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IS THE ECO-EFFICIENCY IN GREENHOUSE GAS EMISSIONS CONVERGING AMONG EUROPEAN UNION COUNTRIES?

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Abstract. Eco-efficiency refers to the ability to produce more goods and services with less impact on the environment and less consumption of natural resources. This issue has become a matter of concern that is receiving increasing attention by politicians, scientists and academics. Furthermore, greenhouse gases emitted as a result of production processes have a heavy impact in the environment and also are the foremost responsible of global warming and climate change. This paper assesses convergence in eco-efficiency from greenhouse gas emissions in the European Union (EU). Eco-efficiency is assessed at both country and greenhouse-gas-specific levels using *Data Envelopment Analysis* techniques and directional distance functions, as recently proposed by Picazo-Tadeo et al. (2012). Then, convergence is evaluated using the Phillips and Sul (2007) approach that allows testing for the existence of convergence groups. Although the results point to the existence of different convergence clubs depending on the specific pollutant considered, they signal the existence of, at least, four clear groups of countries. The first two groups are conformed of core EU high-income countries (Benelux, Germany, Italy, Austria, the United Kingdom and Scandinavian countries). A third club is made up of peripheral countries (Spain, Ireland, Portugal, Greece) together with some Eastern countries (Latvia, Slovenia) and the rest of clubs consists of groups containing Eastern European countries.

Keywords: *Eco-efficiency; convergence; clubs; greenhouse gases emissions; European Union; directional distance functions; Data Envelopment Analysis.*

JEL classification: *C15, C22, C61, F15, Q56.*

1. Introduction

Global warming and climate change are matters of concern for policymakers, researchers and society as a whole. Many scientists claim that climate change is unequivocal and that it is caused by increasing concentrations of greenhouse gases (GHG) produced by human activities (burning of fossil fuels and deforestation, among others). Their influence on international institutions such as the United

Nations and the International Energy Agency have led them to agree on the adoption of deep cuts in GHG emissions in order to achieve long-term sustainable development (UN, 2009; IEA, 2011). The article 2 of the *United Nations Framework Convention on Climate Change* (UNFCCC), an international environmental treaty promoted in 1992 by the United Nations and currently signed by 194 parties, states that '*… The ultimate objective of this Convention and any related legal instruments… is to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient… to enable economic development to proceed in a sustainable manner*'.

The Kyoto Protocol was adopted in the context of the UNFCCC in 1997 and entered into force in 2005; it established binding targets for reducing GHG emissions for industrialized economies, including the European Union (EU). Before the early nineties, the EU policy regarding air pollution was fragmented and only some standards existed for a few air pollutants. In 1993, the 5th Environmental Action Program (CEC, 1993) established long-term objectives for air quality in Europe in a more integrated way by setting ceilings for some air pollutants, including some GHG such as carbon dioxide (CO_2). In addition, under the Kyoto Protocol the members of the older European Union-15 (UE-15) agreed to cut down their collective GHG emissions by 2012 to 8% below the levels recorded in the base year 1990.

In addition to the concern held by politicians and international institutions on climate change, from the nineties of last century onwards researchers in fields such as environmental economics are paying increasing attention to the assessment of the impact of economic activity on the environment. In this paper, we contribute to this burgeoning line of research by analyzing convergence in ecological-economic efficiency in GHG emissions among EU countries. Several international organizations have recognized that assessing eco-efficiency constitutes a powerful instrument capable of providing policymakers with helpful information to design better environmental policies to achieve sustainable development (UN, 2009). Furthermore, according to Westerlund and Basher (2008) a fair distribution of GHG emissions in the long-run entails the achievement of convergence.

The concept of ecological-economic efficiency, the so-called eco-efficiency, refers to the ability of firms, industries or economies to produce more goods and services with less impact on the environment and less consumption of natural resources, encompassing both ecological and economic issues. In practice, eco-efficiency is approached by ratios that relate the economic value of goods and services produced to the environmental pressures or impacts involved in production processes, the larger the ratio the higher the eco-efficiency (Schmidheiny and Zorraquin, 1996; Huppes and Ishikawa, 2005). Regarding GHG emissions, eco-efficiency has been commonly measured by ratios such as GDP over CO_2. Although these simple ratios have the advantage of their straightforwardness and easiness of understanding for policymakers and the general public, they ignore that production processes involve simultaneous emissions of several GHG, and also, that a given GDP can be obtained with different combinations of air pollutants. As a contribution of our paper to previous literature, we measure eco-efficiency in GHG emissions using the recent approach developed by Picazo-Tadeo et al. (2012) which, based on *Data Envelopment Analysis* (DEA) techniques and the computation of the so-called directional distance functions, allows considering several GHG in the computation of the eco-efficiency ratio, and more interestedly, assesses eco-efficiency at country and greenhouse-gas-specific emissions level. Previously, Kortelainen (2008) analyzed global eco-efficiency computing a composite indicator at country-level for 20 European Union members; beyond this analysis, here we contribute an evaluation of eco-efficiency at both country and air pollutant levels.

Furthermore, several papers have assessed convergence in GHG emissions using simple ratios such as per capita CO_2 emissions; these include Strazicich and List (2003), Lanne and Liski (2004); Aldy (2006; 2007), Ezcurra (2007), Westerlund and Basher (2008), Romero-Ávila (2008), Barassi et al. (2008; 2011), Marrero (2010), Jobert et al. (2010) and Ordás Criado and Grether (2011). As far as we know, only Camarero et al. (2008) have tested for convergence in environmental performance using a series of composite indicators computed within the framework of the production theory; these authors analyze convergence among 22 OECD countries during the period 1970-2002, using data on CO_2 emissions as a measure of the impact of economic activity on the environment. In addition, Nourry (2009) tested the hypothesis of stochastic convergence of carbon dioxide and sulfur dioxide analyzing all pairs of per capita emissions gaps across a sample of 127 and 81 countries, respectively. In this paper, we further contribute by the evaluation of convergence in eco-efficiency in GHG emissions among EU countries using the approach by Phillips and Sul (2007) that allows testing for the existence of convergence groups sharing common features regarding their eco-efficiency paths.

In our opinion, the joint assessment of eco-efficiency at greenhouse-gas-specific emission and country level, together with the analysis of convergence testing for the existence of convergence groups could add interesting insights into the current literature in this field of research, also providing policymakers with useful information to design more effective environmental policies.

The rest of the paper is organized as follows, Section 2 is devoted to assessing eco-efficiency; the data and sources of information are described in Section 2.1, the main insights of the methodology are expounded in Section 2.2, while Section 2.3 comments on the results. Section 3 focuses on the measurement of convergence; the methodology is developed in Section 3.1 and the results presented and discussed in Section 3.2. A final Section summarizes and concludes.

2. Assessing eco-efficiency in greenhouse emissions with directional distance functions

2.1. Data and sources of information

The data on greenhouse gas emissions (GHG) used in this research comes from the Annual European Union Greenhouse Inventory 1990-2009 of the European Environmental Agency (EEA, 2011).[1] This database includes information about the six main GHG against which reduction targets were agreed in the Kyoto Protocol, including carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). Furthermore, data are provided at the sector level for all 27 countries currently integrated in the European Union (EU-27).

