Club Convergence of Sectoral CO_2 Emissions in the European Union[1]

Rafael Morales-Lage[a]

Aurelia Bengochea-Morancho[a]

Mariam Camarero[a]

Inmaculada Martínez-Zarzoso[a,b]

Abstract

An understanding of the evolution of sectoral CO_2 emissions for all EU countries in recent decades would clearly be useful for political authorities when designing future environmental policies. This paper investigates the process of convergence in sectoral per capita CO_2 emissions, with a focus on the energy sector. The concept of club convergence is used to analyse emissions in 28 EU countries from 1971 to 2012, with special attention paid to the energy subsectors (power generation and heating, manufactures and construction, transportation, and other minor fuel combustion). We find that core European countries (France, the Netherlands, Germany and the UK) are included in the best performing clubs, no matter the sector or subsector, whereas among Central and Eastern European Countries, a few diverge from the average towards higher emissions. Relative convergence among a large number of EU members would, therefore, support the relevance of both the EU abatement policy and international agreements in this process.

Key words: Convergence, CO_2 emissions, European Union. **JEL**: C22, O47, Q53.

Corresponding author: Mariam Camarero. Economics Department. University Jaume I. E12071 Castellón (Spain) email: camarero@uji.es.

---

[1] The authors gratefully acknowledge the financial support from the Spanish MINECO project ECO2017-83255-C3-3-P and from Project UJI-B2017-33. The authors also thank the Generalitat Valenciana for their funding (project PROMETEOII/2018/102). We are also indebted to Peter C.B. Phillips and Donggyu Sul for providing the Gauss codes used in the econometric analysis. All remaining errors are ours.

[a] University Jaume I.

[b] University of Göttingen.

Club Convergence of Sectoral CO_2 Emissions in the European Union

1. Introduction

Since the adoption of the Kyoto Protocol in 1997, the EU has set targets for cutting greenhouse gas (GHG) emissions until 2020 and beyond by means of a "bubble" system. This system relies on the idea that countries should converge to the same level of emissions per capita. The 2008-2020 European Energy and Climate Change Package sets the 20-20-20 targets to be reached by 2020 (GHG emissions 20% lower than in 1990, 20% of energy from renewable sources and a 20% increase in energy efficiency). Moreover, the roadmap set by the European Commission in 2011 has even more ambitious targets (COM (2011) 885 final). This roadmap indicates that by 2050 the EU should have reduced its emissions to 80% below 1990 levels through domestic reductions and intermediate milestones (to 40% by 2030, 60% by 2040 and 80% by 2050). According to the framework adopted by the European Council in 2014 (COM (2014) 015 final) the key targets for renewables and energy efficiency for 2030 are set as: at least 32% share for renewable energy and 32% improvement in energy efficiency. These targets, originally set at 27%, were revised upwards in 2018. Moreover, EU members have to adopt integrated National Climate and Energy Plans (NECPs) for the period 2021-2030, which drafts had to be submitted by the end of 2018 and the final plans are due by the end of 2019. While each EU country has a mandatory target in terms of emission reduction, renewable energy and energy efficiency targets are only set at the EU level.

To apply effective policies aimed at achieving these goals, it is crucial to identify the trend in each member state and to analyse the evolution of emissions in different economic sectors. This will help determine where efforts should be directed and whether the policies enacted have been effective. Both EU institutions and national (or even regional) authorities have a crucial role in the success of these targets; although climate change is an international problem in scope, domestic or regional policies should be implemented to mitigate CO_2 emissions (Burnett, 2016). The EU has played a leading role in the fight against climate change, pledging to reduce its GHG emissions. In particular, the EU committed to reducing its emissions by 8% in 2008-2012 compared to 1990 levels, through a bubble system, meaning that each member state had its own reduction target, although some counties were actually allowed to increase emissions.

The objectives pursued by the Kyoto Protocol followed on from the Paris Agreement, which entered into force in November 2016. The parties had to submit their NECPs, including specific reduction targets, subject to legally binding obligations. The EU was the first major economy to present its climate plan (Intended Nationally Determined Contributions) in March 2015, as part of the European framework on climate and energy set by the European Council in October 2014, and the European Commission's blueprint for tackling global climate change beyond 2020 (European Commission, 2015). According to the European Commission (European Commission, 2016), in order to properly manage a smooth transition to a low-carbon economy, EU countries' different energy mixes and production structures should be taken into account. Therefore, the EU has maintained the bubble system to reduce GHG emissions and has set several goals with different time horizons. The roadmap to a low-carbon economy stipulates that by 2020 the EU should have cut its emissions by 30% relative to 1990 levels. Individual EU members are also required to develop their own national long-term strategies by the first of January 2020 and ensure consistency between these long-run plans and the corresponding NECPs. The individual targets ranged initially 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, according to which heavier polluters must make cuts while those with lower emissions are allowed to increase them. After submission the NECPs drafts in 2018, those were analysed by the Commission, which published in June 2019 (COM (2019) 285 final) the assessment of the drafts as a whole as well as specific recommendations for each country to be considered for the final NECP.

The main aim of this paper is to test whether convergence in per capita CO_2 emissions has occurred across countries and economic sectors using club convergence econometric methodologies and, in particular, the Phillips and Sul (2007, 2009) method. We consider this approach to be the most suitable for this study since it takes into account not only a static picture of convergence but also the transition path followed by each country in the convergence process. The analysis of relative conditional convergence is a key issue in the European environmental policy framework given that the European Commission has set different targets for EU members depending on their structural and economic characteristics. In this context, it is important to determine whether or not European countries' emissions are converging to different steady states, in order to set them different (or not) reduction targets. Therefore, a more in-depth examination of this issue is crucial to set fair and realistic medium- and long-term reduction targets, both at the supranational level and at the domestic policy level.

We depart from the previous related literature in that we study convergence in CO_2 emissions at the sectoral level. The sectors considered are agriculture, industry, and energy, with a special focus on the energy sector, which in 2014 accounted for about 30% of total GHG emissions in the EU[2]. This sector is further disaggregated into four subsectors: power generation and heating, manufactures and construction, transportation and other minor fuel combustion subsectors.

---

[2] Source: https://www.eea.europa.eu/data-and-maps/indicators/greenhouse-gas-emission-trends-6/assessment.

The main results show weak evidence of convergence and indicate that the EU countries are far from reaching the bubble system target of equalizing per capita emissions. However, the results on relative convergence indicate that all EU countries have at least contained their emissions' growth. In particular, we find convergence within several clubs or groups of countries although, at the same time, we observe major differences among the sectors and subsectors considered. We also find that the majority of the countries analysed have been able to reduce their emissions in some energy subsectors. There are some exceptions, which mostly correspond to the Central and Eastern European Countries (CEECs). However, the time-paths followed are promising and the evidence points towards the effectiveness of EU policies in helping curb emissions.

The paper is organized as follows: Section 2 outlines and explains the different concepts of convergence. Section 3 presents a review of the literature and refers to the state of the art on the subject and methodology. Next, Section 4 describes the empirical approach applied, Section 5 discusses the overall and sectoral results obtained, and Section 6 points out the policy implications of the research. Finally, Section 7 concludes.

2. Convergence: Concepts and Definitions

The concept of convergence originated from Solow's neoclassical growth model (Solow, 1956), starting with Baumol (1986) and later further developed by Barro and Sala-i-Martin (1991). It has since been applied to a range of different economic processes involving groups of countries. Although many different hypotheses have been proposed in this context, three stand out: absolute convergence, conditional convergence and club convergence. ***Absolute or β-convergence*** implies that the countries or units analysed converge to one another in the long run, independently of their initial conditions, whereas ***conditional convergence*** implies convergence that is conditional on the countries having similar characteristics. Conversely, ***club convergence*** means that a set of economies with similar conditions and structural characteristics (such as technology, preferences, political systems) will tend to converge to the same steady state. Thus, as proposed by Quah (1996, 1997), testing for club convergence would consist of testing for absolute or β-convergence[3] in countries that have, a priori, common structural characteristics.

However, these definitions correspond to long-run concepts and have generally been tested under the restriction that, if convergence is found, it has already occurred. Convergence may only be found when in the steady state. Frequently this is not the case, as convergence may be an ongoing process. Thus, some countries may be catching-up without having reached the steady state. In such cases, a rejection of convergence would not be reflecting the process of convergence itself.

Phillips and Sul (2007, 2009) proposed the concept of ***relative convergence***, which considers the transition path of each country together with its growth performance to find convergence. Even among highly integrated countries, there may be heterogeneous characteristics—related not only to technology adoption but also to the institutional system and the structure of the economy—that explain non-convergence or, sometimes, different transition paths towards steady-state growth. Phillips and Sul (2009) are particularly interested in whether transitional heterogeneity may explain divergence in the empirical growth literature. More specifically, they suggest an econometric approach

---

[3] There is *β-convergence* when poor economies tend to grow faster than rich ones; if this is the case, in the long term rich and poor countries tend to converge to the same level, the so-called steady state. *β-convergence* implies that there is a negative correlation between the rate of income growth in a country and its initial income level, reflected in the negative sign of the parameter β in: $\ln \frac{y_{it}}{y_{i,t-1}} = a - \beta \ln(y_{i,t-1}) + u_{it}$ where y_{it} is the income of country *i* in period *t* and u_{it} is a stationary and independent error term. There is *σ-convergence* when some economies reduce the dispersion of the variable under study over time, i.e., $\sigma_{t+T} < \sigma_t$. The indicator of dispersion initially used by Barro and Sala-i-Martin (1992) was the standard deviation but other indicators have been used for this purpose such as the variance, the coefficient of variation or the Gini index.

that jointly considers an economy's transition path with its growth performance. Similarly, this concept can be easily extended to the literature of convergence in emissions, as institutional decisions (international agreements to reduce emissions at fixed dates) and technology adoption are key factors accounting for the varying performance of different countries.

