Sectoral Analysis of the Environmental Kuznets Curve in 27 EU Countries

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Abstract

Since industrialization, prosperity has grown dramatically, but so has the emission of Greenhouse Gases (GHGs). This emissions-income nexus has gotten a considerable amount of attention from scholars. The environmental Kuznets curve (EKC) embodies the relationship between emissions and income. It has been investigated widely, but few studies address sector diversification by using sector emissions and sector income to test the EKC hypothesis on a sectoral level. To fill this gap, this study uses annual data from 27 EU countries from 1995-2020 to test the EKC hypothesis for four sectors using the PMG-ARDL model. Additionally, in contrast to other literature using CO2 as a proxy for environmental degradation, this study uses GHG emissions. Our findings show that two sectors exhibit an inverted U-shape curve and that the other two exhibit a U-shape curve. This evidence can be used by policymakers to shape sector-specific policies based on the pattern that they display, to assure the mitigation of GHGs and sustainable growth.

Introduction

In recent years, environmental degradation has become the most challenging crisis on this globe. Earth's resources are being depleted at an unprecedented rate resulting in pollution harming the environment, animals, and humans. Rapid economic growth in the 20th century goes hand in hand with environmental degradation, but even with the great efforts to fight global warming nowadays, the crisis is still escalating. The United Nations calls for a reduction in emissions through one of their Sustainable Development Goals (SDG 13) which entails climate action. Lack of action will lead to a significant rise in temperature with unforeseeable consequences. The first step in the reduction of greenhouse gasses was the Kyoto Protocol, but it was not until the 2016 Paris Agreement that a major target was set to limit global warming and thus curb GHG emissions. But much more progress is needed to limit the maximum temperature increase of 1,5 degrees. In order to achieve this target, more ambitious and concrete action points have been agreed on at the COP28 last year where 199 agreed to end the production of fossil fuels and triple the number of renewables.

Understanding the dynamics of environmental degradation in relation to economic growth is therefore crucial for the development of impact mitigation strategies. After the work of Grossman and Krueger (1991), suggesting an inverted U-shape relationship, many scholars have researched these dynamics. The basic idea is that environmental degradation rises until a certain level of per capita income is reached and then falls when per capita income levels keep growing. In other words, economic growth could eventually lead to a better environment. A simple graphical representation of this so-called environmental Kuznets curve (EKC) is shown in Figure 1.

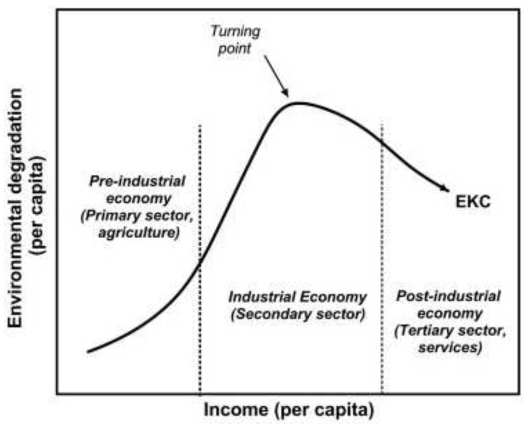
Most of the EKC literature has focused on aggregate national data leaving quite some room for speculation as to what sectors are responsible for this phenomenon. The nuances of the EKC are better understood when dividing the data into sectors. Recently, some scholars began to focus on specific sectors such as transportation and manufacturing, but there is only very scarce research covering multiple countries and multiple sectors. It is important to know if the relationship between economic growth and pollution is not uniform across different sectors so policy can be created and implemented accordingly.

Furthermore, almost all studies have used CO2 emissions as a proxy for environmental degradation. However, CO2 emission is not a perfect proxy as it overlooks other aspects of environmental degradation such as water pollution, soil erosion, air quality, and biodiversity loss. Besides, CO2 is only one of the many greenhouse gasses contributing to environmental degradation. For this reason, we will investigate the relationship using greenhouse gases as an indicator of pollution/environmental degradation. Also, this study aims to test the EKC hypothesis based on economic activity per sector. The sectors will thus be treated as small economies. Previous studies looked at the relationship between the economic growth of a country and pollution but did not consider sector GDP.

