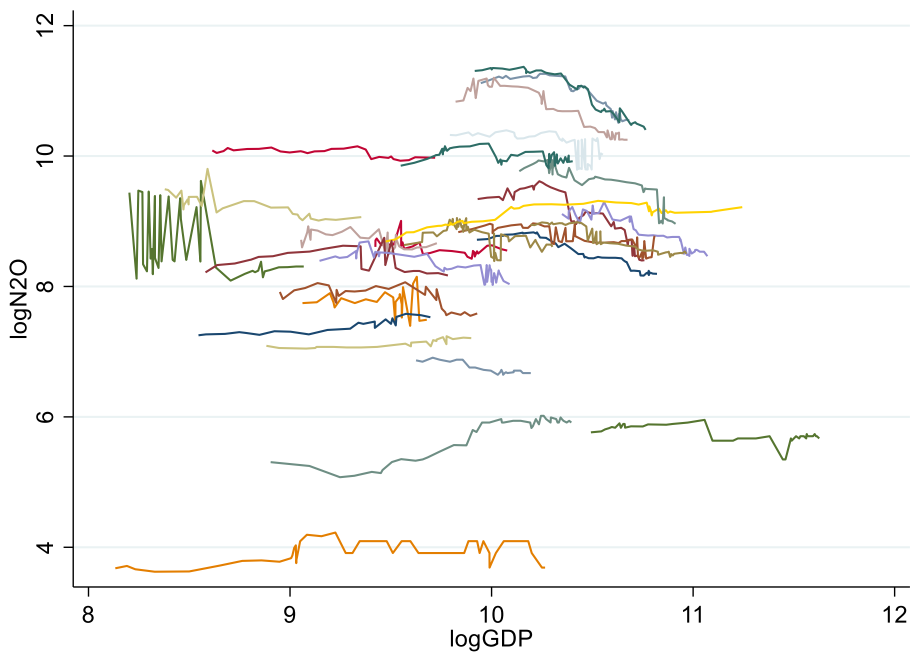

Figure 3.2 Logarithmic function of N2O emissions over the logarithmic function of GDP

Note: Data in this Figure are drawn from The World Bank (2021).

The ecological footprint is “a measure of the biologically productive land and water area an individual, population or activity requires to produce all the resources it consumes, to accommodate its occupied urban infrastructure, and to absorb the waste it generates, using prevailing technology and resource management practices" (Global Footprint Network, 2021). The ecological footprint consists of five components, which are: Cropland, Forest land, Fishing grounds, Grazing land, and Build-up land. The weighted average of these components is the ecological footprint per person that is being used in this thesis. The data for the ecological footprint has been retrieved from the Global Footprint Network (2021) database for the period 1971-2017. Figure 3.3 shows the logarithmic function of the ecological footprint on the y axis and the logarithmic function of GDP on the x axis. The outlier in this figure is Luxembourg, with a maximum of 17.78 (2.88 in logarithmic form) in 2003. Once again, this may be due to the relatively high GDP per capita and low population. At first sight, Figure 3.3 seems to show evidence of an increasing relationship between the ecological footprint and GDP. However, looking at the individual countries data, some countries seem to resemble an inverted U-shaped curve relationship as well. Further tests need to be conducted to provide clearer evidence of the relationship between the ecological footprint and GDP.

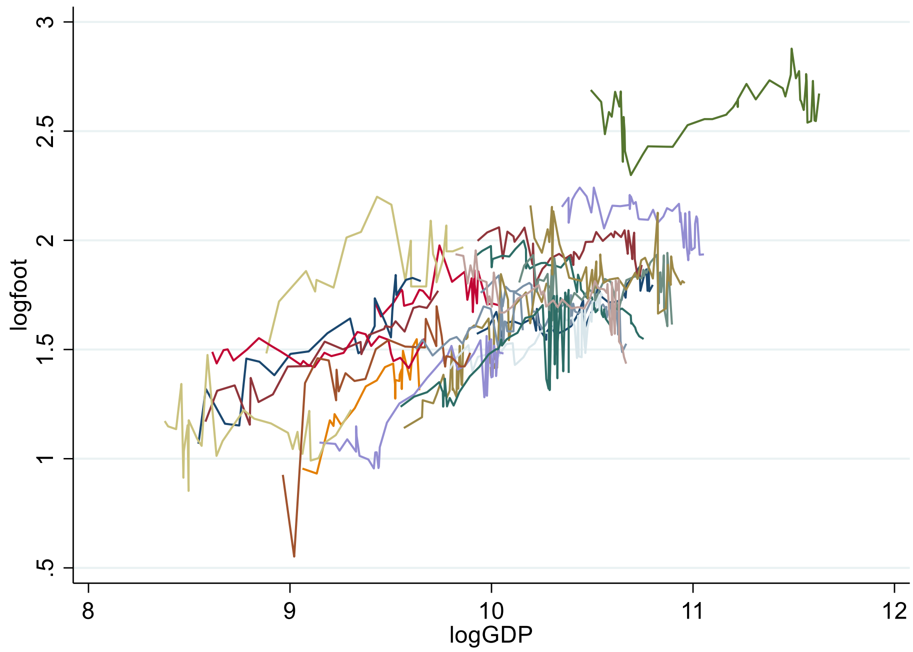

Figure 3.3 Logarithmic function of the ecological footprint over the logarithmic function of GDP

Notes: Data in this Figure are drawn from Global Footprint Network (2021). Out of the 28 countries, some recorded missing values before 1992 (Croatia, Estonia, Latvia, Lithuania, Slovenia) and some before 1993 (Czech Republic, Slovak Republic).

3.2 Independent variables

The aim of this thesis is to find the relation between the dependent variables CO2, N2O, and the ecological footprint on one side and the independent variable GDP per capita on the other side. However, certain control variables must also be taken into account. First, data on the population of a country will be taken as control variable. Grossman and Krueger (1995) were one of the first to include population data in their study and their results showed that population growth was a key predictor for environmental degradation. Apart from that, other studies have also included population data in EKC related studies (Apergis & Ozturk, 2015; Dogan & Inglesi-Lotz, 2020; Hamilton and Turton, 2002; Sinha & Bhattacharya, 2017; Wang et al., 2016) and also found a positive relation between population growth and environmental degradation. Hamilton and Turton (2002) even argued that growth in emissions across the OECD countries were mainly due to both GDP per capita and population growth.

