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Are CO_2 emissions converging in the European Union? Policy implications

As Emissões de CO_2 Estão a Convergir na União Europeia?

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ABSTRACT
This paper focuses on the process of convergence in per capita CO_2 emissions that would occur if the measures taken by the European Union to meet the Kyoto Protocol commitments had been effective. We apply a time series and cross-sectional analysis to test for the existence of convergence among countries and for different economic sectors. The sample covers data for the 28 member countries from 1960 to 2012. The results show weak absolute convergence across countries but clear evidence of conditional convergence, with GDP, the weight of industrial sector and the use of renewable energies being the main drivers of divergence. Concerning sectors, there is an increase of emissions in the agricultural sector, but a reduction in the industrial and energy sectors. Different patterns arise in the energy subsectors where manufacturing and electricity notably reduced their emissions while the transport sector increased them in all countries.
Keywords: Convergence; CO_2 emissions; European Union.

JEL Codes: Q43; Q48; Q53

RESUMO
Este documento enfoca o processo de convergência das emissões de CO2 per capita que ocorreria se as medidas adotadas pela União Europeia para cumprir os compromissos do Protocolo de Kyoto tivessem sido efetivas. Aplicamos uma série temporal e uma análise transversal para testar a existência de convergência entre países e para diferentes setores econômicos. A amostra cobre dados para os 28 países membros de 1960 a 2012. Os resultados mostram uma convergência absoluta fraca entre os países, mas evidências claras de convergência condicional, sendo o PIB, o peso do setor industrial e o uso de energias renováveis os principais fatores de divergência. No que diz respeito aos setores, há um aumento das emissões no setor agrícola, mas uma redução nos setores industrial e de energia. Diferentes

padrões surgem nos subsetores de energia, onde a produção e a eletricidade reduziram notavelmente suas emissões, enquanto o setor de transporte aumentou em todos os países.
Palavras-chave: Convergência; emissões de CO_2; União Europeia.

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1. Introduction

Since the Kyoto Protocol was signed in 1997, the European Union has played a leading role in the fight against climate change, pledging to reduce its emissions of greenhouse gases (GHG). The EU committed to reduce them by 8 % in 2008-2012 related to 1990 levels, by means of a bubble system, whereby a global target was set for the EU but with different specific goals and emission allowances for individual member states according to its specific characteristics. Following the entry into force of the Paris Agreement, the EU have now to complete the process of internally defining targets and implementation tasks. Following the Europe 2020 strategy for smart, sustainable and inclusive growth, a Climate and Energy Package was set in 2008 to ensure that the EU meets its climate and energy targets for the year 2020: 20% cut in greenhouse gas emissions (from 1990 levels), 20% of EU energy from renewables and 20% improvement in energy efficiency. More ambitious targets have even been set to be reached in 2030 and beyond, with a roadmap for moving to a competitive low carbon economy in 2050 (COM/2011/0112 final): 30% by 2020, 40% by 2030 and 80% by 2050, relative to 1990 levels. The European Commission (2016) aims a smooth transition to a low carbon economy taking into account that EU countries are different concerning their energy mix and their production structures. Therefore, the EU has continued with the bubble system to reduce GHG emissions and has set several goals with different time horizons. The targets range from a 20% reduction in GHG emissions for Denmark, Ireland and Luxembourg to an increase of 20% for Bulgaria. Basically, these goals imply a process of convergence in emissions among the member countries: the heavier polluters must reduce them while the countries with lower emissions are allowed to increase them.

Our paper addresses this timely and important matter. We test whether convergence in CO_2 emissions has occurred across countries and economic sectors within the EU using suitable econometric methodologies. We study convergence in specific sectors, namely agriculture, industry, and energy. We have chosen the industrial and energy sectors because their economic relevance and because they are sectors regulated by the IPPC Directive[1] and included later in the European carbon market. We also focus on the agricultural sector since it is the main producer of methane, a greenhouse gas included in the Kyoto Protocol with a warming power around twenty times that of carbon dioxide. In addition, we disaggregate the energy sector into four subsectors: heat and power generation, manufactures and construction, transport and other minor fuel combustion subsectors. We present in the next section the empirical models applied to test for convergence. Sections 3 shows the results obtained and section 4 concludes.

2. Data and Methods

The sample covers data for the 28 member countries from 1960 to 2012. The data set comes from the World Resources Institute (CAIT Climate Data Explorer) and the World

[1] Council Directive 96/61/EC of 24 September 1996 concerning Integrated Pollution Prevention and Control (IPPC).