This thesis explores the environmental degradation and economic growth nexus by looking at different sectors in EU countries. By breaking down the data into distinct economic sectors, the aim is to provide new insights into the impact of the different economic sectors and provide policymakers with novel information to design effective policies. This study will also contribute to the EKC literature as we will use another proxy (GHGs) for environmental degradation instead of merely CO2. Additionally, this study will incorporate multiple macroeconomic indicators in the context of the EKC hypothesis. This addition to the existing field of research about the EKC will help to improve the understanding of the sectoral EKC.

This paper has the following structure. First, a comprehensive literature review will be provided to understand the EKC concept and explore the most relevant research that is conducted. The methodology section will follow after, which includes the data and the econometric model. The empirical results will be exhibited in the results section after which a related discussion will follow. This paper will end with a conclusion where limitations, policy implications, and future research directions will be presented.

Figure 1: Environmental Kuznets curve (Kaika and Zervas, 2016)



Source: Kaika and Zervas (2016)

Literature review

The environmental Kuznets Curve

In the 1990s, Grossman & Krueger (1991) demonstrated an inverted U-shaped relationship between economic development and environmental degradation. But it was not until the work of Beckerman (1992) that the term environmental Kuznets curve (EKC) was used. In his paper, Beckerman states that the only way to attain a decent environment is to become rich. The relationship has been named after Kuznets (1955), who hypothesized a bell-shaped association between economic development and income inequality.

The shape of the EKC suggests that economic growth initially leads to environmental degradation, but that further growth leads to less environmental damage. It is explained as follows: (1) The scale of production increases at first which comes with a severe increase in pollution intensity. (2) The pollution intensity varies per industry and output mix changes will take place. The industry is switching from an agriculture-oriented industry towards an industry causing more extraction and more pollution. Subsequently, the industry changes again and becomes more service-oriented with lower emissions. (3) Then there is the change in input mix where coal, for instance, is replaced by natural gas. This allows the economy to grow which in turn allows for less environmentally damaging inputs. (4) After, technology improves, leading to higher efficiency and less emissions. This is characterized by less pollution per unit of output and an increase in productivity. Lastly, emission-specific changes in the process are done in order to lower emissions per unit of output (Dinda, 2004, Kaika and Zervas, 2013, Stern, 2017, Stern, 2004).

The literary field of the environmental Kuznets curve is rich, and many studies support the inverted U-shaped curve. Alongside the empirical evidence of Grossman and Krueger (1995), Li et al. (2016) found evidence of the EKC in China, Sinha and Shahbaz (2018) found evidence of the EKC in the case of India, Shahbaz et al. (2018) show a validation of the EKC in France, Bhattrarai and Hammig (2001) also showed the EKC pattern in the relationship between deforestation (a part of environmental degradation) and income involving 66 countries Apergis and Öztürk (2015) confirm the EKC hypothesis for 14 Asian countries, Bibi and Jamil (2021) find support for 5 out of 6 regions consisting of 122 countries and Alola and Ozturk (2021) show evidence of the EKC in the United States. The studies often involve other variables such as globalization, urbanization, trade openness, renewable energy use, and natural resources in order to gain more insight into this relationship. This is merely a small share supporting the environmental Kuznets curve hypothesis.

A distinction is being made between three categories of environmental degradation and so different proxies for environmental degradation are used in the literature on the EKC. There are three main categories: air quality, water quality, and other environmental indicators. Air quality indicators such as CO2, SO2, and NOx appear in most research and they tend to reveal the EKC hypothesis most often (2014, Ozatac et al., 2017, Bibi and Jamil, 2020, Sarkodie and Strezov, 2019). The EKC for water pollution is demonstrated by Mousavi (2015) and Zuo et al. (2017). The hypothesis is thus widely supported by studies using time-series data and panel data including nearly every nation globally.

Criticism and inconsistent evidence

But even though there seems to be a great body of research supporting the hypothesis, the empirical evidence on the EKC is mixed. There is a significant portion of opposing evidence and there is quite some criticism on the empirical research due to the use of poor data quality and econometric pitfalls. As income is generally not evenly distributed, a larger number of people find themselves below the mean income level which results in a skewed income distribution (Stern et al., 1996).