Second, data on energy consumption has been widely included in EKC related papers. Often, studies include a variable that accounts for energy consumption per capita (Baek, 2015; Shahbaz et al., 2013; Atici, 2009). Other studies used multiple variables to account for energy use. For example, Altintas & Kassouri (2020) used a variable named 'Renewable Energy' that measures the contribution of renewable energy to total primary energy supply and a variable named 'Fossil' that measured the consumption of fossil fuels. Sinha & Shahbaz (2018) also include a variable that captures per capita renewable energy generation in their paper. These studies often find that energy consumption has a detrimental effect on the environment. In particular, fossil fuels often have a detrimental effect, while a higher share of renewable energy offsets the negative effect on the environment.

The variables that measure financial development and trade openness are often used together in existing literature. Financial development is often proxied by domestic credit to private sector per capita, while trade openness is often proxied by the ratio of goods traded to GDP. The paper by Tamazian et al. (2009) focused on the effect of a country's economic and financial development on environmental quality and showed that a higher level of economic and financial development reduced CO2 levels. Jalil and Mahmud (2009) included the openness ratio as a control variable and observed a negative and insignificant effect on CO2 emissions in China.

The industry share also defines the economic development of a country, since it enables production and industrial activities. Therefore, it has been included in numerous studies as a control variable (Apergis & Ozturk, 2015; Dogan & Inglesi-Lotz, 2020; Tamazian et al., 2009). Besides that, Grossman and Krueger (1995) also mentioned the importance of industry as determinant of environmental degradation. This thesis also controls for the industry share of a country via a variable that captures the industry share in percentage of GDP.

Urbanization can also be the cause of environmental degradation, since higher levels of urbanization are often accompanied by an increase in energy usage and gas emissions. Therefore, urbanization has often been included in EKC related papers (Al-mulalia et al., 2015; Dogan & Inglesi-Lotz, 2020; Iwata et al., 2010; Wang et al., 2016). Al-mulalia et al. (2015) found that urbanization has a positive effect on the ecological footprint of lower middle-, upper middle- and high-income countries.

Another variable that is being used in this thesis is foreign direct investment (FDI). FDI is often transferred from developed to developing countries. Even though this thesis studies the EKC hypothesis in developed countries, it may still be possible that there are other countries with more environment-friendly technologies and that these technologies are being transferred in the form of FDI to one or multiple countries that are being studied in this thesis.

A country can also boost its own development of technologies with the help of R&D costs. Especially with international competition, countries must innovate to grow (or even maintain) their real incomes (Dinda, 2004). Therefore, technical innovation is often necessary for a country to grow. Increased funding on R&D in renewable energy is especially helpful for the ecological transition that many countries desire (Zafar et al., 2019). This thesis includes R&D costs as a control variable, following the paper of Tamazian et al. (2009).

Education is also used in this thesis as a variable that may affect environmental quality. Individuals with a higher education could have a higher awareness and understanding of environmental degradation, which could change environmental quality in multiple ways. First, education could change the mentality of an individual towards the environment and how they relate themselves to the environment. Second, people with a higher education can also engage in economic activities that are helpful to the environment. For example, these individuals can orient themselves towards using renewable energy or buy goods and services that are less harmful to the environment. Therefore, education can offer an individual the necessary determination, knowledge, skills and values that are needed to prevent the scarcity of natural resources (Constantinescu, 2014). However, education will also increase per capita income due to economic growth. This would cause an individual to be able to purchase more of polluting goods and services such as cars. On the other hand, economic growth is also associated with an increase in social awareness and stricter environmental standards. It also increases the creation of resources that are needed for a decline in pollution (Balaguer & Cantavella, 2018). A summary of the variables including their measurements and sources can be found in Table 3.1. In addition, Table 3.2 shows the descriptive statistics.

Table 3.1 Variable measurement and sources

Code	Variable	Measurement	Source
CO2	CO2 emissions	Metric tons per capita	World Development Indicators (2021)
N2O	N2O emissions	Thousand metric tons of CO2 equivalent	World Development Indicators (2021)
PRINT	Ecological footprint	Global hectares (gha) per person	Global Footprint Network (2021)
GDP	Gross domestic product	GDP per capita (constant 2010 US dollar)	World Development Indicators (2021)
POP	Population	Total population	World Development Indicators (2021)
ENERG	Energy use	Kg of oil equivalent per capita	World Development Indicators (2021)
DEV	Financial development	Domestic credit to private sector as % of GDP	World Development Indicators (2021)
OPEN	Trade openness	Imports and exports as % of GDP	World Development Indicators (2021)
INDUS	Industrialization	Industry (including construction), value added (% of GDP)	World Development Indicators (2021)
URB	Urbanization	Total population in urban cities	World Development Indicators (2021)
FDI	Foreign direct investment	Net inflows as % of GDP	World Development Indicators (2021)
RD	R&D	Research and development expenditures as % of GDP	Environment Social and Governance (ESG) Data (2021)
EDUC	Education	Educational attainment, at least completed upper secondary, population 25+, total (%) (cumulative)	World Development Indicators (2021)

Table 3.2 Descriptive statistics

	Obs	Mean	Std. Dev.	Min.	Max.
CO2 (metric tons p.c.)	1.192	8.332	4.542	1.898	40.590
N2O (1000 metric tons)	1.344	13242.14	17566.98	37.552	86568.43
Footprint (gha p.c.)	885	5.780	2.328	1.736	17.778
GDPpercap (in 2010 US$)	1169	28266.78	18109.06	3405.642	111,968.3
Population (total)	1400	17,300,000	21,800,000	301,996	83,200,000
Energyuse (kg p.c.)	1158	3448.414	1651.237	687.988	13023.89
Financial development (%)	670	78.025	45.177	0	255.310
Trade openness (%)	1166	98.128	58.634	23.319	408.362
Industry share (%)	934	26.138	8.111	9.985	64.100
Urbanization (total)	1400	12,300,000	16,300,000	256,310	64,500,000
FDI (%)	1109	6.866	27.660	-58.323	449.083
R&D (%)	504	1.386	.856	.204	3.914
Educational attainment (%)	348	65.715	18.959	12.8	91.145