Bank (World Development Indicators). We present below the empirical models we use tot test for convergence:

2.1. Absolute convergence

We rely on the model of Barro and Sala-i-Martin (1992). We estimate a model that relates emissions at time T with respect to time t. The growth rate is defined as:

$$Y_{i,t,t+T} \equiv \frac{\log\left(\frac{y_{i,t+T}}{y_{i,t}}\right)}{T}, \tag{1}$$

where $\gamma_{i,t,t+T}$ is the annual growth rate of the economy i between t and $t + T$; log is the natural logarithm; $Y_{i,t+T}$ is the value of the variable under study in country i at time T; $Y_{i,t}$ is the value of the variable at time t. The econometric formulation of the Sala-i-Martin (1996) model is:

$$\frac{1}{T} Y_{i,t,t+T} = \alpha - \beta \log(y_{i,t}) + \varepsilon_{i,t}. \tag{2}$$

If $\beta > 0$, there is absolute convergence across economies. The rate of convergence can be estimated as follows:

$$V = -\log(1+T\beta)/T. \tag{3}$$

2.2. Conditional convergence

Conditional convergence implies that countries converge to different steady states. To reflect this heterogeneity across countries, some explanatory variables are added to the model. Sala-i-Martin (1996) presents the following formulation:

$$Y_{i,t,t+T} = \alpha - b \log(y_{i,t}) + \Psi X_{i,t} + \epsilon_{i,t}+T, \tag{4}$$

where $X_{i,t}$ is a vector of variables which keeps the steady state constant. There is absolute convergence (meaning that countries tend to converge to the same value) if none of the exogenous variables is statistically significant and b is significant and negative. There is conditional convergence (meaning that countries converge to different levels of emissions) if some coefficients of the exogenous variables are significant and b is less than 0 and significant.

2.3. Sigma convergence

Sigma convergence analyzes the dispersion of the variable under study. Based on the standard deviation:

$$\sigma_t = \sqrt{\frac{1}{N}\Sigma_{i=1}^{N}\left(\log y_{i,t} - \mu_t\right)^2}, \tag{5}$$

where μ_t is the sample mean of $log(y_{i,t})$, σ-convergence occurs if the standard deviation of all countries decreases over time, indicating that the values are concentrated around the average value.

2.4. Stochastic convergence

We rely on the model defined by Carlino and Mills (1993) based on the order of integration of the difference between the values of the variable and the mean, expressed in logarithms. They test whether relative per capita earnings are converging toward unity with the national average, plus or minus a compensating differential which may differ from region to region according to each one's unique characteristics. Under this assumption, the log of relative per capita income in region *i* at time *t* (RI_{it}) consists of two parts, the time-invariant equilibrium differential, RI^e_t, and the deviation from this equilibrium, $u_{i,t}$.

$$RI_{i,t} = RI_t^e + u_{i,t}. \tag{6}$$

The formulation of the models is based on the decomposition of $u_{i,t}$ into a deterministic linear trend and a stochastic process:

$$u_{i,t} = v_i^0 + \beta_i t + v_{i,t}, \tag{7}$$

where ν^0_i is the initial deviation from the equilibrium and β_i is the rate of deterministic convergence. In our case, income per capita is replaced by emissions per capita and the ν_{it} term is modeled as an ARMA(2,O) process, represented by

$$(1 - \rho L)(1 - \phi L)\, v_t = \varepsilon_t, \tag{8}$$

where L is the lag operator, p and ø are the two roots, |ø|<1, and ϵ_t is the serially uncorrelated shock to ν_t. Shocks will be temporary if |ø|<1. If |ø|=1, ν_t is said to have a unit root and shocks are permanent.

Another set of solutions have been proposed which apply unit root tests in a context of an undetermined number of breaks, such Carrion *et al.* (2005) and Carrion *et al.* (2009).

3. Results

3.1. Descriptive analysis of data

We have analyzed the historical evolution of CO_2 emissions in the 28 EU countries from 1960 to 2012 and we detect three groups of countries showing different patterns:

1. Group 1: countries that record an overall increase in CO_2 emissions, despite a decrease in recent years: Austria, Croatia, Cyprus, Finland, Ireland, Italy, Malta, the Netherlands, Portugal, Slovenia and Spain.
2. Group 2: countries that have reduced their emissions: Belgium, France, Germany, Denmark, Luxembourg, Sweden and the United Kingdom.
3. Group 3: countries with increases in emissions from 1980 to 1990 and a subsequent reduction, perhaps as a result of the productive structural changes since they are countries moving from a planned economy to a market economy: Bulgaria, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania and Slovakia.