While some studies confirm the EKC in certain regions, others do not find any relationship or evidence of the EKC hypothesis. The inverted U-curve shape is not found by all scholars. Looking at the literature at hand, N-shaped, reversed N-shaped, or U-shaped curves are no exceptions. Luzzati and Orsini (2009) investigate absolute energy consumption in relation to GDP but do not find convincing evidence for the EKC hypothesis. Ozokcu and Ozdemir (2017) look at the relationship between income and Carbon Dioxide (CO2) emission for 26 OECD countries and 52 emerging countries. The result of their model is the N-shape which does not support the EKC hypothesis. Churchill et al. (2018) tested the EKC hypothesis for OECD nations between 1870 and 2014 and found support for the panel as a whole but failed to provide support for all individual countries as only nine out of 20 countries have the inverted U-curve shape and three a N-shape. This N-shape is essentially an extension of the inverted U-shape because it suggests that there is a turning point. Emissions begin to rise again when rich countries reach a certain threshold which is the second turning point. Al-Mulali et al. (2015) investigate the environmental Kuznets curve for Vietnam and state that the EKC does not exist because of the positive relationship between pollution and GDP in the short and long run. The recent study of Wang et al. (2022) involves urbanization and analyzes four different income groups in their investigation of the EKC for 134 countries. Where an inverted U-shape is demonstrated for the lower middle-income group, a U-shape curve is shown for the high-income group. Destek and Sinha (2020) investigated the inverted U-shape hypothesis for 24 OECD countries during 1980-2014. The findings show that the EKC does not exist with a U-shaped relation between ecological footprint and GDP.

Environmental Kuznets curve on sectoral level

Studies on the environmental Kuznets curve have become more and more detailed as micro-level data has become more available. Sectoral analyses in the income-pollution nexus are therefore not scarce. Congregado et al. (2016) studied the EKC hypothesis in five sectors in the US between 1973 and 2015 and showed that the hypothesis holds for the commercial, electrical, residential, and transport sectors but does not hold for the industry sector. Moutinho et al. (2020) also do a sectoral analysis of 12 OPEC countries between 1992 and 2015 and provide evidence of the EKC for only the transport sector and the manufacturing sector. This is the only study I found that looked at the relation between sector GDP and sector pollution rather than country GDP and pollution per sector. For Portugal and Spain, Moutinho et al. (2020) investigated 13 different sectors and found for only one sector the inverted U-shape relationship. Villanthenkodath et al. (2021) investigate solely the industrial sector in India between 1971 and 2014 and demonstrate that the EKC does not hold. A wider analysis of 86 countries and 5 sectors between 1990-2015 has been conducted by Htike et al. (2021). The findings of this investigation show that the EKC holds for three out of seven sectors, namely: the electricity and heat production sector, commercial and public services sector, and the other energy industry own use sector. The manufacturing industries and construction sector, the transport sector, the residential sector, and the agriculture, forestry, and fishing sector did not show any evidence of the EKC hypothesis. For African countries, Onifade (2022) shows that the EKC is not upheld convincingly. For the transport sector in China, Guo et al. (2022) show that the relationship between GDP and carbon emissions in the transport sector is an inverted U-shaped curve (between 1998 and 2017). A sectoral analysis of the aviation Kuznets curve for 21 OECD countries is conducted by Hassan et al. (2021).

As we have seen, there is a considerable amount of research linking sectoral emissions with GDP. However, most of this research focuses only on CO2 output as a proxy for environmental degradation while this is not a perfect metric as it is only a small aspect of environmental degradation (Sarkodie and Strezov, 2019). In fact, CO2 is not even the GHG with the most global warming potential but it is only the most abundant This study will add to the literature by using greenhouse gases (GHGs) as a metric for environmental degradation which includes Carbon Dioxide (CO2; Combustion and respiration), Nitrous Oxide (N2O; fertilizer and biomass), Methane (CH4; livestock and natural gas production), Hydrofluorocarbons (HFC; refrigerators and air conditioning), Perfluorocarbons (PFC; aluminum, semiconductors), Sulfur Hexafluoride (SF6; electrical industry, LCDs) and Nitrogen Trifluoride (NF3; production of electronics, used in high tech industry). The sectoral analysis will enable policymakers to make weighted decisions in their pollution mitigation strategies which can be implemented per sector to make policies more goal-oriented.