3.3 Regression models

The methodology will include three regression formulas that will look as follows:

$$lnCO2_{it} = \beta 0 + \beta 1 lnGDP_{it} + \beta 2 lnGDP_{it}^2 + \beta 3 lnGDP_{it}^3 + \beta 4 lnPOP_{it} + \beta 5 lnURB_{it} + \beta 6 lnENERG_{it} + \beta 7 lnOPEN_{it} + \beta 8 lnFDI_{it} + \beta 9 lnIND_{it} + \beta 10 lnDEV_{it} + \beta 11 lnRD_{it} + \beta 12 lnEDUC_{it} + \varepsilon_{it}$$

$$lnN2O_{it} = \gamma 0 + \gamma 1 lnGDP_{it} + \gamma 2 lnGDP_{it}^2 + \gamma 3 lnGDP_{it}^3 + \gamma 4 lnPOP_{it} + \gamma 5 lnURB_{it} + \gamma 6 lnENERG_{it} + \gamma 7 lnOPEN_{it} + \gamma 8 lnFDI_{it} + \gamma 9 lnIND_{it} + \gamma 10 lnDEV_{it} + \gamma 11 lnRD_{it} + \gamma 12 lnEDUC_{it} + \varepsilon_{it}$$

$$lnPRINT_{it} = \alpha 0 + \alpha 1 lnGDP_{it} + \alpha 2 lnGDP_{it}^2 + \alpha 3 lnGDP_{it}^3 + \alpha 4 lnPOP_{it} + \alpha 5 lnURB_{it} + \alpha 6 lnENERG_{it} + \alpha 7 lnOPEN_{it} + \alpha 8 lnFDI_{it} + \alpha 9 lnIND_{it} + \alpha 10 lnDEV_{it} + \alpha 11 lnRD_{it} + \alpha 12 lnEDUC_{it} + \varepsilon_{it}$$

Where $CO2_{it}$ indicates CO2 emission per capita in country i at time t; $lnN2O_{it}$ the N2O emission per capita in country i at time t; $PRINT_{it}$ the ecological footprint per capita in country i at time t; GDP_{it} the GDP per capita in country i at time t; POP_{it} the population in country i at time t; URB_{it} the urbanization share as percentage of population in country i at time t; $ENERG_{it}$ the energy use per capita in country i at time t; $OPEN_{it}$ the ratio of goods traded to GDP in country i at time t; FDI_{it} the degree of foreign direct investment in country i at time t; IND_{it} the industry share as percentage of GDP in country i at time t; DEV_{it} the real domestic credit to private sector per capita in country i at time t; RD_{it} the amount of research and development expenditure as percentage of GDP in country i at time t; $EDUC_{it}$ the primary school enrollment in country i at time t.

3.4 Hypotheses

The aim of this thesis is to find the different type of relationships between three different measures of environmental degradation and GDP per capita. Existing literature has often identified an inverted U-shaped curve relationship between GDP and measures of environmental degradation. Therefore, the three null hypotheses in this thesis are:

H1: The relationship between EU's GDP per capita and CO2 levels follows an inverted U-shaped curve.

H2: The relationship between EU's GDP per capita and N2O levels follows an inverted U-shaped curve.

H3: The relationship between EU's GDP per capita and ecological footprint levels follows an inverted U-shaped curve.

These hypotheses are being tested with the help of fixed- and random effects models, following a large part of the existing literature (e.g. López-Menéndez et al., 2014; Cole et al., 1997; Koop & Tole, 1999). Also, the Hausman test is being included to show which model is more suitable for the data. The Hausman test tests the null hypothesis that the preferred model is the random effects model. In case the value of the Hausman test is significant at the 5% level (<0.05), the null hypothesis can be rejected and the fixed effects model will be the preferred model. Besides that, this thesis deviates from most of the existing literature on the environmental Kuznets curve by allowing polynomial terms to the third power for GDP per capita. Table 3.3 shows the different type of relationships between GDP per capita and the different measures for environmental degradation. In case of an inverted U-shape or U-shape relationship, the turning point can be calculated by: $\varphi = \exp\left(-\beta_1/2\beta_2\right)$. However, if β_3 shows a value other than 0, the turning points can be calculated by $\varphi_i = \exp\left(\frac{-\beta_2 \pm \sqrt{{\beta_2}^2 - 3\beta_1\beta_3}}{3\beta_3}\right), \forall_i = 1,2$ (Plassmann & Khanna, 2007).

Table 3.3 Different forms of relationship between economic growth and evironmental degradation

Relationship between GDP and CO2/N2O/Footprint	Coefficients
No relationship (flat pattern)	$\beta_1 = \beta_2 = \beta_3 = 0$
Monotonic increasing or linear relationship	$\beta_1 > 0$ and $\beta_2 = \beta_3 = 0$
Monotonic decreasing	$\beta_1 < 0$ and $\beta_2 = \beta_3 = 0$
Inverted U-shape (traditional EKC)	$\beta_1 > 0, \beta_2 < 0$ and $\beta_3 = 0$
U-shape	$\beta_1 < 0, \beta_2 < 0$ and $\beta_3 = 0$
N-shape	$\beta_1 > 0, \beta_2 < 0$ and $\beta_3 > 0$
Inverted N-shape	$\beta_1 < 0, \beta_2 > 0$ and $\beta_3 < 0$

4. Results

This section provides the results through empirical analysis. Each of the dependent variables (lnCO2, lnN2O, and lnPRINT) have been analyzed with the help of a fixed effects and random effects model. In terms of robustness checks, the Hausman test and a joint test to see if time dummies are needed in the fixed effects model have been conducted.

The tables are organized based on the importance and availability of the variables. Some variables reported missing values for certain countries and/or years. However, the fixed effects and random effects models exclude observations within a country for certain years if not all variables have a reported value (i.e. no missing values). Therefore, the control variables have been placed in order of their number of observations. This has been done in order to allow multiple tests with gradually more control variables, and still maintain the maximum amount of observations. The only exceptions are the three variables of interest (lnGDP, lnGDP^2, and lnGDP^3), since they have been placed first in the tables because of their importance in testing the hypotheses.

Often, existing literature have focused on exploring the relationship between GDP and environmental forms of degradation without any control variables. Therefore, this thesis also includes this regression in the first columns of both models. In case existing literature added control variables to their regression, it was often one or two control variables that were also a main point of focus throughout the paper. Therefore, the second columns in both models show the inclusion of the variables lnPOP, lnURB, and lnENERG. These variables have often been shown in existing literature to have a meaningful effect on different measures of environmental degradation. Finally, the remaining control variables of this thesis have been added in the third columns.