3. Review of the Literature on Club Convergence of CO_2 Emissions

Following the seminal paper by Barro and Sala-i-Martin (1992), the concept of convergence has been widely used in the empirical literature to evaluate not only economic growth, but also productivity, energy efficiency, technology and interest rates, among others.

Concerning convergence in GHG emissions, List (1999) was one of the first to apply the concepts of cross-convergence, β-convergence and stochastic convergence, finding convergence in emissions of nitrogen oxides and sulfur dioxide among US regions from 1929 to 1994. Since then, and probably influenced by the Kyoto Protocol commitments, a vast literature has been published on this topic[4]. In what follows, we specifically focus on the literature on convergence clubs that is most closely related to this paper. In two seminal papers, Phillips and Sul (2007, 2009) propose a methodology to test for convergence based on an algorithm that also permits countries to be classified into convergence clubs. Using this technique, Panopoulou and Pantelides (2009) examine CO_2 emissions in 128 countries between 1960 and 2003, finding the existence of convergence for the whole sample, with two clubs of countries moving towards different steady states that gradually converge. In a similar fashion, Camarero *et al* (2014) assess convergence in eco-efficiency among 27 European countries during the period 1990-2009, considering

---

[4] See also Bassari et al. (2008) for a revised analysis of stochastic convergence.

CO_2, NO_2 and CH_4 emissions. The authors find four to six convergence clubs depending on the gas considered. CEECs turn out to be less eco-efficient than the rest of the EU members.

Also looking for convergence clubs, Huang and Meng (2013) address the influence of geography on convergence by analysing per capita CO_2 emissions in China from 1985 to 2008 across spatial areas. The results show convergence towards higher levels of emissions per capita in all the areas considered and some evidence indicating that spatial factors accelerate the rate of convergence in neighbouring urban areas. Zhang and Broadstock (2016) use the club convergence approach to study energy intensity in China and their main findings indicate the existence of three clubs of regions that differ significantly from one another.

4. Empirical Methodology

In this section we present a summary of Phillips and Sul's (2007, 2009) approaches to relative and club convergence. Phillips and Sul's (2009) proposal is based on a nonlinear dynamic factor model for the logarithm of the dependent variable, growth in their case and emissions in this paper, given by:

$$\log y_{it} = a_{it} + x_{it}t = b_{it}\mu_t \qquad [1]$$

where a_{it} represents the transitional dynamics of capital (see equation (6) in Phillips and Sul (2009)) and the component $x_{it}t$ captures the idiosyncratic time paths of technological progress. In this case, the growth component μ_t is common across countries, and the individual transition factors b_{it} capture individual economic performance.

Phillips and Sul (2007) defined ***relative convergence***, which implies growth convergence in the long run rather than level convergence; it also holds independently of the order of integration of the common component. This concept of convergence allows for a time-varying β_{it} (instead of a constant speed of convergence, β, as in neoclassical models). *Relative convergence* can be defined as:

$$\lim_{t\to\infty} \frac{\log y_{it}}{\log y_{jt}} = 1 \text{ for all } i \text{ and } j \qquad [2]$$

Furthermore, this approach avoids the pitfalls associated with other convergence tests that have been used in the empirical literature. Traditional convergence tests try to assess whether β is positive or negative. However, when technology is heterogeneous, it makes sense to allow for transition periods when β is time-varying and depends on the rate of technical progress. From an economic point of view, b_{it} measures the relative share in μ_t (see equation [1]), a common trend component in the panel of individual *i* at time *t*. Based on these relations, Phillips and Sul (2009) propose an alternative approach to model the transition elements, to construct the relative transition coefficient:

$$h_{it} = \frac{\log y_{it}}{N^{-1}\sum_{i=1}^{N}\log y_{it}} = \frac{b_{it}}{N^{-1}\sum_{i=1}^{N} b_{it}} \qquad [3]$$

This formulation eliminates the common growth component by scaling, and measures the transition element for economy *i* relative to the cross-section average. The variable h_{it} measures the individual trajectory for each *i* relative to the average and is called *relative transition path*. This can also be considered economy *i*'s departure from the common steady-state growth path μ_t. It is convenient to work with the relative transition coefficients h_{it} rather than with the coefficients b_{it} as the former can be directly measured. Assuming that the panel average and its limit both differ from zero as $N \to \infty$, the cross-sectional mean of h_{it} is unity by definition. Moreover, if the factor loading coefficients converge to *b*, the relative transition parameters h_{it} converge to unity. Then, in the long-run, the cross-sectional variance of h_{it} converges to zero. The relative transition path can be used to assess divergence and whether this divergence is transient.

Next, the authors construct the cross-sectional mean square transition differential H_1/H_t where:

$$H_t = \frac{1}{N}\sum_{i=1}^{N}(\hat{h}_{it} - 1)^2 \qquad [4]$$

measures the distance of the panel from the common limit.

They represent the model accounting for special behaviour in the idiosyncratic element b_{it}, which they model in semiparametric form allowing for heterogeneity over time and across individuals:

$$b_{it} = b_i + \sigma_i \xi_{it} L(t)^{-1} t^{-\alpha} \qquad [5]$$

where b_i is fixed, ξ_{it} is iid(0,1) across i but weakly dependent over *t*, α denotes the speed of convergence and L(t) is a slowly varying function (like *log t*) for which L(t) $\rightarrow \infty$ as $t \rightarrow \infty$. This formulation ensures that b_{it} converges to b_i for all $\alpha \geq 0$ (the null hypothesis of interest). If this null holds and $b_i = b_j$ for $i \neq j$, the model allows for transitional periods in which $b_{it} = b_{jt}$, so that transitional heterogeneity or even transitional divergence are possible across *i*.

The **null hypothesis of (relative) convergence** is formulated as:

$$H_0\text{: } b_i = b \text{ and } \alpha \geq 0 \qquad [6]$$

and involves the weak inequality $\alpha \geq 0$, since:

$$\lim_{t\rightarrow\infty} b_{it} = b \text{ iff } b_i = b \text{ and } \alpha \geq 0$$

$$\lim_{t\rightarrow\infty} b_{it} \neq b \text{ iff } b_i \neq b \text{ and } \alpha < 0$$

The alternative hypothesis is:

$$H_A\text{: } \{\, b_i = b \text{ for all } i \text{ with } \alpha > 0\} \text{ or } \{b_i \neq b \text{ for some } i \text{ with } \alpha \geq 0, \text{ or } \alpha < 0\}$$

According to Phillips and Sul (2009), the role of the slowly varying function *L*(t) is to ensure that convergence holds even when $\alpha = 0$, although at a very slow rate.

Phillips and Sul (2007) recommend starting the regression at point $T_0 = [rT]$, where $[rT]$ is the integer part of *rT*[5]. Thus, the empirical log t regressions are based on time series where the first *r%* of the data is discarded. The term $-2\log(\log t)$ plays the role of a penalty function (to provide power to the test under the alternative).

This formulation leads to the "log t" regression model that can be written as:

$$\log\frac{H_1}{H_t}-2\log(\log t) = a + \gamma\log t + u_t, \text{ for } t = T_0, \dots, T \quad [7]$$

According to Phillips and Sul (2009), under the null hypothesis of convergence, the estimate of γ converges in probability to the speed parameter 2α. The t-statistic diverges to positive infinity when α>0 and converges weakly to the standard normal distribution when α=0. Thus, the null hypothesis of convergence is a **one-sided t-test** of $\alpha \geq 0$. Under the alternative of ***club convergence***, the point estimate of γ converges to zero (no matter the value of α), but the t-statistic diverges to negative infinity. Moreover, we are not only interested in the sign of the coefficient γ=2α but also its magnitude, as this measures the speed of convergence of the relative transition parameter (b_{it}). Values of γ equal to or larger than 2, when the common component μ_t follows a random walk with drift or a trend stationary process of γ, would imply ***convergence in levels***. If $2 \geq \gamma \geq 0$, this speed of convergence corresponds to ***conditional convergence*** (the growth rates converge over time). The log *t* regression tests also have power against club convergence, so that even after we reject the null hypothesis of convergence we can still find club convergence.

---

[5] They suggest r=0.3, as this was the value that reported better size and power in their simulations. We chose the same value for this paper.

In the empirical application of the log t test to testing for convergence, Phillips and Sul (2007) suggest using a four-step ***club convergence algorithm*** if the overall test for convergence resulted in rejection. The first step consists of ordering the panel members according to the last observation. The second step is the core club formation, in which the convergence t-statistic t_k is used, by means of sequential log(t) regressions based on the k highest members (step 1) with $2 \leq k \leq N$. The size of the group is determined based on the maximum t_k with t_k >-1.65. In step 3, the members of the core group (step 2) are selected by adding one at a time. A new country is included if the associated t-statistic is greater than zero. Finally, the non-selected countries in step 3 form a complement group. Then the log *t* regression is applied to this set of countries. If they converge, they form a second convergence club. If not, steps 1 to 3 are repeated, to detect sub-convergence clusters. If no core group is found in step 2, these countries display divergent behaviour.

5. Club Convergence Results

In this section we present the results on convergence in EU countries using the methodology described above, applying the Phillips and Sul (2007, 2009) algorithm. The data are available at two aggregation levels[6] and for completeness, despite the fact that the time period is restricted, we first present results for all sectors at the first level. Next, we specifically focus our analysis on the four energy subsectors (power generation and heating, transportation, manufactures and construction, and other minor combustion emissions). The data are gathered from the CAIT Climate Data Explorer of the World Resources Institute[7]. In Table 1 we present a summary of the evolution of per capita emissions in the EU for the sectors and subsectors considered in the empirical section and

---

[6] The levels are: 1) sectoral emissions (agriculture, industry and energy) and 2) emissions for the four energy subsectors.