Table 1: Literature on the sectoral environmental Kuznets curve

Authors	Country	Sectors	Time frame	Variables	Methodology	Findings
Congregado et al., 2016	United States	5	1973-2015	CO2, GDP	DOLS	EKC holds for every sector accept industrial
Zhang et al., 2019	121 countries	manufacturing and construction	1960-2014	CO2, GDP	Panel fixed effects	EKC valid for 95 out of 121 countries
Moutinho et al., 2020	12 OPEC countries	7	1992-2015	CO2, GDP, Trade openness, Energy use, oil price	ARDL	EKC holds for transport and manufacturing
Moutinho et al., 2020	Portugal and Spain	13	1975-2012	CO2, GDP	ARDL	Only one sector inverted U-shaped relationship
Htike et al., 2021	86 countries	7	1990-2015	CO2, GDP, TFEC, REC, TNRR, TRADE	PMG-ARDL	EKC holds for electricity and heat production, commercial and public services, other energy industry own use
Villanthenkodath et al., 2021	India	Industrial sector	1971-2014	CO2, GDP, URB, POP, ES, IND	ARDL	EKC does not hold
Hassan et al., 2021	21 OECD countries	Aviation	1980-2018	CO2, GDP	GMM	EKC holds for passengers, not for cargo
Onifade, 2022	African countries	Manufacturing sector, energy sector and service sector	1995-2016	CO2, RI, FEC, NR, MGI, SGI	DOLS, QR	EKC not convincingly upheld,
Guo et al., 2022	China	Transport sector		CO2, TSCE	STIRPAD	EKC holds

Hashmi et al., 2023	United States	5	2000-2020	CO2, IPI, CPU	Fourier ARDL	EKC holds for industrial, electrical power, commercial, residential sectors.

Methodology

In this section, the used data, the variables of interest, and the econometric model will be specified. Using comprehensive tables, the countries, descriptive statistics, and correlations between variables will be presented.

This paper uses yearly panel data from 27 EU countries from 1995 to 2020. These are Austria; Belgium; Bulgaria; Croatia; Cyprus; Czechia; Denmark; Estonia; France; Finland; Germany; Greece; Hungary; Ireland; Italy; Latvia; Lithuania; Luxembourg; Malta; Netherlands; Poland; Portugal; Romania; Slovenia; Slovakia; Spain; Sweden. The sample countries are presented in Table 2. The economy will be divided into four distinct sectors, namely: manufacturing industries and construction; Agriculture, forestry, and fishing; transport; and residential. It is possible to add additional sectors, but they do not account for a significant proportion of the pollution (EU Commission, 2024). We also include total GHG emissions per country. From the same dataset, we retrieved the GDP per country at the 2015 exchange rate. However, if we look at the pollution of a sector and the GDP of a country, we do not include the size of the industry in any way which will distort the relationship between growth and pollution. Therefore, we use value-added per activity in order to include a measure of size. This data was retrieved from the OECD (2022). The additional variable renewable energy share is retrieved from the World Bank (2023).

Table 2: Countries used in the sample

Austria	Finland	Malta
Belgium	Germany	Netherlands
Bulgaria	Greece	Poland
Croatia	Hungary	Portugal
Cyprus	Ireland	Romania
Czechia	Italy	Slovenia
Denmark	Latvia	Slovakia
Estonia	Lithuania	Spain
France	Luxembourg	Sweden

The econometric model

According to the meta-analysis of the environmental Kuznets curve by Saqib and Benhmad (2021), the choice of econometric methodology does not matter when it comes to determining a relationship. Therefore, we choose to use the Autoregressive Distributed Lag (ARDL) Model. This model is able to estimate short- and long-run dynamics for the income-pollution nexus and provides unbiased estimates even though some regressors might be endogenous. The problem of endogeneity is mitigated through the use of lag selection. (Harris and Sollis, 2003, Menegaki, 2019). The model, introduced by Pesaran et al. (2001), is considered to be an easy econometric analysis in the energy-growth nexus.

We will start with a presentation of the descriptive statistics of the series which will be presented in table 3. This table contains the mean, standard deviation, minimum value, and maximum value for each variable and the description of the panel data structure. Most GHGs are emitted by the transport sector, followed by the manufacturing and construction sector. Agriculture, forestry, and fishing account for the least amount of GHG emissions.