4.1 Regression results

4.1.1 CO2

Table 4.1 shows the regression results including the logarithmic values of CO2 emissions in the 28 European Union countries as the dependent variable. The first columns of both models (Columns 1 and 4) show the regressions including only the three GDP variables. These coefficients are respectively negative, positive, and negative. Besides that, the coefficients are all significant at the 1% level. Looking back at Table 3.3, this would indicate an inverted N-shaped curve. However, after the inclusion of certain control variables the coefficients change in sign (Columns 2 and 5). Especially the addition of the control variable for per capita energy use seems to have a relatively large effect on the level of per capita CO2 emission. The R-squared also increased significantly in both models after the addition of the first three control variables, which means that both models fit the data better. The number of observations have slightly decreased because of missing values, but this seems to be a relatively small number. The coefficients of the GDP variables are now respectively positive, negative, and positive. They are also significant at the 1% level and would therefore indicate an N-shaped curve. The last columns in both models (Columns 3 and 6) show the results with the inclusion of all control variables that are being used in this thesis. The signs of the three variables of interest have not changed relative to the addition of only the first three control variables, and therefore, the coefficients are also respectively positive, negative, and positive. These coefficients are all significant at the 5% level in the fixed effect model and at the 10% level in the random effects model. The R-squared also slightly increased in both models. However, the amount of observations decreased significantly since the additional control variables have more missing values.

Apart from the variables of interest (GDP, GDP^2, and GDP^3), other control variables also show a relationship with the logarithmic values of per capita CO2 emission. The per capita use of energy seems to have a relatively high and significant positive effect on lnCO2. This is in line with what is expected since it is known that especially fossil fuels is a large contributor to increasing CO2 levels. Besides that, population and education also seem to have a significantly positive relationship with CO2 levels, whereas urbanization levels and R&D expenses seem to have a significantly negative effect on CO2 levels. The positive effect of population and the negative effect of R&D are in line with the expectation, whereas the negative effect of urbanization and the positive effect of education are not in line with the expectation. However, the positive effect of education is relatively small and only significant at the 10% level in the fixed effect model.

The F test shows whether the entire model is significant or not. Table 4.1 shows an F-test value of 0.000 in every column, which means that every column shows a significant regression model. The Hausman test in Columns 2 and 3 show a value higher than 0.05, which means that the random effects model is the preferred model in this case. Columns 5 and 6 both show evidence in support of an N-shaped curve after the addition of control variables. The results, with the addition of the control variables, are in line with the paper by Martínez-Zarzoso and Bengochea-Morancho (2004) mentioned earlier, which uses cubic terms for GDP on data of 22 OECD countries. This paper also found evidence in support of an N-shaped curve between CO2 and GDP per capita.

Table 4.1: Regression results for logarithmic CO2 emission levels in the EU-28.

Variables	OLS (FE) *Dependent variable: $LnCO2_{it}$*			OLS (RE) *Dependent variable: $LnCO2_{it}$*		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
$LnGDP_{it}$	**-31.536*** (3.658)**	**13.015*** (2.338)**	**19.759** (7.780)**	**-31.634*** (3.679)**	**12.547*** (2.342)**	**13.400* (7.304)**
$LnGDP\char`^2_{it}$	**3.383*** (0.372)**	**-1.261*** (0.239)**	**-2.073** (0.815)**	**3.390*** (0.374)**	**-1.221*** (0.239)**	**-1.379* (0.761)**
$LnGDP\char`^3_{it}$	**-0.120*** (0.013)**	**0.040*** (0.008)**	**0.072** (0.028)**	**-0.120*** (0.013)**	**0.038*** (0.008)**	**0.047* (0.026)**
$LnPOP_{it}$		0.331*** (0.106)	0.458 (0.302)		0.179** (0.079)	0.381* (0.210)
$LnURB_{it}$		-0.201*** (0.073)	-0.812*** (0.273)		-0.168** (0.071)	-0.426** (0.208)
$LnENERG_{it}$		1.087*** (0.026)	1.275*** (0.068)		1.095*** (0.025)	1.277*** (0.063)
$LnOPEN_{it}$			0.001 (0.040)			-0.012 (0.039)
$LnFDI_{it}$			-0.001 (0.003)			-0.000 (0.003)
$LnIND_{it}$			0.059 (0.062)			0.065 (0.049)
$LnDEV_{it}$			0.007 (0.007)			0.004 (0.007)
$LnRD_{it}$			-0.058** (0.024)			-0.062*** (0.023)
$LnEDUC_{it}$			0.101* (0.058)			0.020 (0.050)
_cons	98.980*** (11.947)	-52.366*** (7.750)	-65.384*** (24.694)	99.335*** (12.019)	-48.855*** (7.706)	-50.778** (23.368)
Time Effects	NO	NO	NO	NO	NO	NO
Hausman	-	0.0823	0.0775			
R^2	0.1861	0.7519	0.8712	0.1858	0.7511	0.8674
N	1094	1003	217	1094	1003	217
F	.000	.000	.000	.000	.000	.000

Note: OLS is Ordinary Least Square regression; FE is Fixed Effects and RE is Random Effects; robust standard errors are reported in parentheses. *$^*p<0.1$ $^{**}p<0.05$ $^{***}p<0.01$*

4.1.2 N2O

The second type of environmental degradation measure analyzed in this thesis is N2O, and the regression results can be found in Table 4.2. Just like the CO2 results, the first columns in both models show respectively negative, positive, and negative coefficients. However, these coefficients are not statistically significant and can give no meaningful indication of an EKC type. Columns 2 and 5 do show statistically significant coefficients for the GDP variables at the minimum level of 5% and the signs changed to respectively positive, negative, and positive. This indicates an N-shaped EKC. Once again, the R-squared increased significantly in both models (especially in the random effects model) and the number of observations decreased by only a relative small amount. After the inclusion of all the other control variables (Columns 3 and 6) the three GDP variables show no change in sign. However, they do become statistically insignificant in both models. The R-squared increases slightly, while the amount of observations have significantly decreased. This decrease in observations could be the reason that the GDP variables have become statistically insignificant.

Other control variables that show statistical significance in both models are population, urbanization, and per capita use of energy. In contrast to previous table with lnCO2 as dependent variable, the per capita use of energy shows a smaller reported relationship in both models while population and urbanization report a more prominent relationship with lnN2O in both models. The variables concerning energy use and population are positive, while the urbanization variable is negative. The burning of fossil fuels is a less prominent factor in generating N2O emissions comparing to generating CO2 emissions. Therefore, it is expected that the coefficient for energy use is still positive but smaller relative to previous table. Also, it is known that N2O emissions are often formed due to agricultural or chemical processes. Therefore, the positive relationship with population and the negative effect with urbanization are expected. Furthermore, the variable openness seems to have a negative effect at the 10% significance level in the random effects model while education has a positive effect at the 10% significance level in the fixed effects model.