[7] Available at: http://www.wri.org/our-work/project/cait-climate-data-explorer.

for the available time-span, starting in 1990 for the aggregate sectors and in 1971 for the energy subsectors. Agriculture stands out as the only broad sector where the emissions were still increasing between the 1990s and 2000. Concerning the energy subsectors, power generation and heating also shows increasing emissions until 1990, whereas in the case of transportation, CO_2 emissions were still rising in 2012. Even if what matters for climate change is the evolution of total emissions, we should also consider in detail the heterogeneous behaviour of the individual EU members. This is not only because each country is assigned specific objectives in the climate agreements, but also in order to set policy measures that provide incentives for abatement adapted to each country's characteristics.

The stylized facts indicate that the evolution over time of global per capita CO_2 emissions has been such that if convergence occurs, it would be in the weak sense[8]. Moreover, the general level of emissions has increased over the whole period, but has been decreasing (in total terms) since 1990. This means that actions taken to reduce emissions in the EU in order to meet the Kyoto Protocol targets have apparently achieved their goal or, at the very least, that the trend in emissions has changed. The European Environment Agency (EEA, 2015) confirms that in the last two decades, significant advances have been made in decoupling carbon emissions from economic growth. More specifically, greenhouse gas emissions in the EU-28 declined by 19% in the period 1990–2012, despite a 6% increase in population and a 45% expansion in economic output. The report points to both macroeconomic trends and policy initiatives to explain the reduction in emissions. Both the adoption of cleaner technologies by Eastern European countries during their economic transition and, more recently, the financial crisis in Europe, have contributed to a sharp decline in emissions. On the other hand, climate and energy policies have boosted energy

---

[8] The graphs of total per capita emissions are included in the supplementary material.

efficiency and the use of renewables in European countries, leading to lower CO_2 emissions.

Table 1: Mean per capita CO_2 Emissions in the EU between 1971 and 2012. Broad Sectors and Energy Subsectors

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

Source: CAIT, http://www.wri.org/our-work/project/cait-climate-data-explorer. Figures are in tonnes per capita.
Note: Data is available from 1990 for the broad sectors (Agriculture, Industry and Energy) and from 1971 for the Energy subsectors.

Next, we present the results of applying the above-mentioned Phillips and Sul's (2007, 2009) methodology to data on per capita emissions by broad sectors[9]. In most cases, finding evidence on convergence strongly depends on the assumption that all the countries converge to the average; club convergence would be a less restrictive hypothesis. Thus, we apply the PS approach to the data on emissions for up to 27 European countries, testing not only for overall convergence but also for club convergence. Although we focus on the energy sector and subsectors, we also present the

---

[9] We have also tested for stochastic convergence, finding no evidence of it. The results are available upon request.

results for the broad sectors (agriculture and industry) to gain a more complete picture of the whole economy. This also provides a further test of the validity of the methodology we use, since the mitigation measures have only been adopted for some sectors, while others have been (and remain) excluded. In order to avoid the effects of base-year values and to smooth cyclical components, we normalize the emissions by the initial level, as Phillips and Sul (2009) propose.

We have tested first for overall convergence in each one of the sectors and subsectors considered; if found, this would imply that all the countries in the sample were in a single club. Even if we reject this hypothesis in all instances, it is important to highlight that we might still find club convergence using this empirical approach. This would imply that there are some groups of countries or clubs for which there is evidence of convergence within the group. This concept of convergence implies growth convergence (rather than level convergence) and a time-varying beta. To appropriately qualify the results, we should bear in mind that the clustering algorithm starts the selection with the countries that have the highest emissions, at the end of the sample. Thus, in some cases, there is not a clear convergence process among the countries towards a stable or lower emissions level. Instead, different groups of countries tend to different levels of emissions, and some other countries diverge.

5.1. Convergence in the Agriculture, Industry and Energy Sectors

Data availability for the broad sectors was limited to the period 1990-2012. Despite the fact that the short time period renders the club convergence methodology less robust, we have applied it to each sector as a reference, even though our focus is on the disaggregation of energy into subsectors,[10] for which data are available over a longer period. Nonetheless, the period starting in 1990 remains relevant, as this is the reference year for the 2020 EU targets.

The results corresponding to convergence club classification for the three broad sectors, namely, agriculture, industry and energy, are summarized in Table 2, while the relative transition paths followed by the different countries are shown in Figure 1.

In the case of *agriculture*, there are 20 European countries with data available for the whole period. Concerning the overall test for convergence, we reject the hypothesis that agriculture-related per capita emissions converge, as under the null the log t parameter should be equal to or larger than zero, and the test is a one-sided t-test. As mentioned above, this finding does not preclude the existence of convergence clubs. In the second stage of the analysis, the Phillips and Sul algorithm consists of sequentially estimating the log(t) regression and obtaining the t_k statistic, starting with the members with the highest emissions and determining the size of the group using the maximum t_k with $t_k > -1.65$. Thus, in this case, the value of both the log t parameter and the statistic can be negative in some instances. From the application of the algorithm, we find one convergence club that includes the majority of the economies in the sample, except for six diverging countries. The relative transition parameter of this club tends to value 1, or the sample average. However, this does not mean that those forming a club are the best performers[11]. Even for the one convergence club found, the log t parameter has a very small but negative value, implying that their convergence path is slightly above the

---

[10] We are aware of the short length of the data span for aggregated sector emissions, so that these results should be considered as illustrative.

[11] According to the criteria applied by the club algorithm, the countries are ordered from the highest to the lowest values of the variable, emissions in this case. Thus, the most contaminating ones are those considered as potential members of the first club.

average. The t-test value (-0.645) is larger than -1.65, so we cannot reject the hypothesis that this group of countries forms a club. From the transition paths shown in the upper graph of Figure 1, where we also present the countries excluded from the club, we can draw similar conclusions. There we see two types of diverging countries: those that show a transition parameter above 1 and those below 1[12]. Croatia (dotted yellow line) is clearly diverging and increasing emissions, with a transition parameter around 1.4. In contrast, Malta is reducing its emissions and tending towards the average. Bulgaria (grey line) has a transition parameter below 1 and is among the diverging countries but its emissions, though increasing, are still far from the average.

The results for the 22 countries with information available for the *industrial sector* are presented in the second column of Table 2 and in Figure 1 (middle graph). Similar to the agricultural sector, the hypothesis of overall convergence is also clearly rejected for industry. Next, from the application of the club algorithm we find two countries (the Netherlands and the UK) that diverge, whereas the rest form four convergence clubs. The two diverging countries are represented at the bottom of the graph (the dash-brown and dash-dotted grey lines, respectively), where it can be seen that they have systematically reduced their emissions. In contrast, the first convergence club consists of Bulgaria, Lithuania and Poland. They all start off with a high initial level of emissions and follow an upward slope. Looking at the value of the log t parameter (-1.53), we confirm that these countries do not effectively converge, even though they form a club. The case is different for Clubs 2 and 3 (represented by thick continuous lines). Surprisingly, Club 2 (Belgium, Denmark, Italy, Portugal and Sweden) shows emissions with a transition parameter above 1 and a positive slope, meaning that they are simultaneously increasing

---

[12] Note that conditional or relative convergence implies tending towards the sample average and a transition parameter equal to 1.

their emissions and diverging from the average[13]. Club 3 is the largest one and includes those countries whose emissions truly converge towards the average. In these two cases, the log t parameters are positive but small (0.537 and 0.015 in Clubs 2 and 3, respectively), indicating relative or conditional convergence (as described in the previous section). Finally, Club 4 consists only of Croatia and France, both below 1 but with a negative *log t* parameter[14]. We have further tested (see Table 4) whether some of these clubs can be merged, as proposed by Phillips and Sul (2009). This primarily applies to Clubs 2 and 3, as these are the two groups of countries that can be considered convergence clubs. The results indicate rejection of the null hypothesis of merging Clubs 2 and 3; we can see that the two clubs move apart from each other. Moreover, we find that Clubs 2, 3 and 4 cannot be merged.

In the case of the *energy sector*, we have data available for 27 countries. As in the other two broad sectors, the null hypothesis of overall convergence is clearly rejected. Concerning club convergence, four clubs are identified, as well as five non-converging countries. From the transition paths[15] and the convergence results presented in the right-hand column of Table 2, we observe that the first club corresponds to countries with high emissions, including Cyprus, Portugal and Spain. Greece and Slovenia form Club 2, while Club 3 consists of countries with moderate emissions but with a transition parameter still above 1. Only in the latter case is there evidence of conditional convergence towards the average, as the value of the log t parameter is 0.349. The largest club contains 12 countries that have stabilized their per capita emissions and converged, such as Belgium, Denmark,

---

[13] Although this result was unexpected, during the sample period (1990-2012 for the broad sectors), per capita emissions actually grew in the industrial sector in Denmark and Sweden, especially from mid-nineties to 2006.

[14] Note that in the end we decided to exclude these two countries as a club, as the parameter is negative. In the graph they are depicted separately. They tend towards similar levels but follow different trajectories: whereas France is systematically reducing its emissions, Croatia initially improves and later worsens.

[15] In contrast to the previous graph, we have excluded the two non-converging clubs (Clubs 1 and 2) from the graph to simplify the analysis.

France, Germany, Sweden and the UK, but also includes countries in transition such as Bulgaria, Croatia, the Czech Republic, Estonia, Hungary and Poland. While this case is borderline, given that γ and α are very close to zero, we consider that relative convergence is also found in this instance. The transition parameters of the diverging countries are below 1, that is, they are good performers: Austria, the Slovak Republic, Lithuania, Latvia and Romania. Note, however, that diverging in this case means that they are reducing their emissions and as such they do not converge to the average because they are actually improving their performance[16]. Finally, concerning the tests of club merging (Table 3), in this case we again reject the null hypothesis of club merging. Indeed, the only two clubs that really converge (Clubs 3 and 4) maintain but do not reduce their distance.