Table 3: Summary of descriptive statistics

Variable	Countries	Obs	Mean	Std. Dev.	Min	Max
mc	27	702	18.86	28.48	0.02	141.99
amc	27	702	77178.60	135905.40	85.05	834936
aff	27	702	14.50	18.02	0.08	78.62
aaff	27	702	6758.10	9486.61	57.02	38968
trans	27	702	29.78	43.02	0.45	185.97
atrans	27	702	16444.60	25883.74	30.61	139329
ipc	27	702	25117.46	18410.75	3183.51	102131.70
res	27	702	14.51	24.41	0.03	143.70
rec	27	702	16.06	11.77	0.00	58.40

As we investigate and hypothesize a non-linear relationship, we use a quadratic specification of the annual activity (AA) of a sector. The relationship between sectoral greenhouse gas emissions and sectoral income level is captured in the following model and is used for each of the sectors:

$$ln\ GHG_{it} = \beta_0 + \beta_1\ ln\ AA_{it} + \beta_2(ln\ AA_{it})^{\ 2} + \beta_3\ ln\ REC_{it} + \mu_{it}$$

For interpretability purposes, the variables are converted to a logarithmic scale. $ln\ GHG_{it}$represents the greenhouse gas emissions per sector in country *i* (*i*=1, 2, 3, ...,27) in year *t* (*t*=1995, 1996, 1997, …,2020). The annual activity of a sector ($ln\ AA_{it}$) is used to represent the sectoral income level. Annual activity is used in its normal form but also its quadratic form ($(ln\ AA_{it})^{\ 2}$) in order to capture the non-linear relationship. Many other studies on the energy-growth nexus also use this form of equation to capture the non-linear relationship (Congregado et al., 2016, Sinha and Shahbaz, 2018, Zhang et al., 2019, Htike et al., 2021, Moutinho et al., 2020). The share of renewable energy in the total energy consumption of a country is included in the model as a control variable and is indicated by $ln\ REC_{it}$. The last term of the equation is the error term μ_{it}.

Results

Menegaki (2019) provides a comprehensive review of all steps for the ARDL procedure. Therefore, this analysis is based on consulted literature. Different tests are done preparatory to the ARDL estimation. These steps, along with the ARDL estimation itself, will be displayed in this chapter.

Unit root test

We must first check for stationarity in the series as the ARDL model assumes that only stationary series may be used. That is, series that have a constant mean or variance over time. We use the Im-Pesaran-Shin (IPS) test to check if the series is stationary or not. Under the null hypothesis of a unit root, the series is non-stationary, meaning that with a p-value lower than 0.05, we can reject the null hypothesis of non-stationarity. If the series is found to be non-stationary, we can use the first difference of the series and check if it now shows a p-value below 0.05. If we do not find stationarity in either case, we do not include the series. The unit root test is performed on each variable used in the dataset and the corresponding results are presented in table 5.

Table 4: The Unit Root Tests for Stationarity

Variable	Level	1st difference
lnmc	-1.33	-5.12***
lnamc	-2.26***	NA
lnaff	-1.56	-4.69***
lnaaff	-2.21***	NA
lntrans	-1.44	-3.08***
lnatrans	-2.83***	NA
lnres	-1.38	-6.02***
lnipc	-2.03***	NA
lnrec	-0.51	-4.79***
lnamcsq	-2.04**	NA
lnaaffsq	-2.13***	NA
lnatranssq	-2.50***	NA
lnipcsq	-1.95**	NA
lnTotalGHG	-0.39	-4.21***

Note: *Under the null hypothesis, the IPS assumes non-stationarity. The non-stationary variables are tested at their first difference. ***, **, and * denote significance levels of 1%, 5% and 10% respectively.*

Cointegration test

According to the literature, testing for cointegration is the next step of this procedure. We do this to make sure that there is a long-term relationship between the variables. The test for cointegration is carried out using the Westerlund cointegration test (Westerlund, 2007). This test assumes no cointegration. We will thus find that there is cointegration when the null hypothesis is rejected. According to Menegaki (2019), the null hypothesis is often rejected when there is a clear theoretical connection between some variables. Succeeding in finding proof for cointegration means that there is a long-run relationship between the variables that is able to withstand disturbances.