Concerning sectors, Table 1 shows the mean of CO_2 per capita emissions for each sector and subsector in 1990 and 2012. We can observe a reduction in the industrial and energy sectors but an increase in the agricultural sector. Countries belonging to group 2 and, to a larger extent, countries in group 3, are responsible for this increase. When looking at the sources of emissions in the energy sector, the transport sector stands out with a 27.8% increase between 1971 and 2012. This increase was partially offset by decreases in the electricity sector (-22%) and the manufacturing sector (-53%) led by the most developed European countries in group 2. All countries have increased emissions in the transport sector. These findings reflect the effectiveness of the mandatory measures imposed on the sectors covered by the IPPC Directive and included later in the ETS. Agriculture stays out of the ETS, as well as transport whose inclusion in the ETS was late and partial; only the aviation sector is included in the ETS since 1st January 2012, in accordance with Directive 2009/29/EC.

Table 1: Mean of CO_2 emissions in sectors and subsectors (1971-2012)

Year	1971	1980	1990	2000	2012
Agriculture	-	-	0.8861	1.0598	0.9613
Industry	-	-	0.5780	0.5567	0.3648
Energy	-	-	9.5662	8.1165	7.4379
Power Generation and Heating	2.2071	2.7949	3.9308	3.2090	3.0612
Manufactures	2.9605	2.6359	2.1484	1.4097	1.0137
Transport	0,8894	1.1248	1.6098	1.9497	2.0569
Other Fuel Emissions	1.7977	1.8442	1.5902	1.2749	1.0419

3.2. Absolute convergence

Relying on the model of Barro and Sala-i-Martin (1992), we have considered different periods to control for possible structural changes. The results in Table 2 show that all parameters β are significant and negative, which demonstrates the existence of convergence across EU countries in all the periods analyzed. The results are in line with those obtained by Jobert *et al.* (2010) for EU countries and also with Papanopoulou and Pantelidis (2009) and Criado and Grether (2011) for OECD countries.

Table 2: Beta-convergence by periods

	2012	2000	1990	1980	1970
β de 1960	-0.0092 (0.0002)***	-0.0101 (0.0002)***	-0.0107 (0.0005)***	-0.0112 (0,0008)***	-0,0112 (0.0016)***
v	1.27%	1.31%	1.30%	1.27%	1.29%
R^2	0.55	0.48	0.39	0.26	0.15
β de 1970	-0.01 (0.0003)***	-0.0113 (0.0004)***	-0.0119 (0,0006)***	-0.0109 (0,001)***	-
v	1.32%	1.39%	1.36%	1.16%	-
R^2	0.53	0.49	0.44	0.27	
β de 1980	-0.0114 (0.0005)***	-0.0140 (0.0008)****	-0.0156 (0.0013)***	-	-
v	1.44%	1.66%	1.71%	-	-
R^2	0.37	0.34	0.32		
β de 1990	-0.0105 (0.001)***	-0.0175 (0.003)***	-	-	-
v	1.21%	1.94%	-	-	-
R^2	0.13	0.10			
β de 2000	-0,0068 (0.003)***	-	-	-	-
v	0.71%				
R^2	0.08	-	-	-	-

Notes: Standard error in brackets. *** significant 1%; ** significant 5%; * significant 10%.

Concerning sectors (Table A.1 in the appendix), the results show weak convergence in the agricultural sector. The industrial sector exhibits convergence throughout the period under study. In the energy sector, there is evidence of absolute convergence between 1990 and 2000 but no convergence in the following period. In the energy subsectors we find convergence in all subperiods as shown in Tables A.2, A.3, A.4 and A.5 in the appendix, but a different evolution across countries. Group 1 and 3 have registered increases of 3.4% and 89.5% respectively; group 2 has reduced emissions by 39.7% (see Table A.6 in the appendix).

3.3. Conditional convergence

Conditional convergence takes into account individual differences among countries, therefore we have included in the model the following explanatory variables: initial CO_2 emissions, GDP per capita (calculated from real GDP at 2005 prices and annual population), urban population (measured as a percentage of the total population), renewable energy consumption (calculated as a percentage of the total energy consumed), consumption of fossil fuels (as a percentage of the total energy consumption) and the industrial added value as a percentage of the total added value[2].

We have estimated three different models: a fixed-effects model in relation to the initial level of CO_2 emissions, another fixed-effects model with emissions lagged one period, and a dynamic model using the generalized method of moments (GMM) for panel data. Table 3 shows the results of the estimations conducted. All three models have explanatory power, so we should accept the hypothesis of conditional convergence across countries, being GDP per capita, use of fossil fuels and the economic weight of the industrial sector the main significant variables. These results are similar to previous studies, such as Jobert *et al.* (2010), who find conditional convergence in EU emissions, with GDP and industrial weight influencing the differences among countries.