As a general conclusion of the analysis for broad sectors, the evidence in favour of club convergence is weak, as we only find conditional convergence for some convergence clubs. Bearing in mind the limitations of the short sample period, the performance of the EU countries at this level shows evidence of a high degree of heterogeneity, presumably as a consequence of technological differences.

---

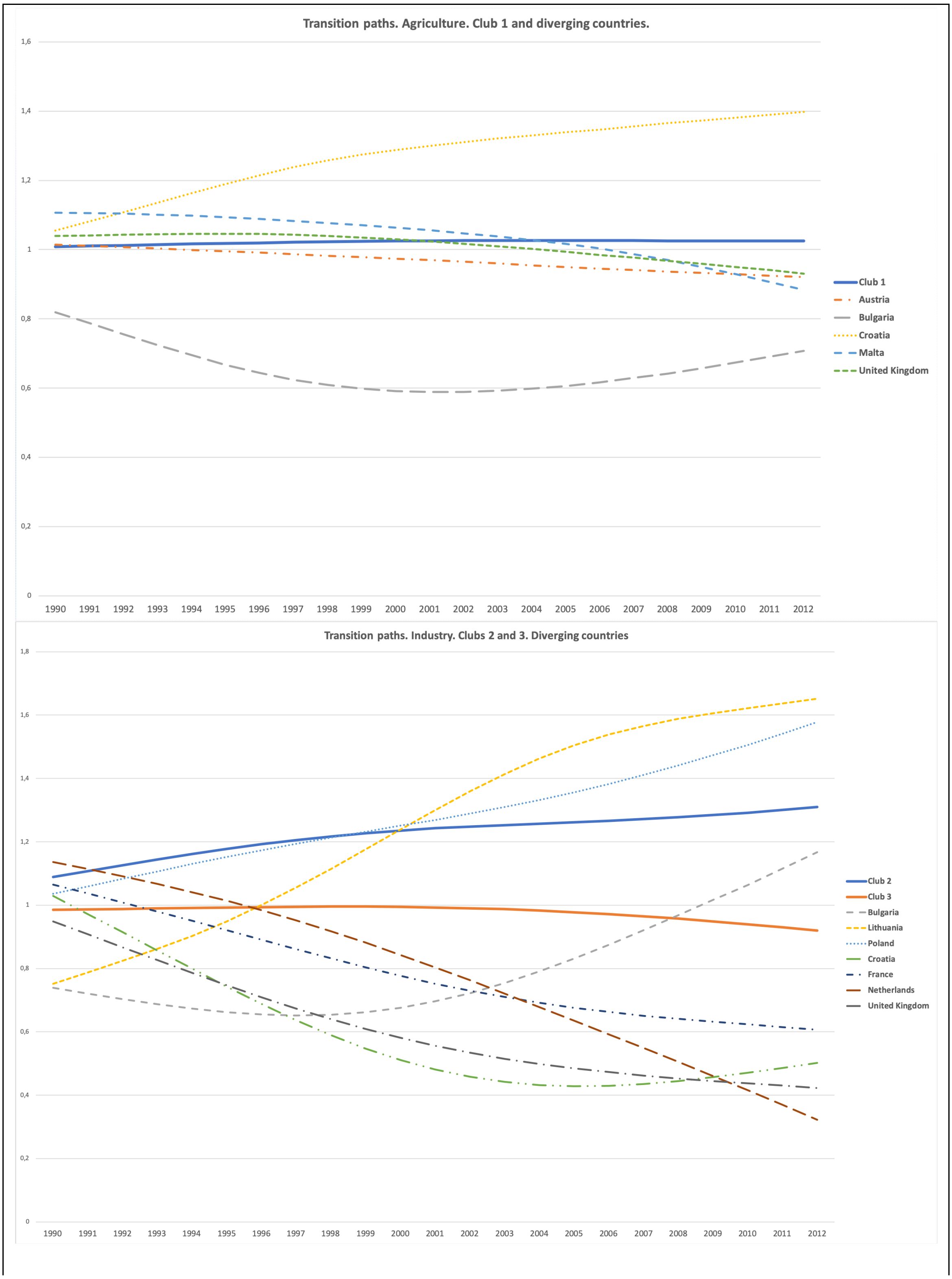
[16] In this sector, changes in the energy mix during the sample period may help explain the composition of the clubs.

Table 2: Convergence Club Classification
Broad Sector Emissions (1990-2012)

Agriculture[20]		**Industry[22]**		**Energy[27]**	
Overall test		**Overall test**		**Overall test**	
log t	t-stat	log t	t-stat	log t	t-stat
-0.621	-6.119	-1.631	-26.463	-1.069	-12.569
Club 1 [Cyp, Dk, FI, Fr, Ger, Gr, Hu, Ire, It, Neth, Pol, Por, Rom, Sp, Sw]		**Club 1** [Bul, Lith, Pol]		**Club 1** [Cyp, Por, Sp]	
log t	t-stat	log t	t-stat	log t	t-stat
-0.099	-0.645	-1.534	-1.31	-0.440	-1.371
Non-converging [Aus, Bul, Cro, Mal, UK]		**Club 2** [Bel, Dk, It, Por, Sw]		**Club 2** [Greece, Slovenia]	
log t	t-stat	log t	t-stat	log t	t-stat
-0.893	-9.059	0.537	1.471	-0.751	-1.296
		Club 3 [Aus, Cz, Fin, Ger, Gr, Hun, Ire, Rom, Slok, Sp]		**Club 3** [Fin, Ire, It, Mal, Neth]	
		log t	t-stat	log t	t-stat
		0.015	0.071	0.349	1.078
		Club 4 [Cr, Fr]		**Club 4** [Bel, Bul, Cro, Cz, Dk, Est, Fr, Ger, Hun, Pol, Sw, UK]	
		log t	t-stat	log t	t-stat
		-0.122	-0.382	-0.006	-0.045
		Non-converging [Neth, UK]		**Non-converging** [Aus, Slovak, Lith, Lat, Rom]	

Note: Shaded cells show the groups of countries that fulfil all the requirements to be considered convergence clubs.

Figure 1: Transition Paths by Sectors



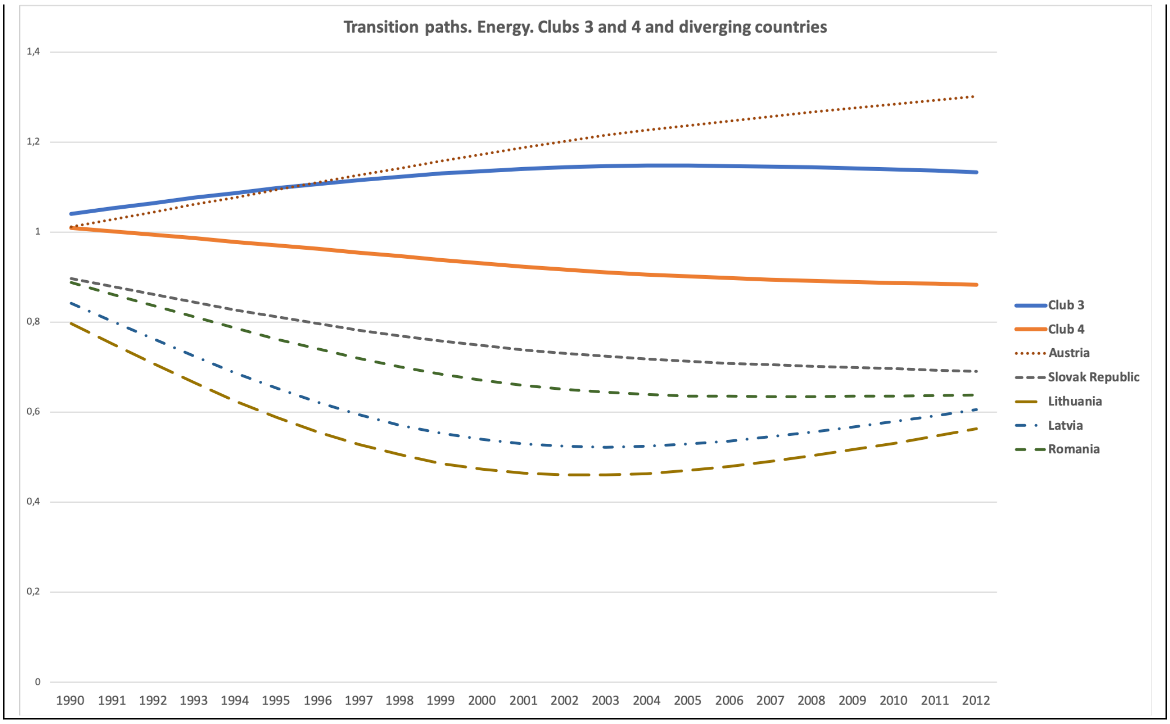


Table 3: Convergence Club Merging

Industry		**Energy**	
Initial classification γ (t of γ)	**Tests of club merging γ (t of γ)**	**Initial classification γ (t of γ)**	**Tests of club merging γ (t of γ)**
Club 1 [3]	**Club 2+3** -0.884 (-8.25)**	**Club 1 [3]**	**Club 2+3** -1.772 (-17.06)**
Club 2 [5]	**Club 2+3+4** -1.148 (-9.95)**	**Club 2 [2]**	**Club 2+3+4** -1.027 (-13.39)**
Club3[10]		**Club3[5]**	
Club 4 [2]		**Club 4[12]**	

Note: These club-merging tests refer to the clubs described in Table 2.

5.2. Convergence in the Energy Subsectors

We now turn to the disaggregated energy sector analysis, for which we have available data on the emissions in each of the subsectors since 1971, giving us 42 years of data. The results from the convergence analysis of subsectors using the PS methodology are presented in Tables 4 and 5 and Figures 2 to 5. Before moving on to the discussion of the results regarding convergence clubs, note that the first row of Table 4 contains the overall convergence tests for the four subsectors. In all instances, the null hypothesis of convergence for the whole group of countries is rejected, meaning that a club convergence analysis is required.