The cointegration test provides four test statistics. $G\tau$ and $G\alpha$ are group mean statistics and indicate cointegration for one cross-section. $P\tau$ and $P\alpha$ are panel statistics that test for cointegration for the entire panel. The results of the cointegration tests show evidence of cointegration for three out of four sectors and that there is indeed a long-run relationship between the variables. We will therefore primarily be interested in the panel statistics. We do not find evidence for cointegration in the transport sector. Omitted variables could be the reason for this. However, the absence of a long-run relationship does not imply that there could be a short-run relationship, so we will also run the model on this sector (Menegaki, 2019).

Table 5: Westerlund cointegration test

Sector	Group statistics		Panel statistics	
	Gτ	Gα	Pτ	Pα
Manufacturing industries and construction	-2.73***	-8.57	-10.63***	-7.18***
Agriculture forestry and fishing	-1.78	-5.52	-9.10**	-5.94*
Transport	-2.12**	-6.92	-8.15	-5.22
Residential	-2.98***	-8.67	-12.61***	-8.22***
TotalGHG	-1.08	-2.27	-4.48	-2.00

Note: *Under the null hypothesis, the Westerlund cointegration test assumes no cointegration. ***, **, and * denote significance levels of 1%, 5%, and 10% respectively.*

PMG-ARDL results

After the investigation of stationarity and cointegration, we will estimate the ARDL model using the pooled mean group estimator. The results of the five models are presented in Table 6. Out of Stata, only the upper part of the output is included for all of the models. This is the most important and shows the long-run coefficients. The ECT is also included in the table which indicates whether there is cointegration among the variables in the panel. The long-run coefficients are valid for all countries that are in the panel. The short-run coefficients are also computed in this model but are not included in the results table as we are interested in the long run relationship. The EKC hypothesis can be confirmed when the activity variable is positive, and its quadratic specification is negative. In other words, the inverted U-shape curve is obtained when $\beta_1 > 0$ and $\beta_2 < 0$. We will go over the results sector by sector starting with a short interpretation of the coefficients.

Table 6: PMG-ARDL estimates

	Total	**Manufacturing and construction**	**Agriculture, forestry and fishing**	**Transport**	**Residential**
$lnAA$	6.51***	-1.22***	0.62***	-1.13***	-0.57
	(0.99)	(0.28)	(0.24)	(0.26)	(0.92)
$lnAA^2$	-0.40***	0.06***	-0.03*	0.09***	0.02
	(0.06)	(0.01)	(0.02)	(0.02)	(0.05)
$lnREC$	*NA*	-0.26***	0.03**	-0.09***	-0.19***
	NA	(0.01)	(0.02)	(0.03)	(0.02)
ECT	-0.13***	-0.24***	-0.12***	-0.12***	-0.36***
	0.02	0.05	-0.02	0.04	0.06

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

interpretation of coefficients

We also run the model for the relationship between the total GHG emissions of countries and the GDP per country to see whether the Kuznets curve exists over the entire panel. The coefficient $lnAA$, representing GDP per capita in this case, is positive (6.51) and its quadratic form is negative (-0.40) at a 1% significance for both coefficients indicating an inverted U-shape curve.

For the manufacturing industries and construction sector. The long-run coefficients of the annual activity, annual activity squared, and renewable energy consumption are significant at a 1% level. Renewable energy consumption negatively impacts the emission of greenhouse gasses within this sector. We have a log-log relationship, so the coefficient of -.26 can be interpreted as an elasticity. We can therefore say that a one percent increase in renewable energy consumption leads to a decrease in greenhouse gas emissions of 0.26%. The long-run coefficients of annual activity and annual activity squared are negative and positive respectively. Hence, we are not dealing with an inverted U-shaped curve, but rather a U-shaped curve. This does not confirm the environmental Kuznets curve for the annual activity (income) - emission relationship in the case of the manufacturing industries and construction sector.

For the agriculture, forestry, and fishing sector we observe that renewable energy consumption does not lead to a decrease in GHG emissions. Rather, a 1% increase in renewable energy consumption leads to an increase in GHG emissions of 0.03% at a significance level of 5%. The statistical evidence reveals the inverted U-shaped relationship between GHG emissions and economic activity which confirms the EKC hypothesis for this sector. However, this result is merely statistically significant at a 10% level which makes it less convincing.

For the transport sector, we also see significant coefficients for all three variables of the model. A 1% increase of renewable energy consumption leads to a decrease of 0.09% of GHG in the transport sector at a 1% significance level. We do not find evidence of the EKC hypothesis in the relationship between economic activity and GHG emissions of the transport sector but the results reveal that there is a U-shape relationship between the variables which is statistically significant at a 1% level.