In order to assess eco-efficiency and convergence, in this paper we use information about emissions of carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4), which jointly represent around 98.5% of aggregated GHG emissions.[2] Concerning GHG-emitting sectors, we use aggregate measures that include emissions from the sectors of energy, industrial processes, solvents and other product use, agriculture, waste, and finally, others; thus, emissions from land use, land use change and forestry, which in most cases are negative, are not considered in our analysis. Finally, our data includes all EU-27 countries and spans for the period 1990-2009 and emissions are measured in million tons of CO_2 equivalent. Table 1 displays the extent of GHG emissions in the EU in 1990 and 2009 (information about fluorinated gases, SF_6, HFCs and PFCc, is also included to illustrate their relative importance on total GHG emissions).

[Please, insert Table 1 around here]

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[1] Accessed on 25th February 2012 through http://dataservice.eea.europa.eu

[2] Although greenhouse gases CO_2, CH_4, and N_2O occur naturally, human activities have changed their concentrations in the atmosphere. According to the International Panel for Climate Change (IPCC, 2007), from the pre-industrial era (ending about 1750) to 2005, concentrations of these greenhouse gases have increased globally by 36, 148, and 18%, respectively.

As already discussed in the Introduction, under the Kyoto Protocol the EU-15 agreed to reduce its collective emissions of GHG by 2012 to 8% below the levels recorded in year 1990.[3] As displayed in Table 1, this objective is in course to be overachieved since in 2009 the emissions are estimated to have been reduced by 12.7%; however, there exist some important differences among countries, e.g., Mediterranean economies such as Spain, Portugal or Greece have even raised their emissions, with increases of 29, 25 and 17%, respectively. In addition, most of the countries that joined the EU in 2004 and 2007 have also agreed important reduction targets so that the combined reduction of GHG emissions in 2009 for the EU-27 has already reached 17.4% (see again Table 1).

The economic performance of countries in the EU is, on the other hand, accounted for by the value of goods and services produced, which is measured by real Gross Domestic Product (GDP) in constant dollars (millions US$, base 2000), with data coming from the World Bank.[4] Table 2 relates GHG emissions to GDP in the EU thus providing information about the so-called intensity of emissions. First, it can be observed that emissions over GDP have significantly decreased between 1990 and 2009. Accordingly, EU-27 collective GHG emissions have decreased by more than half, going down from 1.91 CO_2 equivalent tons per 1,000 US$ of GDP in 1990 to 0.89 in 2009. The reductions achieved in the EU-15 reach a lesser extent but are also important, i.e., in these 20 years they have gone down from 0.72 to 0.45 CO_2 equivalent tons per 1,000 US$. These reductions are particularly important taking into account that the twelve countries that joined the EU in 2004 and 2007 record intensities in GHG emissions perceptibly higher, and that some of the economies showing lower GHG emissions intensities, such as Sweden, the United Kingdom, France, Denmark and Austria, are members of the older EU-15.

[Please, insert Table 2 around here]

2.2. Computing eco-efficiency scores

Let us start the description of the methodology by borrowing the formal definition of eco-efficiency proposed by Kuosmanen and Kortelainen (2005) which, once

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[3] The EU has established a series of ambitious measures to cut down its GHG emissions 20% below 1990 observed levels by 2020, and is offering scaling up this reduction to 30% if other developed economies agree to do their fair share for a global effort. Even more, for a longer term the EU has established the target of reducing emissions to 80-95% below 1990 levels by 2050.

[4] Accessed on 25th February 2012 through http://databank.worldbank.org

adapted to the purpose of our research, is expressed as a ratio between GDP and a composite indicator of the GHG emissions generated by production processes:

$$\mathrm{Eco-efficiency} = \frac{\mathrm{GDP}}{\mathrm{E}\left(\mathrm{CO_2}, \mathrm{N_2O}, \mathrm{CH_4}\right)} = \frac{\mathrm{GDP}}{\mathrm{w_{CO_2}CO_2 + w_{N_2O}N_2O + w_{CH_4}CH_4}} \qquad (1)$$

where E is a function that aggregates individual GHG emissions into a single emission score. Furthermore, we assume that this function takes the form of a linear weighted average of CO_2, N_2O and CH_4 emissions with weights w_{CO2}, w_{N2O} and w_{CH4}, respectively.[5]

According to the classification of Huppes and Ishikawa (2005), we are adopting a macro-level environmental-productivity ratio approach, so that eco-efficiency improves when GDP relative to the aggregated emission score increases. In addition, we assume that behind our eco-efficiency ratio there is a technology, the so-called *emissions generating technology* (EGT) (see Kuosmanen and Kortelainen, 2005; Picazo-Tadeo et al. 2011) that, given the state of knowledge, represents all feasible combinations of GDP, variable g, and GHG emissions, represented by vector e=(CO_2, N_2O, CH_4). This technology is formally represented as:

$$\mathrm{EGT} = \left\langle \left[\mathrm{g},\ \mathrm{e} = \left(\mathrm{CO_2}, \mathrm{N_2O}, \mathrm{CH_4}\right)\right] \in \Re^4_+ \ \middle|\ \text{GDP g can be generated with emissions e} \right\rangle \ (2)$$

In addition, the following assumptions are made on the EGT: i) producing goods and services unavoidably entails some GHG to be emitted on the environment, such that the only way of not emitting GHG is not producing; ii) lower GDP can always be obtained with the same level of emissions; iii) emissions can always be increased for any given GDP; and iv) any convex combination of two or more feasible (observed) pairs of GDP and GHG emissions is considered to be also feasible, i.e., we assume a convex technology.

Once defined the measure of eco-efficiency and characterized the technology, we use the recent proposal by Picazo-Tadeo et al. (2012) for the assessment of eco-efficiency, which is based on the computation of directional distance functions

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[5] Taking a linear weighted average of the particular GHG emissions to build up a composite indicator of the aggregated emission is the most common approach in the literature. However, recent research by Zhou et al. (2010) might be used to integrate a schedule of non-linear preferences in the construction of the composite indicator, as a further extension of our research.

with *Data Envelopment Analysis* (DEA) techniques. Formally, the directional distance function is defined as:[6]

$$\vec{D}\left[g,e;d=\left(d_g,-d_e\right)\right]=\text{Sup}\left[\Phi \,\middle|\, \left(g+\Phi d_g,\ e-\Phi d_e\right)\in \text{EGT}\right] \qquad (3)$$

with $d=\left(d_g,-d_e\right)$ being the so-called direction vector.

This function provides a complete representation of the EGT and is lower-bounded to zero (Chambers et al., 1998). Moreover, an outstanding feature of directional distance functions is their flexibility that, in the particular case of our research, allows computing a wide range of indicators of eco-efficiency representing different objectives of environmental policymakers regarding GHG emissions. These objectives are modelled by means of different assumptions made on the direction vector that allow approaching the technological frontier through alternative paths.

In this framework, let us assume, on the one hand, that researchers and/or policymakers are interested in assessing the extent by which EU countries could proportionally cut down CO_2, N_2O and CH_4 emissions without reducing the value of goods and services produced. These preferences could be modelled by means of the following directional distance function, which assesses what we call here *proportional GHG eco-efficiency*:

$$\text{Eco}-\text{efficiency}_{GHG}=\vec{D}\left[g,e;d=\left(0,-e\right)\right]=\text{Sup}\left[\Phi_{GHG} \,\middle|\, \left(g,\ (1-\Phi_{GHG})e\right)\in \text{EGT}\right] \quad (4)$$

$d=\left(0,-e\right)$ being the direction vector that represents the above-mentioned preferences.

The interpretation of the directional distance function in expression (4) is really straightforward: a value of zero would point to eco-efficiency while a value of, let us say, 0.3 would mean that, given the EGT, all three GHG emissions, i.e., CO_2, N_2O and CH_4 emissions, could be cut down by 30% while maintaining GDP.