Table 3: Conditional convergence

Variable	FE[a]	FE[b]	GMM (DPD)
Constant	-0.177 (-0.97)	-2.57 (-3.30)***	-2.26 (-2.77)***
Log CO2 initial	-0.017 (-4.20)***	-	-
Log CO2 $_{t-1}$	-	-0.41 (-11.06)***	-0.38 (-10.70)***
Log GDPcap	0.0106 (5.03)***	0.15 (4.87)***	0.15 (4.78)***
Log Urban Population	0.0042 (0.04)	-0.24 (-1.46)	0.34 (-1.85)*
Log Renewables	0.0002 (0.17)	-0.01 (-1.01)	-0.01 (-1.49)
Log Fossil	0.0155 (3.34)***	0.65 (6.38)***	0.65 (6.12)***
Log Industry	0.0059 (0.88)	0.032 (0.98)	0.06 (2.05)**
R^2	0.68	0.51	0.51
S.E. regression	0.0065	0.043	0.041
J-statistic	-	-	1.17(0.28)***
F-statistic	33.7582***	8.86***	-

Notes: T statistic in brackets. *** significant 1%; ** significant 5%; * significant 10%. [a] Model of time fixed effects with heterocedascidity correction of White. [b] Model of time and country fixed effects with heterocedascidity correction of White. [c] Number of instruments in GGM estimaton: 7.

[2] For reasons of data availability, we only analyze the period between 1990 and 2012. We have excluded Croatia, Estonia and Slovenia due to missing data and Luxembourg for being an outlier.

With respect to sectors, we report the results corresponding to the GMM models. Some discrepancies arise in the industrial sector between the model relating to the initial level of emissions and the models with the variable lagged. The first shows conditional convergence with GDP per capita and urban population as explanatory variables while the other models show absolute convergence. In the energy sector, we find evidence of conditional convergence, with GDP per capita, population, use of fossil fuels and the weight of the industrial sector as explanatory variables.

Concerning subsectors, there is conditional convergence in the electricity subsector linked to GDP per capita, the use of renewable energies, the use of fossil fuels and the weight of the industrial sector. A similar conclusion is reached in the manufacturing and construction sector, where the explanatory variables are GDP per capita, urban population and the use of fossil fuels. Regarding the transport subsector, we find significant coefficients in GDP per capita. Finally, for other sources of emissions, the evidence of conditional convergence depends on the use of fossil fuels as a significant predictor (Tables 4 and 5).

Table 4: Conditional convergence. Results by sectors

Variable	Agriculture	Industry	Energy
Constant	1.12 (0.59)*	-1.47 (1.34)	-1.96 (0.8)**
Log CO_2 initial	-	-	-
Log $CO_{2\ t-1}$	-0.30 (0.044)***	-0.062 (0.034)*	-0.372 (0.035)***
Log GDPcap	0.21 (0.03)***	0.13 (0.13)	0.138 (0.029)***
Log Urban population	-0.70 (0.165)***	0.117 (0.44)	-0.365 (0.178)**
Log Renewables	0.014 (0.01)*	-0.004 (0.02)	-0.013 (0.009)
Log Fossil	-0.05 (0.07)	-0.065 (0.11)	0.62 (0.10)***
Log Industry	-0.03 (0.02)	-0.04 (0.083)	0.056 (0.027)**
R^2	0.35	0.32	0.51
S.E. regression	0.034	0.095	0.040
J-statistic	5.76 (0.02)**	0.97 (0.32)***	3.298 (0.07) ***

Notes: Standard error in brackets; *** 1% significant; ** 5% significant; * 10% significant.

Table 5: Conditional convergence. Results in the energy subsectors

Variable	Electricity	Manufacturings	Transport	Others
Constant	-3.69 (1.55)**	2.63 (1.89)	-3.38 (1.404)**	-3.153 (1.66)*
Log CO_2 initial	-	-	-	-
Log CO2 $_{t-1}$	-0.468 (0.041)***	-0.441 (0.13)***	-0.237 (0.057)***	-0.117 (0.037)***
Log GDPcap	-0.174 (0.056)***	0.29 (0.10)***	0.301 (0.062)***	0.156 (0.098)
Log Urban population	0.076 (0.293)	-1.65 (0.62)***	0.158 (0.308)	0.102 (0.506)
Log Renewables	-0.047 (0.017)***	-0.012 (0.028)	0.021 (0.013)	0.043 (0.025)*
Log Fossil	1.11 (0.234)***	0.384 (0.22)*	-0.071 (0.078)	0.269 (0.132)**
Log Industry	0.253 (0.057)***	-0.037 (0.087)	0.044 (0.042)	-0.015 (0.083)
R^2	0.41	0.31	0.31	0.26
S.E. regression	0.075	0.138	0.066	0.098
J-statistic	4.47 (0.03)**	0.07 (0.79)***	2.84 (0.09)**	3.132 (0.08)**
Number of instruments	7	7	7	7

Notes: Standard error in brackets. *** 1% significant; ** 5% significant; * 10% significant.