Every regression model in Table 4.2 shows a statistically significant value (F-test value of 0.000 in every column). The Hausman test in Columns 1 and 3 show a value higher than 0.05 which means that the random effects model is preferred, while Column 2 shows a value lower than 0.05 which means that the fixed effects model is preferred. The evidence in support of an N-shaped EKC was also found in the case of APEC countries (Sinha & Sengupta, 2019).

Table 4.2: Regression results for logarithmic N2O emission levels in the EU-28.

Variables	**OLS (FE)** *Dependent variable: $LnN2O_{it}$*			**OLS (RE)** *Dependent variable: $LnN2O_{it}$*		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
$LnGDP_{it}$	**-3.356 (4.388)**	**14.703*** (4.411)**	**19.128 (15.333)**	**-3.635 (4.397)**	**14.696*** (4.447)**	**14.286 (14.427)**
$LnGDP\text{^}2_{it}$	**0.463 (0.446)**	**-1.331*** (0.451)**	**-2.003 (1.606)**	**0.492 (0.447)**	**-1.355*** (0.455)**	**-1.408 (1.501)**
$LnGDP\text{^}3_{it}$	**-0.021 (0.015)**	**0.038** (0.015)**	**0.070 (0.056)**	**-0.022 (0.015)**	**0.039*** (0.015)**	**0.046 (0.052)**
$LnPOP_{it}$		2.667*** (0.202)	3.030*** (0.596)		2.241*** (0.151)	2.937*** (0.402)
$LnURB_{it}$		-1.202*** (0.139)	-3.345*** (0.537)		-1.112*** (0.137)	-2.012** (0.397)
$LnENERG_{it}$		0.408*** (0.050)	0.398*** (0.134)		0.459*** (0.047)	0.587*** (0.125)
$LnOPEN_{it}$			-0.111 (0.080)			-0.145* (0.078)
$LnFDI_{it}$			-0.000 (0.005)			-0.001 (0.006)
$LnIND_{it}$			-0.064 (0.122)			0.043 (0.097)
$LnDEV_{it}$			-0.002 (0.014)			-0.013 (0.014)
$LnRD_{it}$			0.005 (0.047)			0.022 (0.046)
$LnEDUC_{it}$			0.219* (0.114)			0.073 (0.097)
_cons	16.485 (14.330)	-69.947*** (14.588)	-51.754 (48.671)	17.257 (14.364)	-64.357*** (14.617)	-59.723 (46.177)
Time Effects	NO	NO	NO	NO	NO	NO
Hausman	1.0000	0.0004	0.3878			
R^2	0.1845	0.3737	0.4198	0.0000	0.8576	0.8985
N	1113	1022	217	1113	1022	217
F	.000	.000	.000	.000	.000	.000

Note: OLS is Ordinary Least Square regression; FE is Fixed Effects and RE is Random Effects; standard errors are reported in parentheses. **p<0.1* ***p<0.05* ****p<0.01*

4.1.3 Ecological footprint

The ecological footprint is the third type of environmental degradation measure that is being studied in this thesis. The results of this regression can be found in Table 4.3. Columns 1 and 4 show respectively positive, positive, and negative signs for the variables of interest. However, none of the coefficients is statistically significant. On the other hand, the variables of interest are statistically significant at 1% in both models with the addition of the first three control variables (Columns 2 and 5) and show respectively positive, negative, and positive coefficients. This would indicate an N-shaped EKC. The R-squared also increased significantly in both models and the number of observations dropped by a relative small amount. After the addition of all the other control variables (Columns 3 and 6), all three GDP variables changed signs in the fixed effect model but not in the random effect model. However, the coefficients are statistically insignificant and should not be used to give a meaningful conclusion regarding the type of EKC. Besides that, the number of complete observations dropped significantly to a point where it could be the reason for the insignificant results.

Similar to the previous tables, the control variable for per capita energy use has a positive coefficient which is also statistically significant at the 1% level in both models. However, the control variables for population and urbanization show different signs in the regressions. The population variable is only statistically significant in the random effects model at respectively 5% and 1%, but shows a positive sign in Column 5 and negative in Column 6. Something similar is occurring for the variable urbanization, which shows a negative sign in Columns 2 and 5 (at the 1% significance level) and a positive sign in Column 6 (at the 5% significance level). Besides that, the industry variable shows a positive relationship and the openness and R&D variables show a negative relationship. These are all statistically significant at the 1% level in both models.

The F-test values are all 0.000 in Table 4.3, which means that every regression model is statistically significant. The Hausman test values are also significant (<0.05), which means that the fixed effects model is preferred. Due to a lack of existing literature that focuses on the environmental footprint as measure of environmental degradation, with the inclusion of a cubic term for GDP, it is not possible to compare these results to similar papers.

Table 4.3: Regression results for logarithmic ecological footprint levels in the EU-28.

Variables	**OLS (FE)** *Dependent variable: $LnPRINT_{it}$*			**OLS (RE)** *Dependent variable: $LnPRINT_{it}$*		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
$LnGDP_{it}$	**0.952 (3.434)**	**34.953*** (3.063)**	**-8.357 (17.185)**	**0.935 (3.469)**	**32.150*** (3.121)**	**7.924 (12.319)**
$LnGDP\^2_{it}$	**0.018 (0.345)**	**-3.534*** (0.309)**	**0.773 (1.765)**	**0.016 (0.348)**	**-3.200*** (0.315)**	**-0.788 (1.243)**
$LnGDP\^3_{it}$	**-0.004 (0.012)**	**0.119*** (0.010)**	**-0.022 (0.060)**	**-0.004 (0.012)**	**0.106*** (0.011)**	**0.027 (0.042)**
$LnPOP_{it}$		-0.124 (0.164)	-0.774 (0.519)		0.186** (0.076)	-0.522*** (0.186)
$LnURB_{it}$		-0.326*** (0.084)	0.390 (0.472)		-0.220*** (0.072)	0.390** (0.179)
$LnENERG_{it}$		0.696*** (0.029)	0.609*** (0.110)		0.622*** (0.027)	0.517*** (0.078)
$LnOPEN_{it}$			-0.189*** (0.068)			-0.170*** (0.078)
$LnFDI_{it}$			0.004 (0.005)			0.005 (0.005)
$LnIND_{it}$			0.399*** (0.119)			0.415*** (0.083)
$LnDEV_{it}$			-0.002 (0.010)			0.003 (0.010)
$LnRD_{it}$			-0.097*** (0.036)			-0.140*** (0.046)
$LnEDUC_{it}$			0.044 (0.092)			0.073 (0.097)
_cons	-5.828 (11.355)	-111.679*** (10.392)	30.576 (55.820)	-5.728 (11.476)	-110.270*** (10.416)	-28.271 (40.662)
Time Effects	NO	NO	NO	NO	NO	NO
Hausman	-	0.0000	0.0028			
R^2	0.1732	0.5365	0.7125	0.3561	0.7526	0.8541
N	832	784	173	832	784	173
F	.000	.000	.000	.000	.000	.000