On the other hand, researchers and/or policymakers might be interested in evaluating how much a particular GHG emission, namely emission e_i, could be reduced without increasing the remaining emissions, labelled as e_{-i}, and also maintaining the value of goods and services produced. Under this schedule of preferences, the

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[6] Färe and Grosskopf (2000) summarize the theory and applications of directional distance functions, while Picazo-Tadeo et al. (2005) analyze their utility to assess environmental performance.

directional distance function that allows assessing *greenhouse-gas-specific eco-efficiency* is:

$$\begin{aligned}\text{Eco} - \text{efficiency}_{e_i} &= \vec{D}\left[g, e = (e_i, e_{-i}); d = \left(0, -(e_i, 0_{-i})\right)\right] \\ &= \text{Sup}\left[\Phi_{e_i} \middle| \left\langle g, \left((1-\Phi_{e_i})e_i, e_{-i}\right)\right\rangle \in \text{EGT}\right]\end{aligned} \quad (5)$$

where $d = \left(0, -(e_i, 0_{-i})\right)$ is the associated direction vector.

Given the assumptions made on the EGT, the directional distance function when only one GHG emission is reduced is always equal to or greater than the directional distance function when all GHG emissions are simultaneously reduced, thus indicating greater eco-inefficiencies (see Picazo-Tadeo et al., 2012). Assuming, for example, that the GHG being reduced is CO_2, a score of 0.4 for the directional distance function in expression (5) would mean that CO_2 emissions could be reduced by 40% while emissions of N_2O and CH_4 as well as GDP are maintained at their observed levels.[7]

In practice, directional distance functions described in expressions (4) and (5) are computed, as already noted, using *Data Envelopment Analysis* (DEA) techniques. Pioneered by Charnes et al. (1978), this non-parametric approach to efficiency measurement uses mathematical programming and basic assumptions regarding technology to assess the relative performance of a series of decision making units by comparing them to the best observed practices (further details are in Cooper et al., 2007).[8] While assumptions about the technology have been already established, the mathematical program that allows assessing proportional GHG eco-efficiency of the EU-27 country c′, i.e., the directional distance function of expression (4), is the following:

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[7] Further scenarios assessing, for instance, potential increases of GDP while maintaining GHG emissions or even increases of GDP at the same time that emissions are reduced can be modelled through the adequate directional distance functions. However, modelling these scenarios goes beyond the scope of this paper.

[8] In addition, an advantage of *DEA* techniques over other approaches commonly used to build composite indicators is that the weights assigned to individual GHG emissions in computing the aggregated emission score are determined endogenously, so that no a priori weights based on exogenous information are required, e.g., opinion of experts.

$$\text{Maximize}_{\Phi^{c'}_{GHG},\lambda^c}\ \text{Eco-efficiency}^{c'}_{GHG} = \Phi^{c'}_{GHG}$$

subject to:

$$\begin{aligned} & g^{c'} \le \sum\nolimits_{c=1}^{27} \lambda^c g^c & & & \text{(i)} \\ & \left(1-\Phi^{c'}_{GHG}\right) e^{c'}_i \ge \sum\nolimits_{c=1}^{27} \lambda^c e^c_i & & i = CO_2, N_2O, CH_4 & \text{(ii)} \\ & \lambda^c \ge 0 & & c = 1,\ldots,27 & \text{(iii)} \end{aligned} \qquad (6)$$

where λ^c stands for the weighting of each country c in the composition of the eco-efficient frontier country c′ is compared to.

Furthermore, the mathematical program that allows assessing eco-efficiency in the direction of a particular GHG emission, i.e. the directional distance function of expression (5) that assesses greenhouse-gas-specific eco-efficiency, is formulated as:

$$\text{Maximize}_{\Phi^{c'}_{e_i},\lambda^c}\ \text{Eco-efficiency}^{c'}_{e_i} = \Phi^{c'}_{e_i}$$

subject to:

$$\begin{aligned} & g^{c'} \le \sum\nolimits_{c=1}^{27} \lambda^c g^c & & & \text{(i)} \\ & \left(1-\Phi^{c'}_{e_i}\right) e^{c'}_i \ge \sum\nolimits_{c=1}^{27} \lambda^c e^c_i & & e_i \in e \text{ and } e_i \notin e_{-i} & \text{(ii)} \\ & e^{c'}_{-i} \ge \sum\nolimits_{c=1}^{27} \lambda^c e^c_{-i} & & e_{-i} \in e & \text{(iii)} \\ & \lambda^c \ge 0 & & c = 1,\ldots,27 & \text{(iv)} \end{aligned} \qquad (7)$$

2.3. *A brief comment on eco-efficiency*

Eco-efficiency for the EU-27 countries during the period 1990-2009 has been computed by running for each country and year program (6) in the scenario in which all emissions are proportionally reduced, i.e. proportional GHG eco-efficiency, and program (7) when reductions of specific emissions are considered, i.e. greenhouse-gas-specific eco-efficiency. Table 3 displays some descriptive statistics of these scores at the beginning and the end of the period, which allow us to implement a comparative static-type exercise. In 2009, the average of proportional GHG eco-efficiency reaches 0.458, suggesting that by behaving eco-efficiently the EU-27 could simultaneously reduce emissions of CO_2, N_2O and CH_4 by a proportion of 46%. The average scores of greenhouse-gas-specific eco-efficiency in CO_2, N_2O and CH_4 emissions are 0.584, 0.581 and 0.609, respectively, pointing out that the most eco-efficient management corresponds to nitrous oxide while the worst are the emissions of methane. Furthermore, countries behaving eco-efficiently, i.e., countries shaping the technological frontier against which other countries are compared to, are Luxembourg, Malta and Sweden. Conversely, the worst eco-efficiency levels correspond by far to Central and Eastern European countries that joined the EU in 2004 and 2007, such as Bulgaria, Estonia, Poland or the Slovak Republic, among others.

[Please, insert Table 3 around here]

From the comparison of the values calculated at the beginning and the end of the period we can observe that, the profile of eco-efficiency in 1990 is similar to that described above for 2009, with some core European countries and some Scandinavian economies among the most eco-efficient countries, whereas the most recent EU members are the least eco-efficient. Furthermore, many countries have improved their relative levels of eco-efficiency, but some others have worsened in all their scores, particularly Italy, Cyprus, Spain, Portugal and Slovenia.

Finally, it is also worth to highlight the large differences in eco-efficiency among EU countries. These differences might be due to several factors including their respective levels of development, the different structure of economic activity (closely related to the level of development) and differences in environmental awareness, among others. In the group of eco-efficient countries, Luxembourg is a highly developed economy enjoying the greatest GDP per inhabitant in the EU-27, highly oriented to service activities and, particularly, banking and financing services; Sweden is also among the most developed European countries and together with other Scandinavian economies has traditionally shown a high level of environmental awareness; finally, Malta is an small country where tourism and agriculture are the main economic activities. In contrast, the newer EU members are mostly biased towards industrial activities and, moreover, in these countries environmental regulations are more recent than in other Western European countries. However, the analysis of the factors that explain differences in GHG emissions eco-efficiency goes beyond the scope of this paper, so that in the remaining of it we will concentrate on the study of convergence.