The first column of Table 4 contains the club convergence results for *power generation and heating*. With data available for 24 countries for the whole period (1971-2012), we find two small convergence clubs and 16 non-converging countries. Club 1 consists of Cyprus, Finland, Greece and Malta, while the countries classified in Club 2 are Austria, Italy, Slovenia and Spain. Both clubs have transition paths above 1 (see Figure 2). The countries in the first club are converging to a higher value of emissions, while the members of the second club show a decreasing slope and are therefore converging towards the average. Concerning the *log t* parameter, in the first club the value is -0.09, negative but very close to zero, whereas in Club 2 the parameter is positive. The evidence of conditional or relative convergence would be restricted to this second group. As for the countries that do not converge, the relative transition paths become flat in the mid-nineties and run in parallel, although at very low emission levels. Note that the countries with the lowest transition parameters are France and the UK. In this sector, the difference is due to the relatively greater use of nuclear power or other low-emission technologies compared to fossil fuels. In conclusion, a large group of countries is converging towards a lower level, albeit with different slopes, which may explain the lack of additional clubs.

The *manufacturing and construction subsector* results are presented in the second column of Table 4 and in Figure 3. For the 23 countries in our sample, we have found three convergence clubs and 9 non-converging economies. Club 1 includes the Netherlands and Portugal, which approach the value of 2 at the end of the sample, although the trajectories of their relative transition paths are different (the Netherlands moving upward and

Portugal downward). The log t parameter is clearly negative, so we rule out convergence towards the average. The countries that approach 1 (the average) are classified in Clubs 2 and 3, depending on whether they come from higher or lower initial emissions levels. Thus, we find only evidence of relative convergence in these two cases, as the log t values are 0.633 and 0.824 respectively. Similarly, as in the *power generation* results above, the non-converging countries lie below the average and around 0.5, as their relative transition paths become flat and parallel around this value. This non-converging group includes Germany, France, Sweden or the Netherlands. As in the case of *power generation*, technological differences or the type of manufacturing industry (with lower emissions in the non-converging countries) may explain the results. We have also tested whether Clubs 2 and 3 could be merged and conclude in favour of the null hypothesis (see Table 6), thus, the final classification is a single club of 12 countries. This is consistent with the log t parameter values discussed above.

Convergence clubs for the *transportation sector* are displayed in the third column of Table 4 and Figure 4. Only two groups are found using the Phillips and Sul methodology. No convergence is found for eight countries, the majority of them high-income economies: Denmark, Finland, France, Germany, Malta, the Netherlands, Sweden and the UK. The explanation for this diverging result could be related to the trajectory displayed over the sample period, that is, an initial reduction in emissions (downward relative transition path) towards lower values far from the average. In contrast, the first (more heterogeneous) convergence club consists of countries that started with high emissions, have subsequently reduced them and tend towards the average. The opposite happens with the countries in the second club: after an initial reduction in emissions starting from low levels, they converge towards the average. The log t parameter values are relatively large and positive (1.302 for Club 1 and 0.676 for Club 2), indicating relative convergence. Figure 4 presents the transition paths for this subsector. As in other cases, the gap separating the two clubs has increased during the sample period. Whereas the first club drifts and tends towards higher emissions, the second club is approaching the average (level 1), although coming from lower emissions.

These results are in line with the recent evolution of the transport sector in the EU, where the policy of voluntary agreements to curb the emissions from cars to 120g CO_2/km has been a failure. Prior to 2009, when the limits on emissions were established, car companies did not take effective action to achieve reductions. In addition, efforts to ensure CO_2 reductions have not been helped by the omission of the transport sector from the European emission permits market, and at present emissions are far from meeting the 2020 objectives.

Finally, in *other minor fuel combustion*, with 24 countries in the sample, we find five convergence clubs[17] and six diverging countries: Bulgaria, the Czech Republic, Denmark, Finland, Malta and Sweden. The first club does not really display convergence, as the *log t* parameter is negative, but the rest of the clubs (from Club 2 to Club 5) all have positive parameters. Moreover, this is the only case in which we find convergence in levels, as γ=2.028 in Club 4. Looking at the relative transition paths in Figure 5, the divergence is due to the good performance of the latter group of countries, since they separate from the average and tend towards zero. Concerning the results of the club-merging tests, we could not reject the null hypothesis in the case of Clubs 4 and 5 (see Table 5). Moreover, looking at the transition paths, Clubs 2 and 3 (after diverging) have been moving closer to one another recently and also closer to the average, whereas Clubs 4 and 5 are the best performers.

---

[17] The first convergence club includes two countries (Cyprus and Croatia) that tend to separate from the average. Cyprus may be acting as an outlier. The negative sign of gamma also points to separation from the average.

Table 4: Convergence Club Classification
Energy Subsectors (1971-2012)

Power generation-Heating [24]*		**Manufacures-Construction[23]**		**Transportation [24]**		**Other fuel combustion [24]**	
Overall test		**Overall test**		**Overall test**		**Overall test**	
log t	t-stat	log t	t-stat	log t	t-stat	log t	t-stat
-1.445	-75.868	-1.446	-25.724	-0.957	-13.457	-2.941	-140.430
Club 1 [Cyp, Fin, Gr, Mal]		**Club 1** [Neth, Por]		**Club 1** [Aus, Bul, Cz, Gr, Ire, Por, Rom, Slov, Sp]		**Club 1** [Cro, Cyp]	
log t -0.090	t-stat -0.106	log t -0.744	log t -1.355	log t 1.302	t-stat 7.255	log t -0.006	t-stat -0.005
Club 2 [Aus, It, Slov, Sp]		**Club 2** [Aus, Bel, Cyp, Gr, Slov, Spa]		**Club 2** [Bel, Cro, Cyp, Hun, It, Pol, Slovak]		**Club 2** [Gr, Por, Slov, Sp]	
log t 0.142	t-stat 2.809	log t 0.633	log t 3.202	log t 0.676	t-stat 3508	log t 0.523	t-stat 1.88
Non-converging [Bel, Bul, Croa, Cz, Dk, Fr, Ger, Hun, Ire, Neth, Pol, Por, Rom, Slovak, Sw, UK]		**Club 3** [Bul, Cro, Fin, Ire, It, Pol]		**Non-converging** [Dk, Fin, Fr, Ger, Mal, Neth, Sw, UK]		**Club 3** [Hun, Ire, It]	
		log t 0.824	t-stat 2.705			log t 0.520	t-stat 2.573
		No-converging [Cz, Dk, Fr, Ger, Hun, Rom, Slovak, Sw, UK]				**Club 4** [Aus, Bel, Fr, Ger, Neth, Pol, Slovak, UK]	
						log t 2.028	t-stat 17.297
						Club 5 [Fin, Mal, Ro]	
						log t 0.275	t-stat 1.838
						Non-converging [Bul, Czec, Dk, Sw]	

Note: *Number of countries in each column. Shaded cells show the groups of countries that fulfil all the requirements to be considered convergence clubs.

Table 5: Convergence Club Merging in Subsectors

Manufacturing-Construction

Initial classification γ (t of γ)	**Tests of club merging γ (t of γ)**	**Final classification γ (t of γ)**
Club 1 [2]	**Club 2+3** -0.212 (-1.204)	**Club 1[2]**
Club 2 [6]		
Club 3 [6]		**Club 2 [12]**

Other Fuel Combustion

Initial classification γ (t of γ)	**Tests of club merging γ (t of γ)**				**Final classification γ (t of γ)**
Club 1 [2]				**Club 2+3+4+5** -2.573 (-61.12)**	**Club 1 [2]**
Club 2 [4]	**Club 2+3** -2.595 (-33.08)**				**Club 2 [4]**
Club 3 [3]		**Club 2+3+4** -2.490 (-55.18)**		**Club 3+4+5** -1.078 (-27.789)**	**Club 3[3]**
Club 4 [8]			**Club 4+5** -0.044 (-0.531)		**Club 4 [11]**
Club 5 [3]					

Note: These club-merging tests refer to the clubs described in Table 4.