Note: OLS is Ordinary Least Square regression; FE is Fixed Effects and RE is Random Effects; robust standard errors are reported in parentheses. *$p<0.1$* *$**p<0.05$* *$***p<0.01$*

4.1.4 Turning points

After the addition of control variables, the three measures of environmental degradation all show an N-shaped curve relationship with GDP per capita. Looking at an example of an N-shaped EKC (Figure 4.1), the graph shows two turning points. The EU-28 countries can be placed, with the help of the mean GDP per capita in 2018, on this curve. The countries have a mean GDP per capita of 36253.93 in 2018, with the minimum being 8674.72 (Bulgaria) and maximum being 110701.88 (Luxembourg).

In case of CO2 (Table 4.1), the variables of interest are statistically significant with the inclusion of the first three control variables (Column 5) and with all the control variables (Column 6). However, the different coefficients result in different turning points. For Column 5, the turning points are 5183.418 (log: 8.553) and 387640.100 (log: 12.868) GDP per capita. This would mean that all EU-28 countries are on the negative slope between the two turning points. However, for Column 6, the turning points are 8066.442 (log: 8.995) and 38747.285 (log: 10.565). This would mean that most of the EU-28 countries are on the negative slope between the two turning points, but some countries are also on the positive slope behind the second turning point. In case of N2O, the variables of interest are only statistically significant with the addition of the first three control variables (Column 2). The turning points are 7830.585 (log: 8.966) and 1,767,514.248 (log: 14.385) GDP per capita. This would mean that all EU-28 countries are on the negative slope between the two turning points. However, relatively close to the first turning point since the second turning point has a relatively high value. In case of the ecological footprint, the variables of interest are also only statistically significant with the addition of the first three control variables (Column 2). The turning points are 14857.276 (log: 9.606) and 26690.804 (log: 10.192) GDP per capita. This would mean that most of the EU-28 countries are on the positive slope after the second turning point.

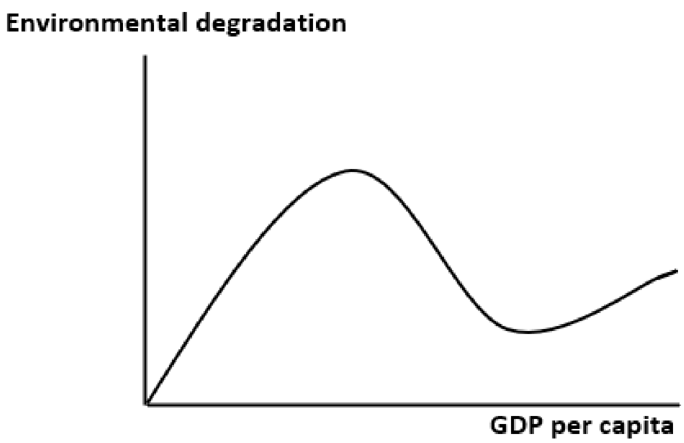

Figure 4.1 N-shaped Environmental Kuznets Curve

4.2 Robustness checks

The first robustness check used in this thesis is the Hausman test in order to decide whether fixed effects or random effects is the preferred model. The results of this test have already been discussed in the previous sections. The second robustness check involves a joint test that helps to decide whether time fixed effects are necessary. The third robustness check is to check whether the results would show an inverted U-curve EKC without the inclusion of the cubic term of lnGDP. Finally, the fourth robustness check includes the lagged values of the GDP variables in order to account for endogeneity problems.

4.2.1 Fixed time effects

The joint test for fixed time effects checks whether the dummies for all years are equal to zero, which means that no time fixed effects would be needed. The results (Table A1) show a value smaller than 0.05 for every regression, which means that the null hypothesis that the time dummies are equal to zero is rejected. Therefore, time fixed effects have been added to the regressions (Table A2-A4). For lnCO2, the results still indicate an N-shaped EKC with the inclusion of all the control variables in the fixed effects model (which is preferred according to the Hausman test). For lnN2O, the signs of the variables of interest seem to have changed to respectively negative, positive, and negative. Column 5 in Table A3 shows the preferred regression model according to the Hausman test with GDP variables that are also statistically significant at the 1% level. This means that, accounting for time fixed effects, the results show an inverted N-shaped EKC for lnN2O. The results concerning lnPRINT still indicate an N-shaped EKC with the addition of the control variables. However, with the time fixed effects the results indicate an inverted N-shaped EKC (negative, positive, negative coefficients) in both regressions without any control variables.

4.2.2 Results without cubic terms

Table 4.4 shows the results of the regressions including only lnGDP and lnGDP^2. This check is performed in order to determine whether the observations in this thesis are in line with the majority of existing literature on the EKC that only use linear and quadratic terms for GDP. For all three measures of environmental degradation in this thesis, the results in Table 4.4 show evidence in support of the traditional EKC hypothesis (the inverted U curve). The results only show the regressions without any control variables and time fixed effects, since adding them did not show any other statistically significant outcome. As discussed in the literature review section of this thesis, multiple papers that only included linear and quadratic terms for GDP found an inverted U curve shaped relationship between GDP and environmental degradation in the EU (Adedoyin et al., 2020; Dogan & Inglesi-Lotz, 2020;

Fosten et al., 2012; Iwata et al., 2010). However, these conclusions could have been stated prematurely since the addition of cubic terms could have resulted in evidence in support of another type of relationship between GDP and environmental degradation.

Table 4.4: Regression results for all three types of environmental degradation without cubic terms.