3. Does eco-efficiency in greenhouse gasses emissions converge in the European Union?

3.1. Methodological approach to measure convergence

As it has already been discussed in the Introduction, the enforcement of environmental policies is not always easy. However, in an integrated area such as the European Union, we may find relatively supportive evidence of similar behavior patterns. Using the concept of convergence in this setting can be too rigid, as the assimilation of cleaner technologies may imply a relatively long process. This is why the econometric methodology that we adopt relies on the concept of convergence clubs. It implies finding groups of countries that converge to more than one reference level. Alternative methodologies have been applied using this less rigid concept, such as the proposal of Quah (1996) or the one of Hobijn and Franses (2000) to relative convergence.

In this paper we test for the existence of convergence clubs in eco-efficiency using the methodology of Phillips and Sul (2007). It is important, when testing for convergence, to allow for some degree of heterogeneity. In their case, they capture heterogeneous behavior using an empirical model based on a common factor structure and idiosyncratic effects. They start from a simple single factor model such as:

$$X_{it} = \delta_i \mu_t + \varepsilon_{it} \tag{8}$$

where δ_i measures the idiosyncratic distance between the common factor μ_t and the systematic part of X_{it}. μ_t may have different interpretations, either represent the aggregated common behavior of X_{it} or any common variable that may influence the individual economic behavior. This model tries to capture the evolution of the elements of X_{it} in relation to μ_t using two idiosyncratic elements: the systematic one (δ_i) and the error one (ε_{it}).

Phillips and Sul (2007) make two contributions to this simple model. First, they extend equation (8) by allowing the systematic idiosyncratic element to evolve over time (aiming at accommodating the heterogeneous evolution of agents). They also allow δ_{it} having a random component, which absorbs ε_{it} and permits possible convergence behavior in δ_{it} over time in relation to the common factor μ_t. In this case, the new model has a time varying factor representation:

$$X_{it} = \delta_{it} \mu_t \tag{9}$$

Thus the model accounts for a special behavior in the idiosyncratic element δ_{it} that they model in semiparametric form:

$$\delta_{it} = \delta_i + \sigma_i \xi_{it} L(t)^{-1} t^{-\alpha} \tag{10}$$

where δ_i is fixed, ξ_{it} ~iid(0,1) across i but weakly dependent over t, 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 δ_{it} converges to δ_i for all $\alpha \geq 0$ (the null hypothesis of interest). The parameter of interest is δ_{it} and the focus is on its temporal evolution and convergence behavior.

The second contribution that Phillips and Sul (2007) make is that this setting permits to develop an econometric test of convergence for the time varying idiosyncratic components. Using a simple regression, the hypothesis to test is:

$$H_0 : \delta_{it} \rightarrow \delta_i \text{ for some } \delta \text{ as } t \rightarrow \infty \qquad (11)$$

Some characteristics make it very useful in applied work: first, the test does not rely on any particular assumption concerning trend stationarity or stochastic nonstationarity in X_{it} or μ_t; second, the nonlinear form of (9) is sufficiently general to include many possible time paths for δ_{it} and their heterogeneity over i, e.g., it allows for transitionally divergent individual behavior.

From an economic point of view, δ_{it} measures the relative share in μ_t (a common trend component in the panel) of individual i at time t. Thus, δ_{it} is a form of individual economic distance between the common trend component μ_t and X_{it}. μ_t trending behavior dominates the transitory component. In this context, it is possible to test for convergence by assessing whether the factor loadings δ_{it} converge. For this purpose, Phillips and Sul (2007) define the *relative transition parameter* h_{it} as:

$$h_{it} = \frac{X_{it}}{\frac{1}{N}\sum_{i=1}^{N} X_{it}} = \frac{\delta_{it}}{\frac{1}{N}\sum_{i=1}^{N} \delta_{it}} \qquad (12)$$

which measures the loading coefficient δ_{it} in relation to the panel average at time t. Phillips and Sul (2007) assume that the panel average and its limit as $N \rightarrow \infty$ differ from zero. The cross sectional mean of h_{it} is unity by definition. Moreover, if the factor loading coefficients converge to δ, the relative transition parameters h_{it} converge to unity. Then, in the long-run, the cross sectional variance of h_{it} converges to zero.

Next, Phillips and Sul (2007) construct the cross-sectional mean square transition differential H_1/H_t where:

$$H_t = \frac{1}{N}\sum_{i=1}^{N}\left(\hat{h}_{it} - 1\right)^2 \qquad (13)$$

that measures the distance of the panel from the common limit. Using a semiparametric model for δ_{it} they get:

$$\delta_{it} = \delta_i + \frac{\sigma_i \xi_{it}}{L(t) t^{\alpha}} \qquad (14)$$

where ξ_{it} ~iid(0,1) across i, L(t) is a slowly varying function (such as log t) and α denotes the speed of convergence. Thus, δ_{it} converges to δ_i for all positive values of α or when this parameter is zero. The null hypothesis is:

$$H_0 : \delta_i = \delta \text{ and } \alpha \geq 0 \tag{15}$$

and the alternative:

$$H_A : \delta_i \neq \delta \text{ for some i and/or } \alpha < 0 \tag{16}$$

The null hypothesis is tested using the following log t regression:

$$\log\left(H_1/H_t\right) - 2\log L(t) = \hat{c} + \hat{b}\log t + u_t \tag{17}$$

where L(t)=log(t+1).

The coefficient of log t is $\hat{b} = 2\hat{\alpha}$, where $\hat{\alpha}$ is the estimate of α in H_0. Using the t-statistic t_b, the null hypothesis of convergence is rejected when $t_b<-1.65$. In empirical analysis the practice is to remove a part of the sample. Phillips and Sul (2007) recommend starting the regression at point t=[rT], where [rT] is the integer part of rt and r=0.3.

In the empirical application of the log t test to testing for convergence, Phillips and Sul (2007) suggest using the following *club convergence algorithm:*

1. Step 1 (Ordering): Order the panel members according to the last observation.

2. Step 2 (Core Group Formation): Calculation of the convergence t-statistic, t_k; for 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 $t_k>-1.65$.

3. Step 3 (Club Membership): Selection of the members of the core group (Step 2) by adding one at a time. A new country is included if the associated t-statistic is greater than zero.

4. 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 a divergent behavior.

3.2. Results and discussion

In this Section we discuss the main results on eco-efficiency convergence in emissions of pollutants that cause greenhouse effects. As highlighted in the Introduction, there exists an extensive literature that provides evidence of convergence, mainly in CO_2 emissions, for different sets of industrialized countries; the papers by Jobert et al. (2010) and Marrero (2010), which show evidence on the existence of conditional convergence in terms of GHG emissions among the EU27, are of particular interest for the purpose of our research.

As Schmalensee et al. (1998) signaled, high-income countries, such as Germany, France, Sweden, Netherlands and the UK have started to reduce per capita GHG emissions, while others in the same area, such Spain, Portugal, Italy and Austria, have increased emissions over the same period. Moreover, some Eastern European countries, such as the Czech Republic, Hungary, Poland and Slovakia, have reduced GHG emissions even more than the richest EU countries. The literature on growth and convergence (Barro and Sala-i-Martin, 1992) has recently been applied to explain the evolution of emissions. According to this theory countries with initial higher levels of emissions tend to reduce emissions more than countries with lower initial levels. That would give a possible explanation to understand the substantial drop in the emissions of Eastern European countries despite having a small per capita GDP. However, this theory is not able to explain the case of Spain, Greece or Ireland, whose emissions growth is clearly above those associated with their 1990 levels. Some authors have stressed the different economic growth rates as an explanatory variable for this heterogeneous behavior. However, there are still cases that cannot be explained even by this dual growth-convergence relationship.[9] Therefore, the relationship between growth and GHG emissions can be better analyzed through eco-efficiency indicators. The dynamics of these indicators points to the existence of other factors, as technological change and energy mix variations, that can help to explain the change in emissions between 1990 and 2009 in Europe.