Figure 2: Transition Paths in the Power Generation and Heating Subsector

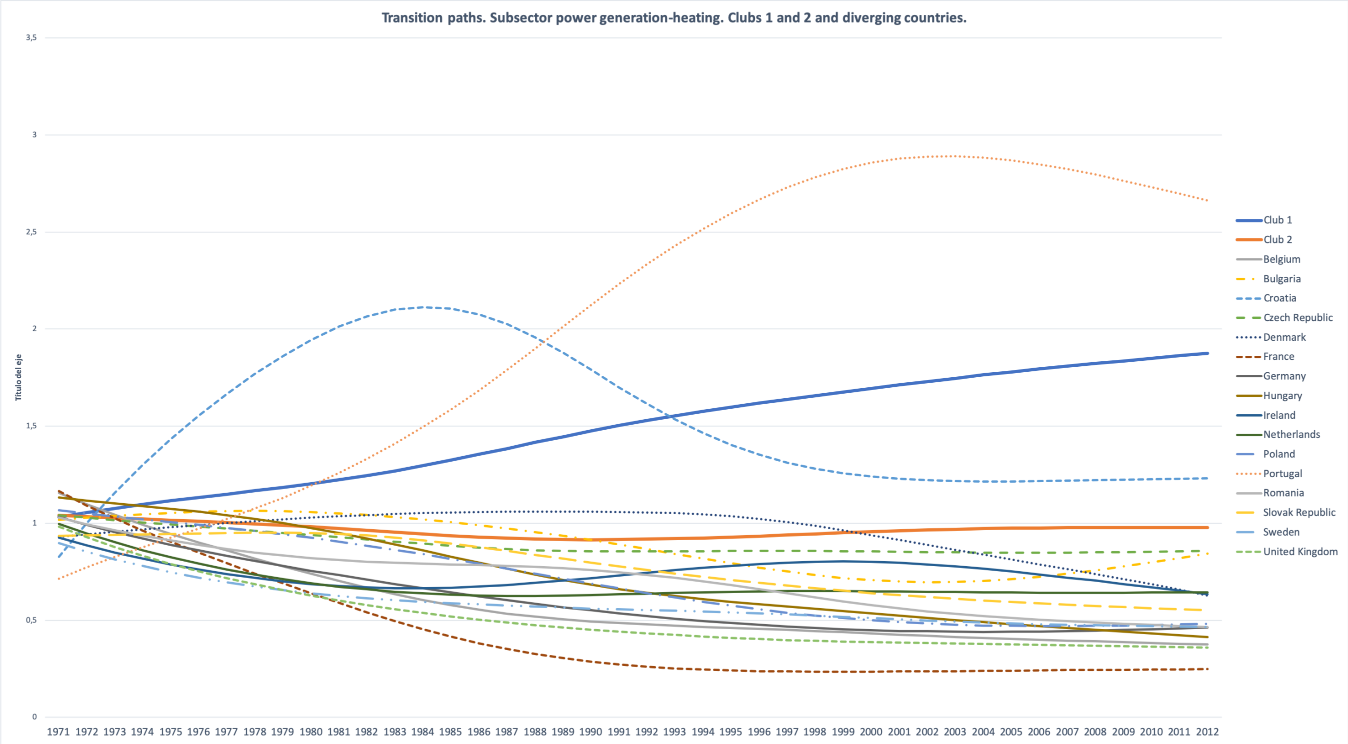


Figure 3: Transition Paths in the Manufacturing and Construction Subsector

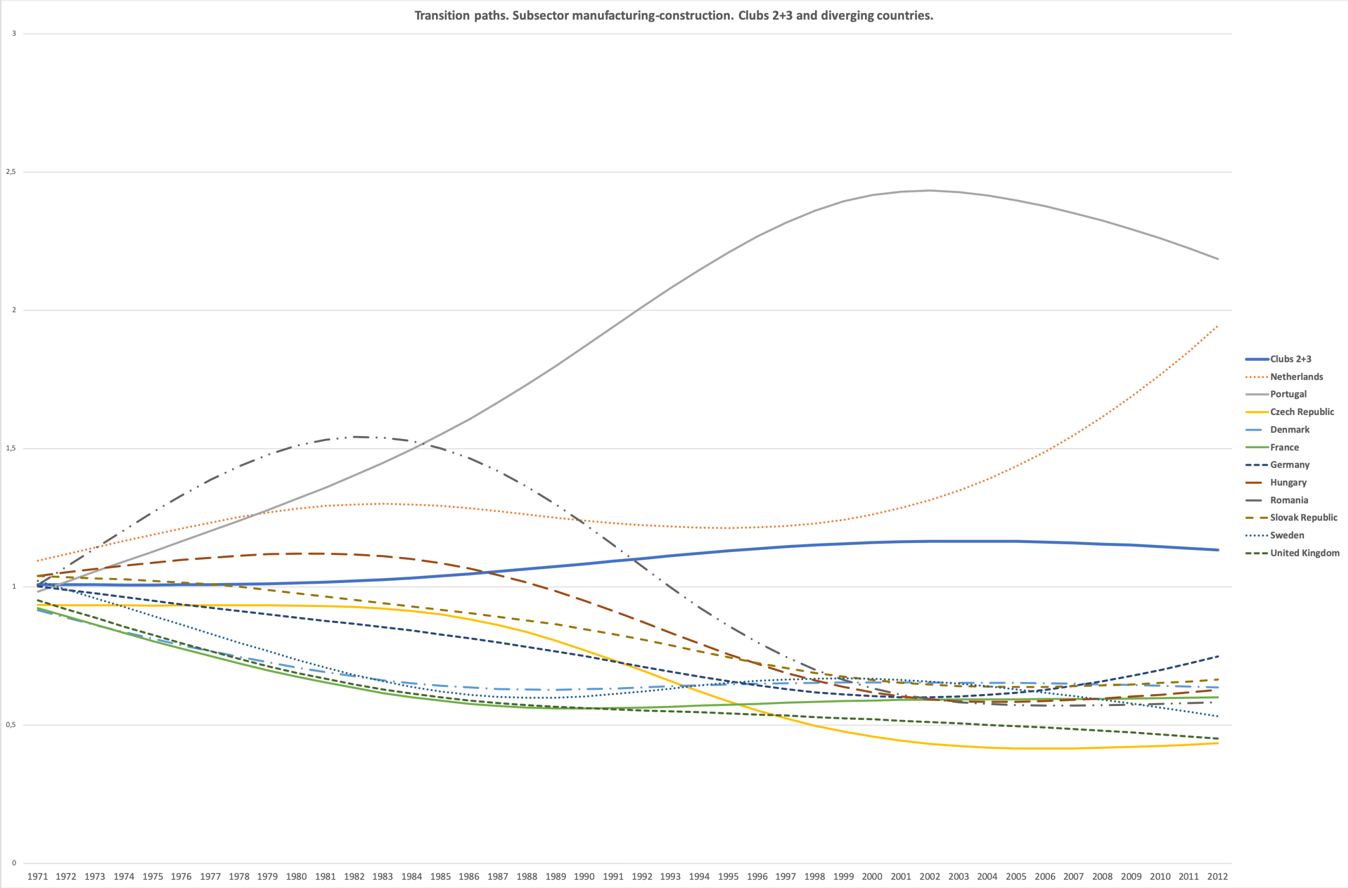


Figure 4: Transition Paths in the Transportation Subsector

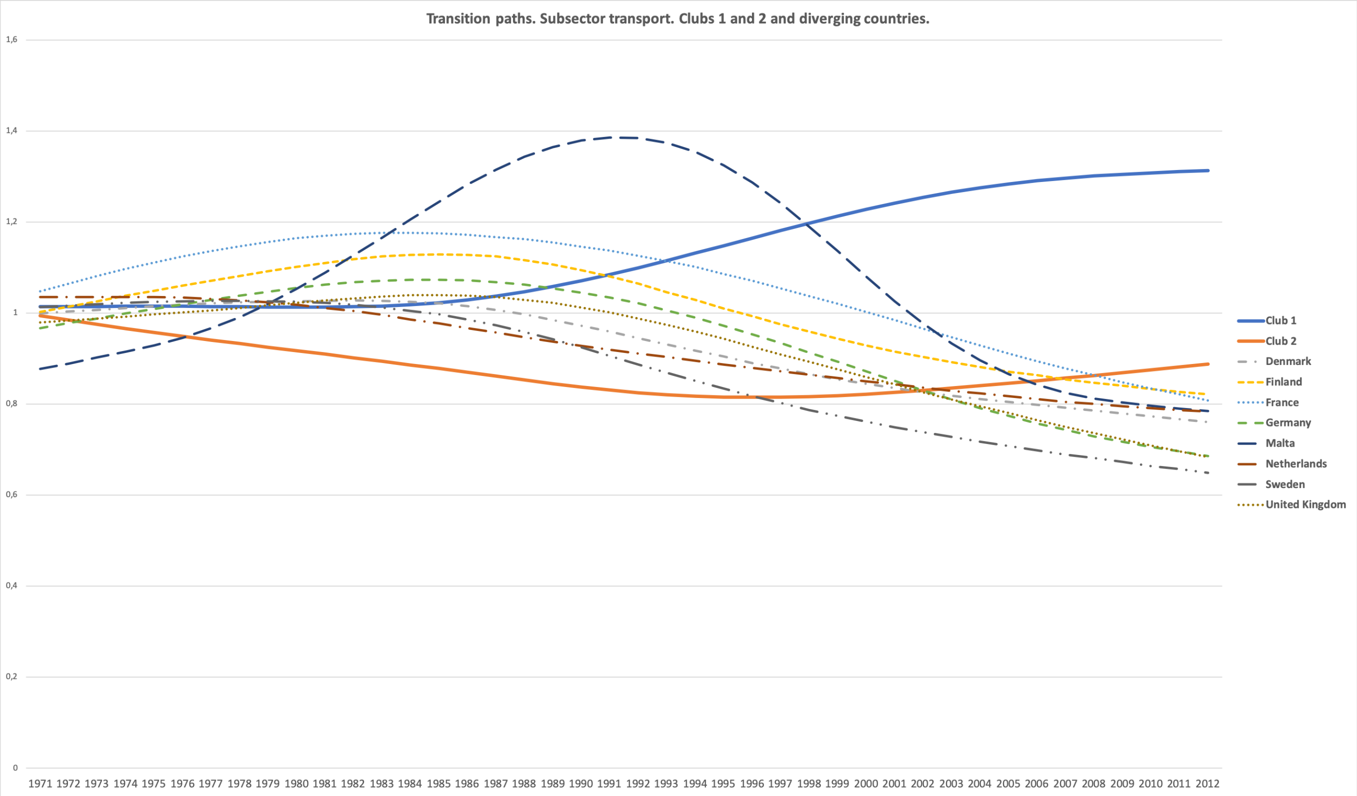
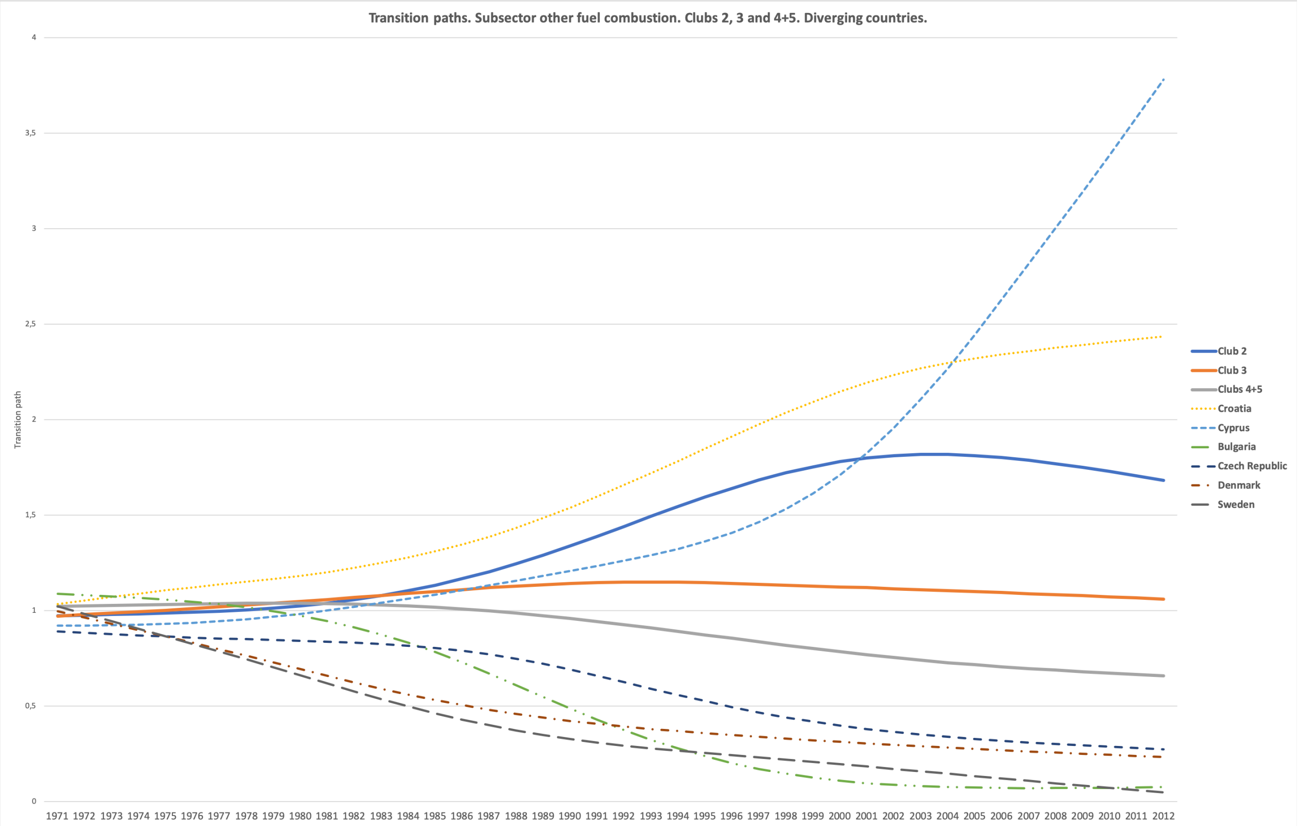