Variables	**OLS (FE)**			**OLS (RE)**		
	(1) *$LnCO2_{it}$*	(2) *$LnN2O_{it}$*	(3) *$LnPRINT_{it}$*	(4) *$LnCO2_{it}$*	(5) *$LnN2O_{i}$*	(6) *$LnPRINT_{it}$*
$LnGDP_{it}$	**3.279*** (0.278)**	**2.623*** (0.321)**	**2.066*** (0.242)**	**3.212*** (0.279)**	**2.629*** (0.320)**	**2.009*** (0.242)**
$LnGDP$^2_{it}	**-.164*** (0.014)**	**-.146*** (0.016)**	**-.094*** (0.012)**	**-.160*** (0.014)**	**-.146*** (0.016)**	**-.091*** (0.012)**
_cons	-14.325*** (1.380)	-2.967*** (1.592)	-9.501*** (1.218)	-14.083*** (1.387)	-3.124** (10.416)	-9.284*** (1.220)
R^2	0.1164	0.1831	0.1731	0.0024	0.0009	0.3526
N	1094	1113	832	1094	1113	832
F	.000	.000	.000	.000	.000	.000

Note: OLS is Ordinary Least Square regression; FE is Fixed Effects and RE is Random Effects; robust standard errors are reported in parentheses. *$*p<0.1$* *$**p<0.05$* *$***p<0.01$*

4.2.3 Lagged values of GDP

The fixed effects and random effects estimators both share the assumption of strict exogeneity, which means that the error term is uncorrelated with the regressors (Leszczensky & Wolbring, 2019). However, if this assumption is violated, reverse causality introduces bias to the regression estimates. In that case, this problem can be overcome by lagging the independent variables (Bellemare et al., 2017). This robustness check is performed in order to check whether the measures of environmental degradation do not impact GDP per capita in the regressions. Therefore, the lnGDP variables (linear, quadratic, and cubic) have been replaced by their respective lagged values. For CO2 and N2O emissions, the results were quite similar. The signs of the coefficients stayed the same in all regression models, including the models with time fixed effects, and the magnitude of the coefficients were also quite similar. For the ecological footprint, the results also did not change much. The only noteworthy difference is that the three GDP variables in Column 2 in Table A4 (with the addition of time fixed effects) become statistically significant at the 5% level, indicating an N-shaped EKC.

5. Discussion

In this section, the hypotheses in this thesis will be discussed. The first hypothesis concerning CO_2 emission can be answered differently based on which regression is focused on. The regressions show evidence of an inverted N-shaped curve relationship between GDP and per capita CO_2 emission without controlling for any other variables. However, with the addition of control variables the regressions show evidence of an N-shaped curve relationship. Especially the control variable for per capita energy use seems to be an important predictor for CO_2 emissions. Therefore, the first hypothesis is rejected.

The second hypothesis concerns N_2O emissions. At first, the regressions showed evidence in support of an N-shaped curve relationship between GDP and N_2O emissions. However, after introducing time fixed effects as a robustness check the regression results provided evidence in support of an inverted N-shaped curve. Nevertheless, no evidence has been found in support of an inverted U-curve. Therefore, the second hypothesis is rejected.

Finally, the relationship between GDP and the ecological footprint has been studied with the help of the third hypothesis. At first, the results indicate an N-shaped curve relationship between GDP and the ecological footprint. However, after the addition of time fixed effects the results show this N-shaped curve only in the random effects model after the addition of the control variables. Without any control variables, both fixed effects and random effects models show an inverted N-shaped curve. Therefore, the third hypothesis is also rejected since there is no evidence of an inverted U-shaped curve relationship.

Table 5.1 Discussion of hypotheses

Hypotheses	Accepted/Rejected
H1: The relationship between EU's GDP per capita and CO_2 levels follows an inverted U-shaped curve.	Rejected
H2: The relationship between EU's GDP per capita and N_2O levels follows an inverted U-shaped curve.	Rejected
H3: The relationship between EU's GDP per capita and ecological footprint levels follows an inverted U-shaped curve.	Rejected

6. Conclusion

This study aims to identify the type of relationship between GDP and three measures of environmental degradation (CO_2, N_2O, and the ecological footprint). This relationship has often been proven to be increasing at first, but after a certain point this relationship decreases. This can be seen as an inverted U-shaped curve, and is called the environmental Kuznets curve (EKC). The data consists of 28 European Union countries for the period 1970-2018. However, data on the ecological footprint was only available until 2017 for each country. Overall, the results seem to deviate slightly from most of the existing literature because of the addition of lnGDP^3. Existing literature often only included lnGDP and lnGDP^2 as their variables of interest in order to examine the type of EKC. In that case, a positive lnGDP and negative lnGDP^2 would indicate an inverted U curve relationship between GDP and the environmental degradation measure. However, the inclusion of lnGDP^3 in this thesis showed evidence of an N-shaped curve relationship between GDP and the three measures of environmental degradation. The regressions have also been performed without the cubic term for GDP, which resulted in the inverted U-shaped curve. This means that existing literature may have stated their conclusions prematurely, since the addition of a cubic term could alter the shape of the EKC. One limitation of this thesis is that omitted variable bias will always be present. Therefore, there will always be variables that have an effect on environmental measures of degradation which have not been accounted for in the regressions of this thesis. An example is the start of a nationwide objective to reduce CO_2 levels before a certain year or an agreement between multiple countries to reduce those levels. The possibility is that CO_2 emissions will decrease even more after the introduction of such an agreement. Further research could be conducted with the help of dummy variables to account for different environmental agreements across time. Besides that, future research could include quartic terms into the polynomial regression formula to test for different curves (e.g. M-shaped or inverted M-shaped).

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Appendix A

Table A1: Joint test results for time fixed effects

	OLS (FE)			OLS (RE)		
Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
$LnCO_{it}$	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
$LnN2O_{it}$	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
$LnPRINT_{it}$	0.0000	0.0000	0.0473	0.0000	0.0000	0.0001

Note: OLS is Ordinary Least Square regression; FE is Fixed Effects and RE is Random Effects; results have been obtained in Stata via the command 'testparm'.

Table A2: Regression results for logarithmic CO2 emission levels in the EU-28 including time fixed effects.