3.4. Sigma convergence

Figure 1 shows the evolution since 1924 of the standard deviation of the natural logarithm of CO_2 emissions, measured in tons per capita. We observe a slightly negative trend until the 80s (excluding the Second World War period) and stabilization thereafter. We thus conclude that there has been no σ-convergence across European countries since the 80s. Similar results in terms of σ-divergence have been produced in previous studies such as Aldy (2006) and Criado and Grether (2011) for OECD countries.

Figure 1: σ-convergence (all countries)

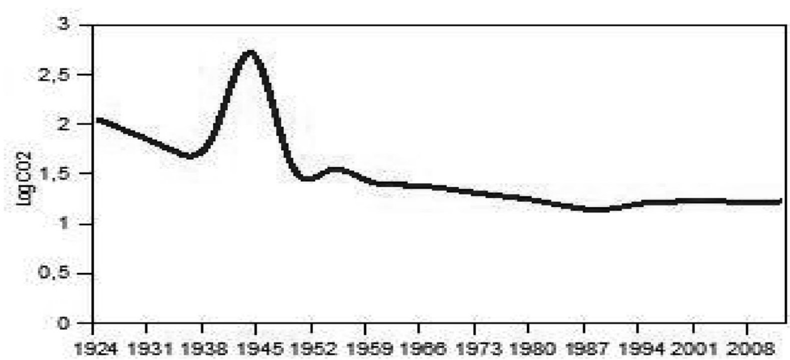
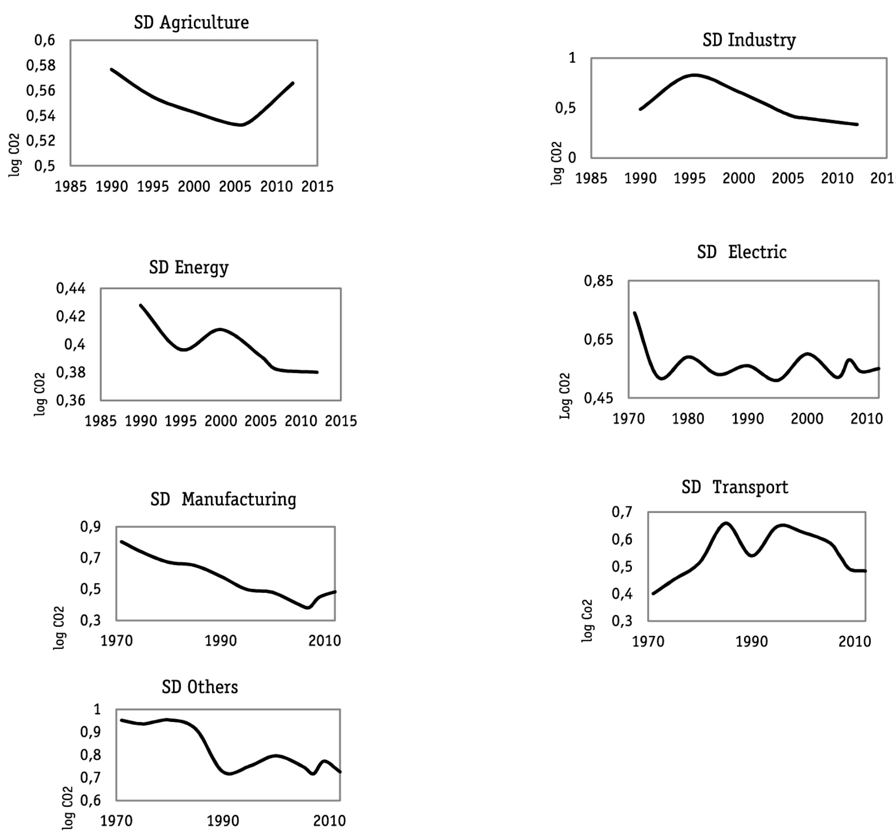


Figure 2 shows the evolution of the lnCO_2 standard deviation in all sectors and subsectors considered. The industrial sector and the electricity sector have reduced their variation relative to the mean, with their dispersion tending to stabilize from 2005 onwards. The agricultural sector shows a turning point in 2007, with an increase in its dispersion from then on. As far as the energy sector is concerned, the manufacturing sector shows clear evidence of sigma-convergence with a reduction of the dispersion of about 40%, occurring steadily throughout the period 1971-2012. The other subsectors also have reduced their dispersion if we compare the initial and final values but these reductions happen in the first years of the sample: up until 1985 in the electricity and heat subsector, and up until 1990 in other sources of emissions. The transport sector shows a higher dispersion over the period.