Figure 5: Transition Paths in Other Fuel Combustion Subsector



6. Policy implications

Some policy insights can be drawn from this study. A simple descriptive analysis of emissions shows that, during the period analysed, per capita emissions have increased in agriculture, while decreasing in industry and energy production since 1990. Different patterns arise as well in the energy subsectors, with notable reductions in emissions reported in manufacturing and power generation but an overall increase observed in the transportation sector.

Due to the high degree of heterogeneity found in emissions per capita by country, and the limited evidence of convergence, two main implications arise from the results obtained in this paper. First, the bubble system seems to be an appropriate tool to move towards the 2020 targets for energy efficiency and emissions reduction, that is, different measures and targets should be set for different countries. Second, the results point towards the effectiveness of the IPPC regulation[18] and the European carbon market[19] in curbing GHG emissions in the industrial and manufacturing sectors, as we observe a general decline in emissions in the industrialized countries.

The EU is currently taking action in several areas to meet the 2020 targets (a 20% cut in GHG emissions from 1990 levels, 20% of EU energy from renewables, a 20% improvement in energy efficiency). Concerning emissions, specific domestic targets have been set for every member state according to their national wealth, ranging from a 20% cut for the richest countries to a maximum 20% increase for the least wealthy. With respect to renewable energy, EU member countries have also taken on binding national targets for raising the share of renewables in their energy consumption by 2020. These

---

[18] The IPPC (Integrated Pollution Prevention and Control) Directive was first adopted in 1996 (Directive 96/61/EC) and set common rules for granting permits to and monitoring industrial installations in the EU. The most recent directive on industrial emissions (Directive 2010/75/EU) recasts the IPPC Directive and other existing directives related to this topic into a single legislative instrument.

[19] Directive 2003/87/EC established a scheme for GHG emission allowance trading within the European Community. Directive 2004/101/EC, following the Kyoto Protocol, included the project-based mechanisms in the ETS. In 2009, a new directive extended the ETS to the aviation sector (Directive 2009/29/EC).

targets also vary, to reflect countries' different starting points for renewables production and their ability to further increase it, ranging from 10/13% in Malta to 49% in Sweden. However, according to the analysis of the NECPs drafts made by the European Commission (Memo (18/06/2019), the national plans fall short in terms of renewable and energy efficiency contributions. The gaps to be addressed could be as big as 1.6 and 6 percentage points for energy efficiency and final energy consumption, respectively. EU countries have a few months until December 2019 to address the Commission recommendations.

The sectoral analysis also yields some important insights. By subsectors, a substantial reduction is observed in manufacturing and power generation (53% and 22%, respectively) but an increase of around 30% is found in the transportation subsector. When we focus on the disaggregated energy sector, there is some evidence in favour of convergence in power generation and manufacturing, whereas there is little convergence in the subsectors transportation and other fuel combustion. These results reinforce the appropriateness of setting emission-reduction targets for other economic sectors not initially included in the EU emissions trading system (ETS). The ETS is a key tool for cutting GHG from large-scale facilities in the power and industry sectors, as well as the aviation sector, but it only covers 45% of the EU's total emissions. Therefore, a target has been established for the sectors not included in the ETS, such as housing, agriculture, waste and transport (excluding aviation). The emissions from these sectors have to be 21% lower in 2020 than in 2005. National emission-reduction targets are binding until 2020 under the "Effort-sharing decision". We believe that these actions are a step in the right direction, especially considering the 2050 roadmap, which envisages an 80% reduction of emissions compared to 1990 levels. The roadmap also shows how the major sectors responsible for emissions can transition to a low-carbon economy in a costeffective way. These sectors are energy generation, industry, transport, building and construction, as well as agriculture. All of them have been considered in our research.

7. Conclusions

The EU has set an overall target for reducing CO_2 emissions by 2020, by means of the bubble system, which establishes specific goals and emission allowances for each member state. This system relies on the idea that countries should converge to the same level of emissions per capita. In order to test whether EU environmental policies have been effective in this regard, the main question we have addressed in this study is whether CO_2 emissions per capita in the EU have indeed converged. The concept of club convergence is used to analyse CO_2 emissions in EU countries from 1971 to 2012. We consider this approach to be the most suitable for this analysis since it takes into account not only a static picture of countries' emissions but also the transition path followed by each country in the convergence process. The sample covers three main economic sectors: agriculture, energy and industry. In addition, we analyse disaggregated data, breaking up the energy sector into four subsectors for a more in-depth study. The subsectors are power generation and heating, manufacturing and construction, transportation and other fuel combustion.

It is worth noting that the convergence process taking place up to the nineties points to steady states with a per capita emissions average higher than the one registered later, when the EU implemented measures aimed at meeting commitments related to the Kyoto Protocol. Therefore, the bubble system seems to be an effective tool to move towards the 2020 emissions reduction targets. Emission ceilings and the European CO_2 market have achieved their objectives, with a decrease of 52.8% in 2012 compared to 1990 levels. This course of action involves a process of convergence, either absolute or relative, if different countries tend towards different steady states. We observe significant differences among countries. While countries that have registered higher levels of emissions have a rate of convergence of around 2% as part of the catching-up process, the countries that have curbed their emissions converge at a slower rate. Countries that are undergoing a transition to a market economy do not show any convergence in recent years.

Therefore, the results for club convergence support weak convergence for the whole sample of countries, as the null hypothesis of overall convergence is rejected for sectoral and subsectoral CO_2 emissions. However, there is evidence of club convergence, as some groups of countries or clubs converge towards the group average. As far as economic sectors are concerned, we observe an increase in emissions in the agricultural sector and a decline in the energy and industrial sectors, possibly as a result of the control measures implemented. This could indicate that emissions regulations and the ETS for carbon allowances have been effective in curbing emissions in the above-mentioned sectors. The same cannot be said, however, about the transport sector, whose inclusion in the ETS was late and partial (only the aviation sector is part of this system). In addition, the policy of voluntary agreements to cut car emissions to 120g CO_2/km has been a failure; prior to 2009, when limits on emissions were established, companies took no effective actions to achieve reductions.

Since the energy sector is the cornerstone to achieve CO_2 reductions, we have focused on its subsectors. The pattern that emerges from the analysis is that core European countries (such as France, the Netherlands, Germany and the UK) and Nordic countries (Finland, Sweden and Denmark) are either included in the best performing clubs or diverging from the average towards lower emissions, no matter the sector or subsector. Peripheral EU members (Ireland, Italy, Portugal, Greece and Spain) are among intermediate clubs, converging towards the average and, in some cases above the average, but the general trend is a reduction in emissions. Some CEECs such as Slovenia, the Slovak Republic and the Czech Republic, are also reducing their emissions and converging in many cases, whereas the rest of the CEECs are among those with very high—and still rising—emissions.