Variables	**OLS (FE)** *Dependent variable: LnCO2*			**OLS (RE)** *Dependent variable: LnCO2*		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
$\boldsymbol{LnGDP_{it}}$	**-33.466*** (3.267)**	**3.221 (1.975)**	**21.283*** (6.881)**	**-32.727*** (3.257)**	**4.211** (2.002)**	**3.147 (7.606)**
$\boldsymbol{LnGDP\text{^}2_{it}}$	**3.588*** (0.331)**	**-0.288 (0.202)**	**-2.231*** (0.724)**	**3.509*** (0.330)**	**-0.400* (0.205)**	**-0.287 (0.777)**
$\boldsymbol{LnGDP\text{^}3_{it}}$	**-0.126*** (0.011)**	**0.009 (0.007)**	**0.078*** (0.025)**	**-0.123*** (0.011)**	**0.013* (0.007)**	**0.009 (0.026)**
$LnPOP_{it}$		-0.075 (0.089)	0.046 (0.260)		-0.185*** (0.067)	0.171 (0.147)
$LnURB_{it}$		0.233*** (0.063)	0.094 (0.254)		0.196*** (0.062)	-0.159 (0.143)
$LnENERG_{it}$		1.060*** (0.025)	1.102*** (0.067)		1.076*** (0.024)	0.848*** (0.077)
$LnOPEN_{it}$			0.201*** (0.050)			0.185*** (0.060)
$LnFDI_{it}$			-0.004 (0.003)			-0.004 (0.004)
$LnIND_{it}$			-0.098* (0.056)			-0.079 (0.063)
$LnDEV_{it}$			0.007 (0.006)			0.011 (0.011)
$LnRD_{it}$			-0.003 (0.022)			-0.080*** (0.031)
$LnEDUC_{it}$			0.068 (0.053)			0.009 (0.055)
_cons	98.980*** (11.947)	-20.852*** (6.524)	-77.702*** (21.927)	101.670*** (10.649)	-21.537*** (6.583)	-17.274 (24.632)
Time effects	YES	YES	YES	YES	YES	YES
Hausman	-	-	0.0077			
R^2	0.4259	0.8419	0.9187	0.2540	0.7123	0.5834
N	1094	1003	217	1094	1003	217
F	.000	.000	.000	.000	.000	.000

Note: OLS is Ordinary Least Square regression; FE is Fixed Effects and RE is Random Effects; robust standard errors are reported in parentheses. *$p<0.1$ **$p<0.05$ ***$p<0.01$

Table A3: Regression results for logarithmic N2O emission levels in the EU-28 including time fixed effects.

Variables	**OLS (FE)** *Dependent variable: LnN2O*			**OLS (RE)** *Dependent variable: LnN2O*		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
$LnGDP_{it}$	**-24.304*** (3.239)**	**-10.130*** (2.841)**	**20.733 (14.697)**	**-24.262*** (3.251)**	**-8.832*** (2.865)**	**22.711* (13.231)**
$LnGDP\text{^}2_{it}$	**2.511*** (0.328)**	**1.113*** (0.291)**	**-2.088 (1.546)**	**2.507*** (0.330)**	**0.963*** (0.293)**	**-2.242 (1.377)**
$LnGDP\text{^}3_{it}$	**-0.083*** (0.011)**	**-0.038*** (0.010)**	**0.071 (0.054)**	**-0.083*** (0.011)**	**-0.033*** (0.010)**	**0.074 (0.048)**
$LnPOP_{it}$		1.679*** (0.129)	2.601*** (0.556)		1.478*** (0.109)	2.473*** (0.342)
$LnURB_{it}$		-0.256*** (0.091)	-2.140*** (0.543)		-0.268*** (0.091)	-1.498*** (0.338)
$LnENERG_{it}$		0.336*** (0.036)	0.250* (0.144)		0.378*** (0.034)	0.345*** (0.135)
$LnOPEN_{it}$			-0.082 (0.106)			-0.054 (0.103)
$LnFDI_{it}$			-0.004 (0.005)			-0.006 (0.006)
$LnIND_{it}$			-0.193 (0.121)			-0.070 (0.095)
$LnDEV_{it}$			0.017 (0.014)			0.018 (0.014)
$LnRD_{it}$			0.120** (0.047)			0.105** (0.046)
$LnEDUC_{it}$			0.242** (0.113)			0.274*** (0.097)
_cons	84.260 (10.585)	12.109 (9.370)	-51.754 (48.671)	84.181 (10.630)	11.672 (9.427)	-88.042** (42.327)
Time effects	YES	YES	YES	YES	YES	YES
Hausman	1.0000	0.5191	0.0456			
R^2	0.6092	0.7694	0.5702	0.0482	0.8931	0.9175
N	1113	1022	217	1113	1022	217
F	.000	.000	.000	.000	.000	.000

Note: OLS is Ordinary Least Square regression; FE is Fixed Effects and RE is Random Effects; standard errors are reported in parentheses. **p<0.1* ***p<0.05* ****p<0.01*

Table A4: Regression results for logarithmic ecological footprint levels in the EU-28 including time fixed effects.

Variables	**OLS (FE)** *Dependent variable: LnPRINT*			**OLS (RE)** *Dependent variable: LnPRINT*		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
$LnGDP_{it}$	**-14.991*** (3.814)**	**4.757 (3.254)**	**-13.645 (18.204)**	**-8.646** (3.485)**	**17.995*** (2.941)**	**59.925*** (9.389)**
$LnGDP\text{^}2_{it}$	**1.618*** (0.380)**	**-0.459 (0.329)**	**1.348 (1.864)**	**0.980*** (0.348)**	**-1.801*** (0.295)**	**-5.864*** (0.927)**
$LnGDP\text{^}3_{it}$	**-0.056*** (0.013)**	**0.017 (0.011)**	**-0.042 (0.063)**	**-0.035*** (0.011)**	**0.061*** (0.010)**	**0.192*** (0.030)**
$LnPOP_{it}$		0.353** (0.145)	-0.950* (0.514)		0.038 (0.068)	-0.459*** (0.077)
$LnURB_{it}$		-0.119 (0.073)	0.411 (0.485)		-0.078 (0.065)	0.390*** (0.072)
$LnENERG_{it}$		0.606*** (0.029)	0.346** (0.141)		0.567*** (0.027)	0.212*** (0.060)
$LnOPEN_{it}$			-0.201* (0.111)			-0.010 (0.052)
$LnFDI_{it}$			-0.005 (0.005)			-0.006 (0.008)
$LnIND_{it}$			0.216 (0.131)			0.085 (0.064)
$LnDEV_{it}$			-0.008 (0.011)			-0.005 (0.015)
$LnRD_{it}$			-0.034 (0.040)			-0.094*** (0.030)
$LnEDUC_{it}$			-0.001 (0.097)			0.110*** (0.031)
_cons	45.830*** (12.627)	-24.856** (10.533)	51.602 (59.910)	25.245** (11.566)	-63.536*** (9.827)	-203.819*** (31.540)
Time effects	YES	YES	YES	YES	YES	YES
Hausman	1.0000	0.0000	0.0000			
R^2	0.4157	0.6806	0.7579	0.4914	0.8500	0.9235
N	832	784	173	832	784	173
F	.000	.000	.000	.000	.000	.000

Note: OLS is Ordinary Least Square regression; FE is Fixed Effects and RE is Random Effects; robust standard errors are reported in parentheses. **p<0.1* ***p<0.05* ****p<0.01*