Figure 2: Sigma convergence by sector and subsectors



3.5. Stochastic convergence

To identify stochastic convergence we check for the existence of unit roots in the series to detect whether, after a shock, the series returns to the trend (stationary) or it is affected permanently (unit root). The variable under study is the natural logarithm of the rate of emissions from each country relative to the annual average of the whole set of countries. We observe different patterns with several changes in trend and in levels at different times. To detect when the structural change happens in each country, we use different approaches based on the Bai-Perron test (1998) with trimming = 0.25. Table 6 summarizes the moments when structural changes happen in each country. The periods that contain the most breaks correspond to the early 70s, with the first oil crisis, and 1991-1993, when a financial crisis coincided with the transition of Central and Eastern European countries to market economies and the implementation of environmental protection measures.

Table 6: Bai-Perron test, dates of structural changes

Country	Year	Country	Year	Country	Year	Country	Year
Austria	1986, 1999	Estonia	1992	Italy	1972, 1985, 1999	Portugal	1984, 1999
Belgium	1984, 1998	Finland	1972, 1993	Letonia	1973, 1986, 1999	Romania	1983, 1998
Bulgaria	1972, 1990	France	1972, 1985, 1999	Lithuania	1991	Slovakia	1974, 1990
Croatia	1982, 1996	Germany	1973	Luxembourg	1980, 1994	Slovenia	1980, 1994
Cyprus	1991	Greece	1974, 1999	Malta	1974, 1993	Spain	1973, 1986, 1999
Czec Republic	1974, 1989	Hungary	1974, 1987	Netherlands	1978, 1991	Sweden	1972, 1991
Denmark	1972, 1993	Ireland	1983, 1999	Poland	1974, 1989	United Kingdom	1975, 1987, 2000

To analyze the stochastic convergence by sectors we apply first the test for structural change proposed by Bai-Perron (1998), then we apply the ADF test to check for a structural change and finally, the test proposed by Carrion *et al.* (2009) to check for several structural changes. Table 7 shows the list of countries in the main economic sectors which have rejected in some cases the existence of a unit root and, consequently, their emissions converge. The most countries exhibit convergence in all three main sectors considered. The countries in bold print (Greece and Luxembourg) satisfy the conditions to accept absolute convergence.

We apply the same procedure to the energy subsectors. We observe a higher number of countries that do not converge in both tests (ADF and Carrion). These results underline the fact that focusing on the energy sector is a priority when seeking to reduce emissions in the EU. When considering the sector as a whole, a few countries diverge, but the results are very different when we analyze the data by subsectors. The transport sector is particularly notable: half the countries (according to the Carrion test) do not converge and the emissions are growing, as mentioned earlier. The detailed results are available upon request.

Table 7: Stochastic convergence by countries and sectors

Sector	Test	Convergence			No convergence		
		G1	G2	G3	G1	G2	G3
Agriculture	ADF	Austria, Cyprus, Croatia, Finland, Greece, Italy, Netherlands, Malta, Portugal, Eslovenia, Spain	Belgium, France, Denmark, Germany, Luxembourg, Sweden, United Kingdom	Bulgaria, Czec Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia	Ireland		
	Carrión	Austria, Croatia, Finland, Greece, Ireland, Italy, Netherlands, Malta, Portugal, Eslovenia, Spain	Belgium, France, Denmark, Germany, Luxembourg, United Kingdom	Bulgaria, Czec Republic, Estonia, Hungary, Lithuania, Slovakia	Cyprus,	Sweden	Latvia, Poland, Romania
Industry	ADF	Austria, Croatia, Finland, Greece, Ireland, Italy, Netherlands, Malta, Portugal, Eslovenia	Belgium, France, Germany, Luxembourg , Sweden, United Kingdom	Bulgaria, Czec Republic, Hungary, Latvia, Lithuania, Romania, Slovakia	Cyprus, Spain	Denmark	Estonia, Poland
	Carrión	Austria,Croatia, Greece, Ireland, Italy, Malta, Spain	Belgium, Denmark, Luxembourg, Sweden, United Kingdom	Bulgaria, Czec Republic, Hungary, Latvia, Poland, Slovakia	Cyprus, Finland, Netherlands, Portugal, Eslovenia	France, Germany	Estonia, Lithuania, Romania
Energy	ADF	Austria, Cyprus,, Finland, Greece, Ireland, Italy, Netherlands, Malta, Portugal, Eslovenia, Spain	France, Denmark, Germany, Luxembourg, Sweden, United Kingdom	Bulgaria, Czec Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia	Croatia	Belgium	
	Carrión	Austria, Croatia, Finland, Greece, Ireland, Italy, Netherlands, Portugal, Eslovenia, Spain	Belgium, France, Denmark, Germany, Luxembourg, Sweden, United Kingdom	Bulgaria, Czec Republic, Estonia, Hungary, Latvia, Poland, Romania, Slovakia	Cyprus, Malta		Lithuania