Although the group of countries that we analyze is relatively homogeneous and subject to common policies and laws, EU countries exhibit heterogeneous characteristics associated to their differences in income and development level. Moreover, many of its members (the Central and Eastern European countries plus the

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[9] Marrero (2010) singles out the comparative case of the UK and Finland. Even if both economies had similar emission levels in 1990 and had a comparable growth pace over the sample period analyzed (1990-2006), the UK lowered its emissions to a much greater extent than Finland.

Baltic republics) joined the EU much later and their economic systems were not adapted to international markets competition. Therefore, the adoption of cleaner technologies has evolved at different paces among them. In this Section we present the results of the application of Phillips and Sul (2007) club convergence methodology in Table 4. The first column reports the results for total emissions while each one of the rest of the columns refer to specific pollutants on an individual basis. As already described in section 3.1 above, these results have been obtained from the application of the club convergence algorithm. The main hypothesis is that the countries form a converge club. If the value of the t-statistic is > -1.65, there is convergence among this group. A common result to all the air pollutants analyzed is that all the countries can be included in a convergence club. Therefore, no single country diverges from the whole set of countries.

[Please, insert Table 4 around here]

The first column includes the results for the measure of proportional GHG eco-efficiency in which all pollutants are reduced. The first club, which corresponds to the best countries, consists of those three that were on the efficiency frontier (Luxemburg, Malta and Sweden) and the UK. A second group includes some of the richest European economies: Austria, Belgium, Denmark, Finland, France, Germany, Italy and the Netherlands. The next group consists of Cyprus, Greece, Ireland, Latvia, Portugal, Slovenia and Spain, most of them peripheral countries or some of the more dynamic recent members, such as Slovenia and Latvia. Former communist countries and two Baltic republics form the final three groups (clubs 4, 5 and 6). As we have already stated above, all the 27 countries analyzed are included in a club, so that no one rests outside the different clubs (groups) formed by the algorithm. The t-statistic of the sixth group is also larger than the critical value (-1.65), and therefore Bulgaria and Romania (those countries with the worst performance) form also a club.

The clubs obtained for eco-efficiency in CO_2 emissions are reported in the second column and are quite similar to the aggregate case, although the number of clubs is smaller: only four in this case. The first group consists of the same countries, the best performers and the UK. A second club includes Denmark, France, Ireland and Latvia, whereas the third is formed by Austria, Belgium, Finland, Germany, Italy, Lithuania and the Netherlands. Finally, the fourth club includes the 12 remaining countries, among them Greece, Spain and Portugal.

A similar pattern is displayed in N_2O and CH_4 emissions, third and fourth columns, respectively, where we find five clubs in each of them. Although the particular members of each club are not the same, there are many coincidences and common patterns similar to two previous variables. The first club includes also the Netherlands in the case of N_2O emissions eco-efficiency, whereas Belgium, Germany and the four best performers are those included in Club 1 for CH_4 emissions. The second and third clubs consist of core European countries (Austria, Denmark, France and Italy) whereas Southern European countries and the newest additions to the EU are those that compose the fourth and fifth clubs.

Next, in Tables 5 to 8 we apply Phillips and Sul (2009) test for club merging. The main purpose of this testing procedure is to find out whether some of the clubs already identified by the convergence club algorithm can be merged, so that the final number of clubs is reduced. We have tested for several group formations, concluding that none of them can be merged, so that we should maintain the original club classification.

[Please, insert Tables 5 to 8 around here]

Further information concerning the dynamics of convergence clubs can be obtained from the graphs of the relative transition paths that are shown in Figures 1 to 4. The transition paths represent the relative evolution of each country relative to the average. We should note that the best performing countries appear at the upper part of the graph, whereas the countries lagging behind are at the lower part. In the four cases the three most efficient countries (Luxemburg, Malta and Sweden) are represented by just one line (light pink in the four graphs), as they display the same path.

[Please, insert Figures 1 to 4 around here]

As for the total measure of emissions eco-efficiency, we can observe that the UK converges rapidly towards the best performers, all of them members of Club 1. The next club can be also identified, as it includes Austria (dark blue diamond-shaped line) and the adjacent group of countries. We should emphasize that the countries whose parameter is below 1 tend to show a positively sloped transition path. This is not always the case with the first three clubs, where some countries converge upwards and some others downwards. Finally, Romania and Bulgaria are in the lower part of the graph, close to zero but slowly improving.

In the next graphs we report the breakdown by pollutants. Concerning CO_2 eco-efficiency, the first club consists of the same four countries and the UK also shows a clearly improvement and convergence towards the best countries. In the case of Clubs 2 and 3 below, some of the countries present an upward trend, such as Ireland and the Netherlands (clearly improving) whereas the majority worsens. We can cite among them Italy, Germany, Finland and Belgium. As in the previous variable, the majority of the less eco-efficient countries follow an upward convergence trend toward, at least, the average. The most evident is Latvia (green line) in Club 4, as well as Lithuania, in Club 5.

The third figure showing transition paths corresponds to eco-efficiency convergence in N_2O emissions. Club 1 consists now of 5 members (Luxemburg, Malta, Netherlands, Sweden and the UK). Whereas the UK converges very fast, other countries that initially were closer to the three best have a downward slope (Austria and Italy, blue and dark red lines, respectively). In contrast, the Netherlands (light purple and burgundy) are quite rapidly approaching 1.5 in the graph, so that they can also be included in the first club. Club 2 is formed by eight countries, the above-mentioned Austria and Italy, as well as other countries approaching 1.5, such as Finland, Germany and Italy. The majority has upward trajectories. The third club contains peripheral European countries, many of them following downward sloping convergence towards 0.75 approximately, such as Spain and Portugal, whereas others are improving. The two remaining clubs are closely together and follow a slow progress towards 0.5.

Finally, in Figure 4, Club 1 has six countries, not only the best performers, but also other that are approaching quite quickly level 2 (so that they double the average speed of transition). These are notably the cases of the UK, as well as Belgium and Germany. The next three countries (Austria, Denmark and Finland) form Club 2 and are very close to the first group with upward sloping trajectories. The next club, in contrast, shows a downward slope, worsening their positions relative to the average, and approaching it. With four exceptions (Slovenia, Slovak Republic, Cyprus and Portugal), the other two club members are again slowly progressing toward the average.

4. Concluding remarks and policy implications

In this paper we contribute to previous literature on GHG emissions convergence in two respects. First, we refine the definition of the variable analyzed by constructing an indicator of eco-efficiency for both the aggregate GHG emissions and for each of the most important individual pollutants included in this class of gases. Second, the methodological approach that we follow to measure convergence allows us to classify countries in a flexible way inside convergence clubs. This approach is especially suited for environmental variables where the classical concepts of convergence (absolute or conditional) may be too rigid to be fulfilled. Moreover, this methodology allows us to measure the dynamics of the convergence process and accounts for cross-section dependence in a common factor modeling framework.

To sum up, our results are compatible with previous studies that analyze GHG emissions convergence within EU countries for similar sample periods using rough indicators. The eco-efficiency analysis shows along the whole period studied that countries behaving eco-efficiently, i.e., countries shaping the technological frontier against which other countries are compared to, are Luxembourg, Malta and Sweden. Conversely, the worst eco-efficiency levels correspond by far to Central and Eastern European countries that joined the EU in 2004 and 2007. From a dynamic point of view, the results found point to the existence of four to six convergence clubs depending on the specific pollutant. The first club is generally formed by Luxembourg, Malta and Sweden together with the UK. A second club with countries having similar characteristics is composed of core EU countries, like Germany, Austria, Belgium, France, Italy, Denmark and Finland. Moreover, a third club is made up of peripheral countries, such as Spain, Greece, Cyprus and Portugal, together with Latvia and Slovenia. All of them have increased notably their emissions, and therefore have worsened their evolution in eco-efficiency terms.