Lastly, the results of the residential sector. A 1% increase in renewable energy consumption leads to a decrease of 0.19% in GHG emissions at a 1% significance level. We do not find any statistical evidence of the EKC. This leads us to believe that there is a linear relationship rather than a nonlinear relationship as we assumed.

Consistency with literature

The results from the model containing total GHG emissions show that the inverted U-shape EKC is confirmed for the income-emission relationship. These findings are consistent with previous literature investigating this matter such as Bekun et al. (2021), Htike et al. (2021), and Sun et al. (2020). This enables us to inspect why sectors show a trend and verify if the composition of the sectors changes.

As such, we will not necessarily look at if sectors become cleaner, but rather if they change what they produce. For instance, the textile industry has moved to other countries creating space for other and cleaner industries.

The results we obtained can only partly be compared to other studies as we have used another proxy for environmental degradation. On top of that, this study treated each sector as a small economy. The results obtained in this study concerning the manufacturing industries and construction sector are not consistent with findings in earlier studies. Zhang et al. (2019) validate the EKC hypothesis for 95 out of 121 countries, and Moutinho et al. (2020) find evidence for the inverted U-shape curve for the industry sector but show a U-shape curve for the construction sector in OPEC countries. Htike et al. (2021) only find evidence of a negative relationship between economic growth and CO2 emissions. However, the study of Moutinho et al. (2020) is the only study I found that looked at the relation between sector GDP and sector pollution rather than country GDP and pollution per sector. Thus, this is the only comparable study when it comes to the relationship between sector GDP and sector emissions. It must however be noted that Moutinho et al. (2020) use CO2 emission to capture environmental degradation. Moutinho et al. (2020) also highlight the verification problem due to the limited amount of research in their review of the results. The first part of the U-shape relationship for this sector could be explained by initial improvements through the adoption of cleaner technologies, improvements in efficiency, and scale effects. The second part of the U-shape, where GHG emissions rise again, could be explained by the fact that output keeps increasing, but improvements fall behind. The first efficiency gains are easiest to achieve, and the adoption of cleaner technologies is hardest at the end. We could relate this to the learning curve theory, where improvements are getting smaller and smaller over time. On top of that, some activities that require energy cannot be substituted by renewable energy.

For the agriculture, forestry, and fishing sector, the results do match previous research and more specifically the study of Moutinho et al. (2020). Both their investigation and this study find evidence for the EKC hypothesis. Other research also demonstrates evidence of the environmental Kuznets curve for this sector but not in the same research setting. For example, Gokmenoglu et al. (2020) confirm the inverted U-shape relationship in the case of China, and Zafeiriou et al. (2017) confirm the relationship for Bulgaria, Czech Republic, and Hungary.

Now, for the transport sector, we do not find supporting evidence for our results in other research. Moutinho et al. (2020) find opposite evidence and confirm the EKC hypothesis. Htike et al. (2021) show a positive relationship between economic growth and CO_2 emissions. The findings of Romero (2017) testing the transport transport EKC on the 27EU countries are quite similar to Htike et al. (2021). Romero (2017) proves the same phenomenon where the turning point of the EKC is not reached. For the residential sector, there is no evidence of the EKC either, but there is a negative relationship between renewable energy consumption.

For now, we have mainly covered the results we obtained about the annual activity-GHG relationship. But the results of the renewable energy consumption-GHG relationship are also rather interesting as this relationship is negative for the agriculture, forestry, and fishing sector exhibiting a U-shape cure and positive for sectors showing an inverted U-shape curve. This is surprising at first glance but could be explained as follows: 95% of GHG emissions in this sector are from enteric fermentation (=fermentation in the digestive systems of animals), emissions from soils, and manure management (European Environment Agency, 2023). Hence, the benefits of reducing GHG emissions through the introduction of renewable energy are marginal in comparison to other improvements that could reduce GHG emissions in the sector. For the manufacturing industries and construction sector and the transport sector we see the opposite relationship. An increasing renewable energy share leads to a reduction in GHG emissions. This relationship is harder to grasp but has been demonstrated earlier by Htike et al. (2021). They show an upward relationship between economic growth and CO_2 emission in the transport sector but find a negative relationship between renewable energy consumption and CO_2 emission in this sector.