4. Conclusions

Two main insights are drawn from the results obtained in this study. When considering global emissions by country, only weak absolute convergence across countries is found. Nevertheless, there is clear evidence of conditional convergence, with GDP, the weight of industrial sector and the use of renewable energies being the main drivers of divergence.

Concerning the specific sectors, we observe an increase of emissions in the agricultural sector, but a reduction in the industrial and energy sectors. More specifically, different patterns arise in the energy subsectors, where emissions from manufacturing and electricity have notably been reduced, while those from transportation have increased for all countries.

The investigation conducted offers several useful policy implications. When considering the emissions by country, three main statements can be made. The first one is the appropriateness of the bubble system to move towards the 2020 targets concerning energy efficiency and emissions reduction. Since a visual inspection of the data reveals different country patterns, specific measures and targets should be implemented and fixed for each country. The second implication is the effectiveness of the IPPC regulation and the European carbon market to curb GHG in the industrial and manufacturing sectors, which could be associated to the reported emissions decline in the industrialized countries. A third implication is the influence that economic structure and technology have on emissions. The stochastic convergence tests show a great heterogeneity across countries, providing different patterns with several changes in trend and in levels at different times, being the early 70s and 90s the periods with more breaks, coinciding with the oil crisis and financial crisis respectively. The conditional convergence analysis reveals that these cross-country differences are explained mainly by GDP, the use of fossil fuels and the weight of the industrial sector, i.e, the economy's sectoral structure. These determinants may explain the evolution of countries involved in a transition process to a market economy. They increased their emissions in the eighties and reduced them notably in the following decades as a consequence of the structural and technological changes that occurred in this period.

Since the early 2000s, the EU is taking action in several areas to meet the 2020 targets (20% cut in GHG emissions from 1990 levels, 20% of EU energy from renewables, 20% improvement in energy efficiency). Concerning emissions, domestic targets for every member state has been set according to national wealth, from a 20% cut for the richest countries to a maximum 20% increase for the least wealthy. This action is in line with the results obtained in the conditional convergence analysis, according to which GDP appears as the main driver of divergence. With respect to renewable energy, EU member countries have also taken on binding national targets to increase the share of renewables in their energy consumption by 2020. These targets also vary to reflect countries' different starting points for renewables production, and ability to further increase it from 10% in Malta to 49% in Sweden. Again, our results support this action, given that the use of fossil fuels is significant to explain the conditional convergence.

The analysis performed by sectors also yields some important insights. The stylized facts show a decrease of emissions in the energy and industrial sectors jointly with an increase in agriculture. By subsectors, a substantial reduction is observed in manufacturing and electricity (53% and 22% respectively), while a 30% increase is found in the transport subsector. We find absolute convergence in the agricultural, energy and industrial sectors, which is weak in the former sector. When analyzing deeper the energy sector, absolute convergence is present in electricity and manufacturing but not in transport and other minor subsectors. However, all sectors and subsectors exhibit conditional convergence. Sigma-convergence is present in industry and energy sectors but not in agriculture, neither in the transport sector. These results reinforce the appropriateness of setting the national reduction targets of emissions according to each country's per capita income and to focus in other economic sectors currently not included in the ETS. The EU emissions trading system is a key tool for cutting GHG from large-scale facilities in the power and industry sectors, as well as the aviation sector, but the ETS only covers 45% of the EU's global emissions. Therefore, a target has been established for the sectors not included in the ETS, such as housing, agriculture, waste and transport (excluding aviation). According to the target, the emissions from these sectors in 2020 have to be -on average- 20% lower than in 2005. National emission reduction targets have taken on binding annual targets until 2020 under the "Effort-sharing decision". Our results support the view that these actions are in the right direction, moreover when considering the 2050 roadmap, which envisages an 80% reduction of emissions below 1990 levels. The roadmap also shows how the major sectors responsible for emissions can transition to a low-carbon economy in a cost-effective way. These are the sectors considered in this paper, namely, energy generation, industry, transport, buildings and construction, as well as agriculture.