A possible explanation of this different evolution between countries in Clubs 1-2 on the one hand, and Club 3 on the other, could come from the difference in the initial income levels among the countries belonging to the different clubs. However, this relationship between emissions and initial income levels fades out once we analyze the performance of Eastern European countries included in the rest of the convergence clubs, which has improved greatly in eco-efficiency terms. This fact reveals the existence of other factors, like technological improvements or energy-mix changes, which might help to explain the heterogeneous evolution in terms of eco-efficiency in the EU so far. Therefore, although the EU seems to be progressing in the right direction, more effort in regulatory aspects is still missing to achieve a dynamic convergence in eco-efficiency terms.

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Table 1 Emissions of GHG in the European Union (CO_2 equivalent tons)

	European Union-27		European Union-15	
	1990	2009	1990	2009
Carbon dioxide (CO_2)	4,395.7	3,765.0	3,359.4	3,063.2
Nitrous oxide (N_2O)	528.3	354.9	399.1	277.4
Methane (CH_4)	605.8	413.3	450.6	309.5
Sulphur hexafluoride (SF_6)	11.0	6.5	10.9	6.1
Hydrofluorocarbons (HFCs)	28.1	72.4	28.1	65.6
Perfluorocarbons (PFCs)	20.0	2.5	16.8	1.9
Aggregated emission (GHG)	5,588.9	4,614.6	4,264.9	3,723.7

Table 2 Intensity of GHG emission in the European Union (CO_2 equivalent tons per 1,000 US$ of GDP)

	Year 1990				Year 2009			
	GHG	CO_2	N_2O	CH_4	GHG	CO_2	N_2O	CH_4
Austria (Au)	0.52	0.42	0.04	0.06	0.37	0.31	0.02	0.03
Belgium (Be)	0.77	0.64	0.06	0.05	0.48	0.42	0.03	0.02
Bulgaria (Bu)	7.65	5.72	0.86	1.06	3.08	2.38	0.24	0.45
Cyprus (Cy)	0.85	0.68	0.05	0.12	0.77	0.66	0.03	0.09
Czech Republic (Cz)	3.54	2.98	0.22	0.33	1.75	1.50	0.10	0.15
Denmark (Dk)	0.55	0.43	0.08	0.05	0.36	0.29	0.04	0.03
Estonia (Es)	6.85	6.05	0.33	0.47	2.05	1.74	0.12	0.17
Finland (Fi)	0.71	0.57	0.07	0.06	0.47	0.39	0.04	0.03
France (Fr)	0.52	0.36	0.08	0.06	0.35	0.25	0.04	0.04
Germany (De)	0.81	0.68	0.06	0.07	0.46	0.39	0.03	0.02
Greece (Gr)	1.05	0.84	0.10	0.10	0.73	0.62	0.04	0.05
Hungary (Hu)	2.20	1.64	0.29	0.27	1.14	0.86	0.12	0.14
Ireland (Ie)	1.13	0.67	0.18	0.28	0.49	0.33	0.06	0.10
Italy (It)	0.55	0.46	0.04	0.05	0.44	0.37	0.03	0.03
Latvia (La)	2.55	1.83	0.36	0.36	0.96	0.62	0.15	0.17
Lithuania (Li)	3.12	2.30	0.43	0.40	1.26	0.75	0.29	0.21
Luxembourg (Lu)	1.03	0.96	0.04	0.04	0.45	0.41	0.02	0.02
Malta (Ma)	0.88	0.78	0.02	0.07	0.65	0.57	0.01	0.06
Netherlands (Nl)	0.75	0.56	0.07	0.09	0.46	0.39	0.02	0.04
Poland (Pl)	3.84	3.12	0.32	0.39	1.56	1.29	0.11	0.14
Portugal (Pr)	0.68	0.50	0.06	0.12	0.61	0.46	0.04	0.10
Romania (Ro)	5.69	3.91	0.76	0.97	2.34	1.53	0.33	0.47
Slovak Republic (Sk)	2.69	2.28	0.23	0.17	1.00	0.81	0.08	0.10
Slovenia (Sl)	1.11	0.89	0.08	0.13	0.75	0.62	0.05	0.08
Spain (Sp)	0.64	0.51	0.06	0.06	0.51	0.42	0.04	0.05
Sweden (Sw)	0.36	0.28	0.04	0.03	0.21	0.16	0.02	0.02
United Kingdom (UK)	0.67	0.51	0.06	0.10	0.34	0.28	0.02	0.03
Averages								
European Union-15	0.72	0.56	0.07	0.08	0.45	0.37	0.03	0.04
European Union-27	1.91	1.50	0.18	0.22	0.89	0.70	0.08	0.11

Table 3 Scores of eco-efficiency in greenhouse gases emissions

	Eco-efficiency scores in 1990				Eco-efficiency scores in 2009			
	GHG	CO_2	N_2O	CH_4	GHG	CO_2	N_2O	CH_4
Austria (Au)	0.104	0.324	0.151	0.373	0.144	0.476	0.207	0.318
Belgium (Be)	0.313	0.557	0.497	0.351	0.283	0.610	0.429	0.305
Bulgaria (Bu)	0.951	0.951	0.979	0.967	0.907	0.932	0.959	0.962
Cyprus (Cy)	0.360	0.583	0.566	0.711	0.439	0.753	0.676	0.798
Czech Republic (Cz)	0.849	0.905	0.917	0.895	0.797	0.892	0.898	0.883
Denmark (Dk)	0.236	0.337	0.552	0.236	0.343	0.433	0.442	0.482
Estonia (Es)	0.899	0.953	0.943	0.926	0.837	0.907	0.921	0.899
Finland (Fi)	0.445	0.506	0.618	0.451	0.402	0.586	0.580	0.428
France (Fr)	0.218	0.218	0.554	0.427	0.360	0.360	0.501	0.593
Germany (De)	0.368	0.583	0.584	0.498	0.271	0.589	0.480	0.293
Greece (Gr)	0.611	0.663	0.817	0.644	0.514	0.740	0.725	0.671
Hungary (Hu)	0.828	0.828	0.936	0.869	0.795	0.812	0.916	0.880
Ireland (Ie)	0.577	0.577	0.868	0.875	0.515	0.515	0.678	0.817
Italy (It)	0.082	0.312	0.142	0.201	0.203	0.567	0.311	0.482
Latvia (La)	0.846	0.846	0.949	0.903	0.739	0.739	0.935	0.901
Lithuania (Li)	0.877	0.877	0.956	0.913	0.785	0.785	0.966	0.917
Luxembourg (Lu)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Malta (Ma)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Netherlands (Nl)	0.441	0.501	0.600	0.615	0.170	0.454	0.277	0.560
Poland (Pl)	0.883	0.910	0.942	0.911	0.811	0.874	0.914	0.881
Portugal (Pr)	0.369	0.436	0.502	0.700	0.435	0.644	0.629	0.835
Romania (Ro)	0.928	0.928	0.975	0.964	0.894	0.894	0.970	0.963
Slovak Republic (Sk)	0.800	0.876	0.918	0.800	0.730	0.799	0.883	0.828
Slovenia (Sl)	0.535	0.682	0.757	0.737	0.553	0.740	0.783	0.781
Spain (Sp)	0.369	0.450	0.508	0.415	0.414	0.610	0.585	0.663
Sweden (Sw)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
United Kingdom (UK)	0.333	0.446	0.466	0.635	0.016	0.054	0.024	0.314
Averages								
European Union-15	0.298	0.394	0.457	0.428	0.271	0.442	0.391	0.451
European Union-27	0.490	0.565	0.618	0.593	0.458	0.584	0.581	0.609