Robustness

For the purpose of robustness, the model is also run without renewable energy consumption (REC). The correlation between annual economic activity and renewable energy has been demonstrated by many scholars (Ntanos et al., 2018, Bhattacharya et al., 2016). These two variables are on the same side of our equation which could result in multicollinearity. So, in order to check for this problem, we will look if the results remain consistent when dropping this variable. The results are presented in Table 8. For all sectors, except for the residential sector, we see that the results are quite consistent with the results exhibited in Table 6. The results of the residential sector changed and now show evidence of the EKC at a 1% significance level. The reason for which this only occurs in the residential sector is probably that economic growth is more directly linked with a shift in energy consumption. Other sectors have different dynamics and emission patterns that are less correlated to the growth of the sector. These results are now consistent with the finding of Hashmi et al. (2023) finding the same pattern for the residential sector in the USA. However, it remains difficult to really compare the results due to the difference in research design.

Table 7: Model without REC

	Manufacturing and construction	**Agriculture, forestry and fishing**	**Transport**	**Residential**
$lnAA$	-1.12***	0.70**	-0.63***	8.15***
	(0.29)	(0.23)	(0.18)	(0.96)
$lnAA^2$	0.04**	-0.03**	0.05***	-0.47***
	(0.01)	(0.02)	(0.01)	(0.05)
ECT	-0.17***	-0.14***	-0.14***	-0.29***
	(0.03)	(0.03)	(0.04)	(0.05)

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

Discussion and conclusion

In this study, we investigated the economic growth-environmental degradation nexus on a sectoral level, treating each sector as its own economy. With value-added being a proxy for economic growth and sectoral GHG emissions being a proxy for environmental degradation, this study contributes to the existing literature by introducing economic activity sector diversification for the 27 EU countries for the period 1995-2020.

For the total GHG emissions model across countries, our results confirm the EKC hypothesis. This inverted U-shaped relationship is consistent with other EKC literature. Meanwhile, the results also reveal differences when it comes to the sector-specific growth-emission relationship, suggesting that sector composition influences the shape of the EKC. The manufacturing industries and construction sector and the transport sector do not follow the inverted U-shape curve. The agriculture, forestry, and fishing sector and the residential sector (after dropping renewable energy consumption) do follow the EKC. This suggests that the technology effect and the composition effect play a role in how the sector develops. The within-sector complexity is often overlooked in this nexus but could clarify why the aggregate EKC is not consistent with the sectoral EKC's. These dynamics are important to consider and could help policymakers to shape policies accordingly.

This study also has its limitations. To begin, we have not been able to include all sectors within this analysis which gives only a limited picture of the dynamics between sectors. This could also partly explain why the aggregate EKC is not consistent with the sectoral EKC's. Also, the obtained results from the four sectors differ quite a bit and are not easy to compare because of the very limited material to compare it to. More research is therefore needed to confirm or at least compare these results. Furthermore, as far as the relationship between GHG emissions and other variables go, we have only included one. Other studies have also examined the relationship with for example globalization, urbanization, financial development, oil prices, trade openness (Hashmi et al., 2020, Moutinho et al., 2020), and per capita energy consumption (Pata, 2018). Additionally, we used renewable energy consumption as a share of total energy consumption in a country whereas sectoral renewable energy consumption would have been more appropriate for this study. This gives a warped image of the results. For future research, including sectoral renewable energy consumption is urged in order to capture true effects.

We have focused on the long-run relationship for the entire panel without providing coverage per country. For future research, it might be interesting to test the hypothesis for all sectors by country. It might even be interesting to zoom in specifically on one industry in order to do an in-depth analysis and uncover the sectoral dynamics and composition of a sector. This could involve analyzing sector-specific activities to explore potential opportunities within sectors.

Even though our proxy for environmental degradation is better than merely CO2, GHG is not perfect either. This is also an atmospheric indicator while including land, sea, coast, freshwater, and biodiversity indicators would provide a better picture of the actuarial environmental degradation. It is suggested that for example ecological footprint is used as a proxy for environmental degradation in this nexus (Sarkodie and Strezov, 2019). Lastly, as the results vary considerably it would be advisable to use different methodological techniques in order to check for robustness of the results and gain insight into what methodology is best in the economic growth-pollution nexus.

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