Summarizing, the main results of this study highlight the existence of important differences among EU member states in terms of the evolution of per capita CO_2 emissions across sectors and over time. Nevertheless, most EU countries have gradually reduced, if not their level, at least their emissions growth, especially in the energy subsectors. Finding relative convergence among a large number of EU members would, therefore, support the relevance of both the EU abatement policy and international agreements in this process, as there is less evidence of convergence and emissions abatement in those sectors excluded from the international agreements. This could have important policy implications in relation to the measures applied to curb emissions in high-emitting sectors, namely transportation and the other energy sectors, and can also provide insights into how effective these measures are. First, transportation and energy are the main sectors that should implement effective measures to reduce CO_2 as part of the process of 'greening' key areas of EU policy, as Baldock (2016) states. Second, according to Haigh (2016), environmental policy reaches the central stage only when individual measures are applied by member states, although he argues that the EU has enabled member states to progress in a way they would never have done individually.

Even though the EU has significantly reduced CO_2 emissions in the last two decades, the average level of CO_2 emissions remains far from the 40% (80%) reduction set for 2030 (2050). As stated in the TERM reports (Transport and Environment Reporting Mechanism), published by the European Environment Agency, the EU will need to accelerate the implementation of new policies, while restructuring the energy mix in order to meet the increasing demand for energy, food, transport and housing.

The 2015 TERM report estimated that transport generated about 25% of European GHG emissions in 2009. With a long-term vision, the EU set a 60% reduction target (compared to 1990 levels) for 2050 in the transport sector. Considering that there has been a 27% increase in emissions from 1990 to 2009, it would now appear to be very difficult to achieve this goal. The last TERM report confirms this point since it states that GHG emissions from transport were 28 % above 1990 levels in 2017 (EEA, 2018). Therefore, reducing fossil fuel dependence would clearly have positive effects for European countries. Reduced fuel dependence would contribute not only to improving energy security throughout Europe but it would also help to curb GHG emissions, both of which are desirable goals for the whole EU.

Our findings support the appropriateness of the actions taken by the European Commission related to energy and CO_2 emissions. Under the Paris Agreement, the EU has to translate the 2030 targets into concrete measures to be applied in all countries and economic sectors. The proposed binding annual GHG reduction targets vary from 0 to 40% across different member states, depending on their GDP per capita. There are also different national targets regarding the share of renewables in 2020, depending on the countries' characteristics.

With respect to the sectors under study, our results reinforce the need to focus on other economic sectors that are not currently included in the ETS, such as housing, agriculture, waste and, particularly, transport (excluding aviation). All of them are considered in the 2050 roadmap set by the European Commission in 2011. In November 2016, the European Commission presented a draft law on energy strategy as part of a broader clean energy package, in line with the European Energy Programme for Recovery established in 2009 to address both the economic crisis in Europe and European energy policy objectives. More recently (5th March 2018), the International Renewable Energy Agency (IRENA) presented the report "Perspectives on Renewable Energy in the European Union", as requested by the European Commission. The report envisaged a 30% share, upgraded to 32% by the Commission, of renewable energies in the 2030 energy mix by promoting solar and wind energy and the use of electric cars. This goal will clearly have positive effects on the economy and the achievement of the emission reduction objectives. We hope that all the environmental policy measures mentioned in our study will continue to be effective, and thus simultaneously contribute to ensuring economic recovery, improving energy security and reducing harmful emissions.

References

ALDY JE, (2006) Per capita carbon dioxide emissions: convergence or divergence?, *Environmental and Resource Economics* 33(4): 533-555.

BAI J, CARRION-I-SILVESTRE JL, (2009) Structural Changes, Common Stochastic Trends, and Unit Roots in Panel Data, *Review of Economic Studies* 76: 471–501.

BAI J, PERRON P, (1998) Estimating and Testing Linear Models with Multiple Structural Changes, *Econometrica*, 66: 47–78.

BALDOCK, D. (2016) Retaining the centre stage. In N. Haig (2016): EU Environmental Policy - Its Journey to Centre Stage. Routledge, 181-196.

BARASSI MR, COLE MA, ELLIOTT RJR, (2008) Stochastic divergence or convergence of per capita carbon dioxide emissions: re-examining the evidence, *Environmental and Resource Economics* 40(1): 121-137.

BAUMOL WJ, (1986) Productivity growth, convergence, and welfare: what the long-run data show, *American Economic Review* 76(5):1072-1085.

BARRO RJ, SALA-I-MARTIN X, (1992) Convergence, *Journal of Political Economy* 100(2): 223-251.

BERNARD AB, DURLAUF S, (1995) Convergence in international output. *Journal of Applied Econometrics* 10: 97–108.

BURNETT, J. W. (2016) Club convergence and clustering of U.S. energy-related CO_2 emissions, *Energy and Resource Economics,* 46, 62-84.

CAMARERO M, CASTILLO J, PICAZO-TADEO J, TAMARIT C. (2014) Is eco-efficiency in greenhouse gas emissions converging among European Union countries?, *Empirical Economics* 47(1): 143-168.

CARLINO GA, MILLS LO, (1993) Are US regional incomes converging? *Journal of Monetary Economics* 32(2): 335–346.

CARRION-I-SILVESTRE JL, KIM D, PERRON P, (2009) GLS-based unit root tests with multiple structural breaks under both the null and the alternative hypotheses. *Econometric Theory*, 25: 1754–1792.

CRIADO CO, GRETHER JM, (2011) Convergence in per capita CO_2 emissions: a robust distributional approach. *Resource and Energy Economics* 33(3): 637-665.

EUROPEAN COMMISSION (2011). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "Energy Roadmap 2050"*. COM(2011) 885 final.

EUROPEAN COMMISSION (2014): A policy framework for climate and energy in the period from 2020 to 2030. COM(2014) 015 final.

EUROPEAN COMMISSION (2015): Energy union package. Communication from the Commission to the European Parliament and the Council. The Paris Protocol – a blueprint for tackling global climate change beyond 2020. COM (2015) 81 final.

EUROPEAN COMMISSION (2016): Communication from the Commission to the European Parliament and the Council. The road from Paris: assessing the implications of the Paris agreement and accompanying the proposal for a Council decision on the signing, on behalf of the European Union, of the Paris agreement adopted under the United Nations framework Convention on Climate Change.

EUROPEAN COMMISSION (2019): Communication assessing the 28 draft NECPs COM(2019) 285 final.

EUROPEAN COMMISSION (2019): Energy Union: Commission calls on Member States to step up ambition in plans to implement Paris agreement. Memo (18/06/2019).EUROPEAN ENVIRONMENT AGENCY (2015) SOER 2015. The European environment. State and outlook 2015.

EUROPEAN ENVIRONMENT AGENCY (2015) Evaluating 15 years of transport and environmental policy integration - TERM 2015: Transport indicators tracking progress towards environmental targets in Europe.

EUROPEAN ENVIRONMENT AGENCY (2018) Progress of EU transport sector towards its environment and climate objectives. TERM 2018.ELLIOTT G, ROTHENBERG TJ, JH STOCK (1996) Efficient tests for an autoregressive unit root, *Econometrica* 64: 813–836.

EZCURRA R. (2007) Is there cross-country convergence in carbon dioxide emissions? *Energy Policy* 35(2): 1363-1372.

FAO (2014) Agriculture, forestry and other land use emissions by sources and removals by sinks. 1990-2011 Analysis ESS Working Paper No. 2.

GLYNN J, PERERA N AND VERMA R, (2007) Unit root tests and structural breaks: a survey with applications, *Journal of Quantitative Methods for Economics and Business Administration* 3(1): 63-79.

GREASLEY D, OXLEY L, (1997) Time-series based tests of the convergence hypothesis: some positive results. *Economics Letters*, 56(2), 143-147.

HAIGH, N. (2016): EU Environmental Policy - Its Journey to Centre Stage. Routledge.

HUANG B, MENG L, (2013) Convergence of per capita carbon dioxide emissions in urban China: a spatio-temporal perspective, *Applied Geography* 40: 21-29.

IRENA (International Renewable Energy Agency) (2018): *Perspectives on Renewable Energy in the European Union*. Available at www.irena.org. Accessed on 8th March 2018.

JOBERT T, KARANFIL F, TYKHONENKO A, (2010) Convergence of per capita carbon dioxide emissions in the EU: legend or reality?, *Energy Economics* 32(6): 1364-1373.

LIST J, (1999) Have air pollutant emissions converged among us regions? Evidence from unit root tests, *Southern Economic Journal* 66(1): 144-155.

PANOPOULOU E, PANTELIDIS T, (2009) Club convergence in carbon dioxide emissions. *Environmental and Resource Economics* 44(1): 47-70.

PERRON, P (1989): The Great Crash, the Oil Price Shock, and the Unit Root Hypothesis. Econometrica 57(6): 1361-1401.

PHILLIPS, P.C.B. and D. SUL (2007): "Transition modeling and econometric convergence tests*", Econometrica*, vol. 75(6), 1771-1855.

PHILLIPS, P.C.B. and D. SUL (2009): "Economic transition and growth", *Journal of Applied Econometrics*, vol. 24, 1153-1185.

QUAH, D. (1996): "Twin Peaks: Growth and Convergence in Models of Distribution Dynamics", *The Economic Journal*, vol. 101(407), 938-948.

QUAH D, (1997) Empirics for growth and distribution: stratification, polarization, and convergence clubs. *Journal of Economic Growth* 2(1): 27–59.

SALA-I-MARTÍ, X. (1996) Regional cohesion: evidence and theories of regional growth and convergence, *European Economic Review* 40: 1325-1352.

SOLOW, RM (1956) A contribution to the theory of economic growth. *Quarterly Journal of Economics* 70: 65-94.

VAN NGUYEN P, (2005) Distribution dynamics of CO_2 emissions. *Environmental and Resource Economics* 32(4): 495-508.

WANG J, ZHANG K, (2014) Convergence of carbon dioxide emissions in different sectors in China, *Energy* 65, 605-611.

ZHANG D, BROADSTOCK DC (2016) Club Convergence in the Energy Intensity of China. *The Energy Journal* 37(3): 137-158.