Table 4 Convergence Club classification. Eco-efficiency of emissions

Total emissions		**CO2 emissions**		**N2O emissions**		**CH4 emissions**	
Club 1		**Club 1**		**Club 1**		**Club 1**	
[Lu, Ma, Sw, UK]		[Lu, Ma, Sw, UK]		[Lu, Ma, Nl, Sw, UK]		[Be, De, Lu, Ma, Sw, UK]	
log t	t-stat	log t	t-stat	log t	t-stat	log t	t-stat
6.03	3.90	2.42	7.55	0.244	3.122	0.008	0.138
Club 2		**Club 2**		**Club 2**		**Club 2**	
[Au, Be, DK, Fi, Fr, De, It, Nl]		[Dk, Fr, Ie, La]		[Au, Be, Dk, Fi, Fr, De, Ie, It]		[Au, Dk, Fi]	
log t	t-stat	log t	t-stat	log t	t-stat	log t	t-stat
0.14	2.96	0.12	1.99	0.319	4.262	0.238	2.812
Club 3		**Club 3**		**Club 3**		**Club 3**	
[Cy, Gr, Ie, La, Pr, Sl, Sp]		[Au, Be, Fi, De, It, Li, Nl]		[Cy, Es, Gr, Pr, Sl, Sp]		[Fr, Gr, It, Nl]	
log t	t-stat	log t	t-stat	log t	t-stat	log t	t-stat
0.29	4.83	0.27	3.83	-0.022	-0.831	0.133	1.952
Club 4		**Club 4**		**Club 4**		**Club 4**	
[Es, Li, Sk]		[Bu, Cy, Cz, Es, Gr, Hu, Pl, Pr, Ro, Sk, Sl, Sp]		[Cz, Hu, La, Pl, Sk]		[Cy, Cz, Es, Hu, Ie, La, Li, Pl, Pr, Sk, Sl, Sp]	
log t	t-stat	log t	t-stat	log t	t-stat	log t	t-stat
0.26	12.69	-0.083	-1.35	-0.489	-49.56^{**}	0.034	0.497
Club 5				**Club 5**		**Club 5**	
[Cz, Hu, Pl]				[Bu, Li, Ro]		[Bu, Ro]	
log t	t-stat			log t	t-stat	log t	t-stat
0.43	25.64			0.568	9.81	3.861	2.788
Club 6							
[Bu, Ro]							
log t	t-stat						
1.58	10.13						

Table 5 Convergence Club classification. Merging total emissions eco-efficiency

Initial classification γ (t of γ)		Tests of club merging γ (t of γ)					Final classification	
Club 1 [4]	6.03 (3.90)	**Club 1+2** -0.957 (-61.927)**					**Club 1 [4]**	6.03 (3.90)
Club 2 [8]	0.14 (2.96)		**Club 2+3** -0.336 (-13.896)**	**Club 2+3+4** -0.423 (-16.39)**	**Club 2+3+4+5** -0.495 (-20.67)**		**Club 2 [8]**	0.14 (2.96)
Club 3 [7]	0.290 (4.83)				**Club 3+4** -0.12 (-3.43)**		**Club 3 [7]**	0.290 (4.83)
Club 4 [3]	0.26 (12.69)					**Club 4+5** -0.42 (-10.58)**	**Club 4 [3]**	0.26 (12.69)
Club 5 [3]	0.43 (25.64)					**Club 3+4+5** -0.278 (-10.39)**	**Club 5 [3]**	0.43 (25.64)
Club 6 [3]	1.58 (10.13)						**Club 6 [3]**	1.58 (10.13)

Table 6 Convergence Club classification. Merging CO_2 emissions eco-efficiency

Initial classification γ (t of γ)		Tests of club merging γ (t of γ)				Final classification γ (t of γ)	
Club 1 [4]	2.419 (7.551)	**Club 1+2** -0.657 (-72.55)				**Club 1 [4]**	2.419 (7.551)
Club 2 [4]	0.119 (1.997)		**Club 2+3** -0.094 (-2.45)**	**Club 2+3+4** -0.348 (-11.55)**		**Club 2 [4]**	0.119 (1.997)
Club 3 [7]	0.266 (3.832)				**Club 3+4** -0.329 (-8.52)**	**Club 3 [7]**	0.266 (3.832)
Club 4[12]	-0.073 (-1.35)					**Club 4 [12]**	-0.073 (-1.35)

Table 7 Convergence Club classification. Merging N_2O emissions eco-efficiency

Initial classification **γ (t of γ)**		**Tests of club merging** **γ (t of γ)**				**Final classification** **γ (t of γ)**	
Club 1 [4]	0.244 (3.12)	**Club 1+2** -0.355 (-6.38)**				**Club 1 [4]**	0.244 (3.12)
Club 2 [4]	0.319 (4.26)		**Club 2+3** -0.347 (-9.45)**	**Club 2+3+4** -0.502 (-19.46)**		**Club 2 [4]**	0.319 (4.26)
Club 3 [7]	-0.022 (-0.831)			**Club 3+4** -0.329 (-8.52)**		**Club 3 [7]**	-0.022 (-0.831)
Club 4[12]	-0.486 (-49.56)**				**Club 4+5** -0.822 (-54.63)**	**Club 4 [12]**	-0.784 (-49.56)**
Club 5 [3]	0.568 (9.81)					**Club 5 [3]**	0.568 (9.81)

Table 8 Convergence Club classification. Merging CH_4 emissions eco-efficiency.

Initial classification **γ (t of γ)**		**Tests of club merging** **γ (t of γ)**				**Final classification** **γ (t of γ)**	
Club 1 [6]	0.008 (0.138)	**Club 1+2** -0.55 (-32.49)**				**Club 1 [4]**	0.008 (0.138)
Club 2 [3]	0.238 (2.812)		**Club 2+3** -0.45 (-12.55)**	**Club 2+3+4** -0.664 (-29.68)**		**Club 2 [4]**	0.238 (2.812)
Club 3 [4]	0.133 (1.95)			**Club 3+4** -0.444 (-14.45)**		**Club 3 [7]**	0.133 (1.95)
Club 4[12]	0.034 (0.497)				**Club 4+5** -0.157 (-2.80)**	**Club 4 [12]**	0.034 (0.497)
Club 5 [2]	3.861 (2.78)					**Club 5 [3]**	3.861 (2.78)

Figure 1 Total emissions of greenhouse gases eco-efficiency. Transition paths.