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APPENDIX

Table A.1: Absolute convergence by sectors

Sector		2012	2000
Agriculture	β de 1990	-0.002 (0.001)***	-0.004 (0.002)***
	v	0.19%	0.46%
	R^2	0.02	0.03
	β de 2000	0.001 (0.001)***	-
	v	-	-
	R^2	0.01	
Industry	β de 1990	-0.018 (0.001)***	-0.009 (0.002)***
	v	2.28%	0.95%
	R^2	0.34	0.05
	β de 2000	-0.026 (0.002)***	-
	v	3.21%	-
	R^2	0.40	
Energy	β de 1990	-0.01 (0.001)***	-0.019 (0.003)***
	v	1.30%	2.10%
	R^2	0.17	0.13
	β de 2000	0.004 (0.001)***	-
	v	-	-
	R^2	0.03	

Notes: Standard error in brackets. *** significant 1%; ** significant 5%; * significant 10%.

Table A.2: Absolute convergence in the generation of electricity subsector

	2012	2000	1990	1980
β de 1971	-0.014 (0.00044)***	-0.016638 (0.000696)***	-0.01759 (0.001106)***	-0.015909 (0,001954)***
v	2.12%	2.30%	2.21%	1.73%
R^2	0.48	0.42	0.34	0.21
β de 1980	-0.014138 (0.000673)***	-0.01896 0.001244)***	-0.024351 (0.002684)***	-
v	1.90%	2.42%	2.83%	-
R^2	0.33	0.29	0.23	-
β de 1990	-0.009710 (0.001065)***	-0.017697 (0.003087)***	-	-
v	1.10%	1.97%	-	-
R^2	0.12	0.10	-	
β de 2000	-0.015385 (0.001844)***	-	-	-
v	1.72%			
R^2	0.16	-	-	-

Table A.3: Absolute convergence in the manufacturing subsector

	2012	2000	1990	1980
β de 1971	-0.007497 (0.00036)***	-0.008681 (0.000518)***	-0.008425 (0.000674)***	-0.009605 (0,001312)***
v	0.90%	1.01%	0.92%	1.01%
R^2	0.29	0.27	0.24	0.18
β de 1980	-0.007925 (0.000498)***	-0.009103 (0.000087)***	-0.005415 (0.001105)***	-
v	0.92%	1.01%	0.01%	-
R^2	0.22	0.17	0.08	-
β de 1990	-0.017271 (0.001118)***	-0.024813 (0.003035)***	-	-
v	2.20%	2.90%	-	-
R^2	0.28	0.18	-	
β de 2000	-0.012818 (0.001955)***	-	-	-
v	1.40%			
R^2	0.11	-	-	-

Table A.4: Absolute convergence in the transport sector

	2012	2000	1990	1980
β de 1971	-0.000704 (0.000822)	-0.001833 (0.001212)	0.006852 (0.001609)***	0.006898 (0,002695)**
v	-	-	-	-
R^2	0.01	0.00	0.03	0.02
β de 1980	0.000504 (0.000708)	0.004188 (0.001171)***	0.009355 (0.001876)***	-
v	-	-	-	-
R^2	0.00	0.02	0.08	-
β de 1990	-0.001327 (0.000911)	0.006864 (0.002172)***	-	-
v	-	-	-	-
R^2	0.00	0.34	-	
β de 2000	-0.012242 (0.001151)***	-	-	-
v	1.33%			
R^2	0.24	-	-	-

Table A.5: Absolute convergence in others minor combustion subsectors

	2012	2000	1990	1980
β de 1971	-0.007321 (0.000431)***	-0.006324 (0.000542)***	-0.0104316 (0.00061)***	-0.001986 (0.000889)**
v	0.87%	0.70%	0.45%	0.20%
R^2	0.21	0.15	0.09	0.02
β de 1980	-0.0111 (0.000628)***	-0.011693 (0.000966)***	-0.010024 (0.001288)***	-
v	1.38%	1.34%	1.06%	-
R^2	0.25	0.21	0.18	-
β de 1990	-0.007774 (0.00112)***	0.035843 (0.005067)***	-	-
v	0.85%	-	-	-
R^2	0.07	0.15	-	
β de 2000	-0.007901 (0.001306)***	-	-	-
v	0.83%			
R^2	0.09	-	-	-

Table A.6: Increase of CO2 emissions in the electricity subsector by group of countries

	Group 1			Group 2			Group 3		
	1971	2012	Incr.	1971	2012	Incr.	1971	2012	Incr.
Mean	2.94	3.04	3.4%	4.06	2.45	-39.6%	1.90	3.60	89.5%