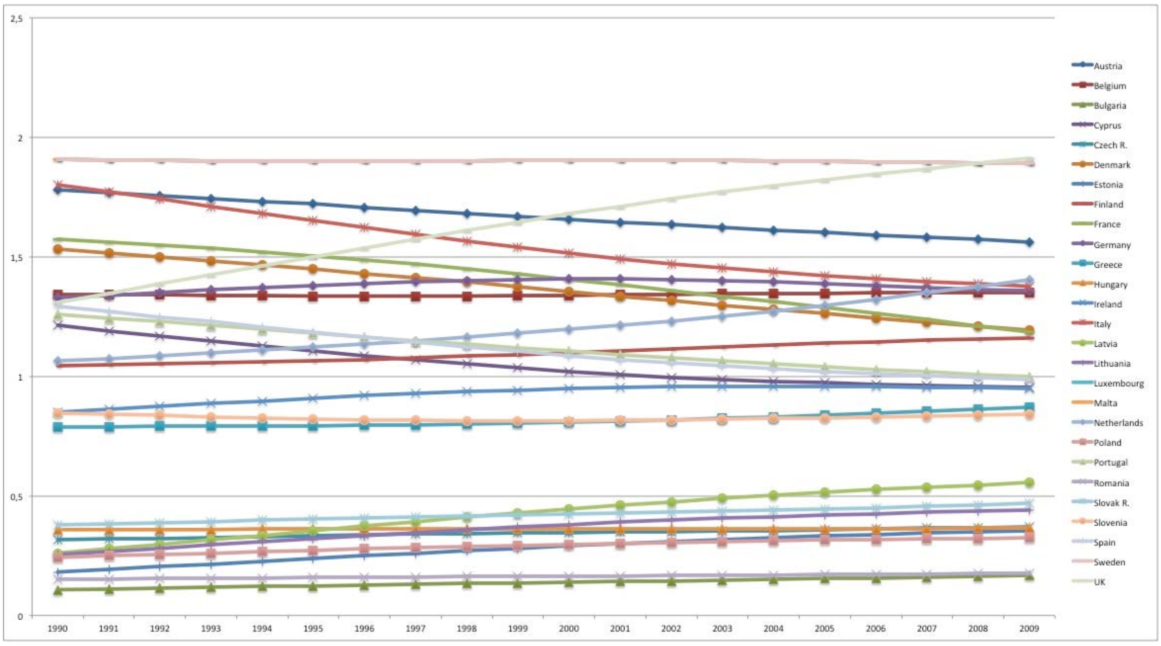

Figure 2 CO_2 emissions eco-efficiency. Transition paths

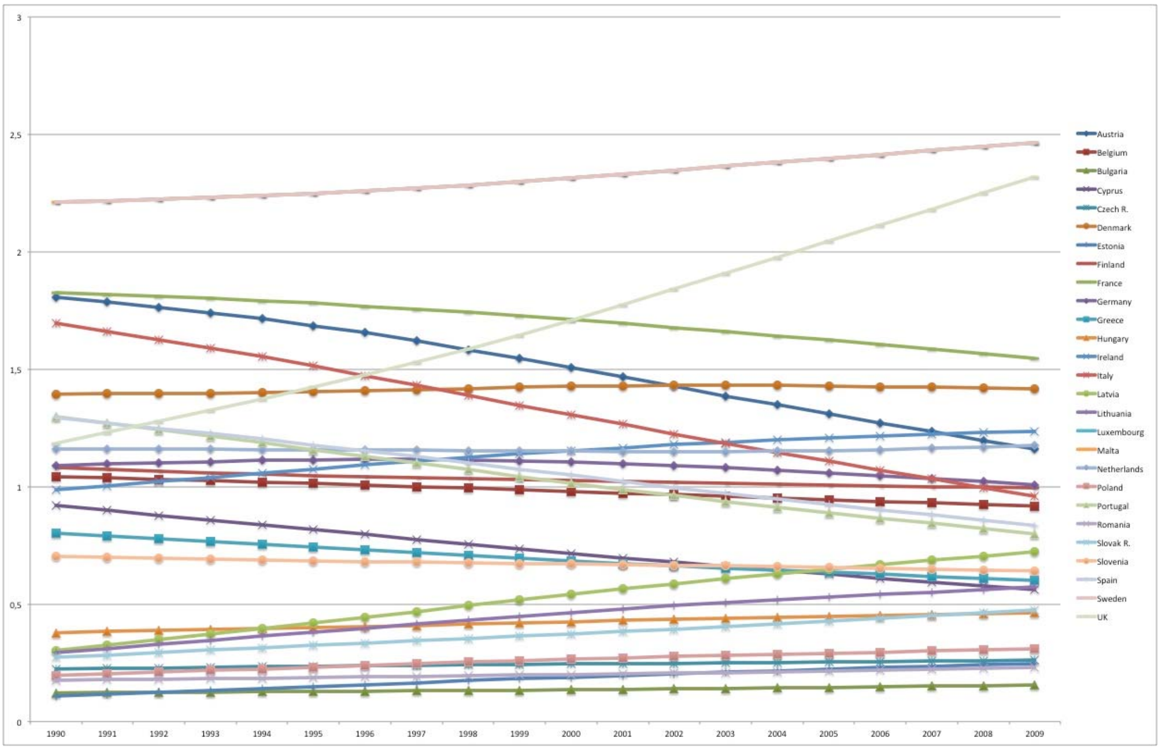

Figure 3 N_2O Emissions eco-efficiency. Transition paths

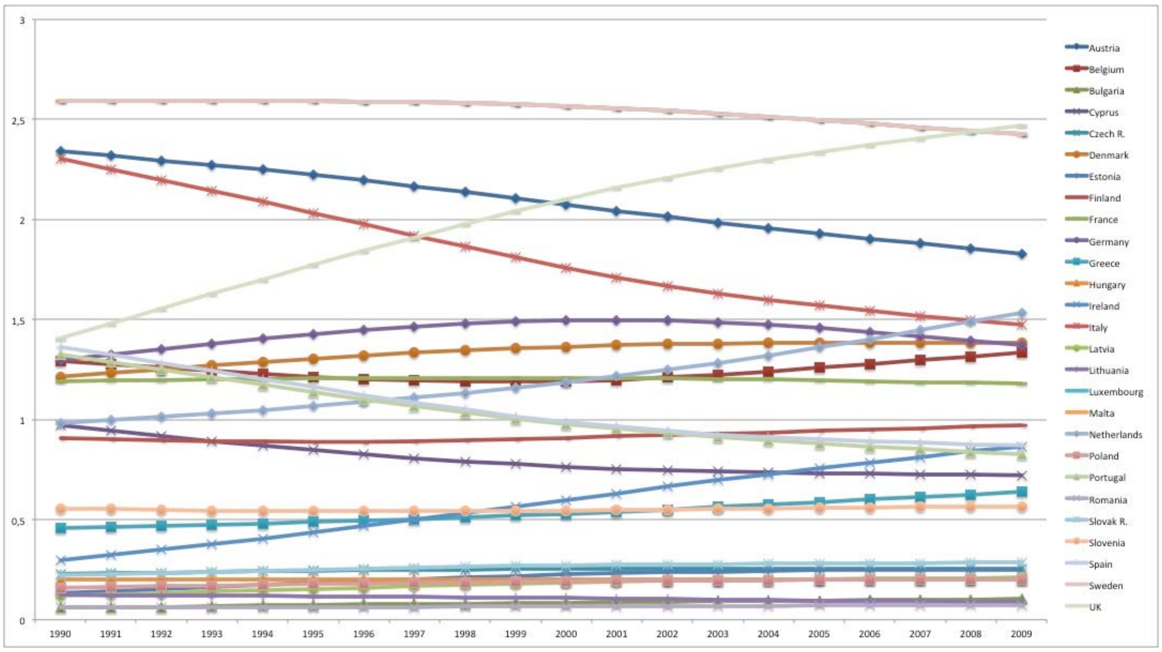

Figure 4 CH_4 emissions eco-efficiency. Transition paths