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Energy Regulation in the EKC Model with a Dampening Effect

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Abstract

The empirical environmental kuznets curve (EKC) model provides a popular means to analyze the correlation between economic growth and environmental destruction. This study seeks to verify if implementing environmental regulations has effects beyond the EKC. An elaborated panel data model applies to 28 OECD countries to analyze not only the relationship between economic growth and environmental destruction but also the effect of regulatory activities on the replacement of energy sources and their efficiency. The proposed model also accounts, for the first time, for the effect of level of income on the replacement of energy sources. Using the EKC, this study demonstrates that energy regulation measures help reduce greenhouse gas emissions (GHG). To validate this hypothesis, we have also added the dampening effect that income level has over the contribution of renewable energy sources to the total of energy consumption. The estimation reveals increases in the explanatory power of the model. This study concludes that pollution will not disappear automatically when economic growth increases. Therefore the need to develop energy efficiency RD&D in order to reduce environmental pollution.

Keywords: Energy RD&D; Energy efficiency; Environmental kuznets curve; Sustainable development

Introduction

In economic growth theories, environmental sustainability has only recently become relevant. For example, studies of economic growth and environmental destruction rely on the Environmental Kuznets Curve (EKC for short), which originated with [1], to contrast environmental destruction against economic growth. The EKC refers to the hypothesis that the relationship between environmental quality and per capita income expose an inverted U-shaped. Such analyses incorporate the potential impacts of public incentives on both energy efficiency and efforts to replace conventional energy sources with renewable ones. The EKC hypothesis reveals that the economic growth could be compatible with environmental improvements, the main motivation is to search the evidence of a relationship between income and environmental degradation, so if the answer is that economic growth can be a part of the solution for environmental problems.

Market failures in the energy sector continue the need for public intervention, whether in the form of an adequate judicial system of property rights that considers more comprehensive expenses or direct management of the process to internalize external effects. Both approaches have the same goals: to minimize the risk associated with depending on external energy sources and to prevent the destruction of the environment.

To undertake such an analysis of an energy regulation policy, this study identifies characteristic features of existing energy substitution and efficiency measures and their impacts on the reduction of greenhouse gas emissions (GHG). In addition, this study considers the importance of applied technologies in environmental control processes. After we review the theoretical contributions that this study makes to the EKC model, we establish an econometric panel data model for 28 OECD countries that incorporates fixed effects, such that we can assess the characteristics of every country and the impact of the public budget for research, development, and demonstration (RD&D) in energy efficiency and energy reduction on GHG reductions. A greater dampening effect suggests an improvement to the standard EKC model and thus constitutes a methodological novelty. Finally, we individually omit the variables that configure the model, to verify the impact of each regulatory measure.

Material and Methods

Economic growth and regulatory measures

Pressures on natural resources and increased international dependence on fossil energy sources have accelerated environmental destruction and heightened indicators of GHG emissions. According to the worldwide scientific community [2], environmental destruction endangers some of the world's most advanced economic systems and could lead to the loss of welfare, on global and structural scales. Many studies have argued that increasing carbon dioxide emissions produce a build-up of greenhouse gas, which considerably contributes to warming global temperatures and associated climatic instability (IPPC, 1996). Concerns about environmental sustainability have translated into some corrective actions to address the effects of economic growth, including more efficient energy policies that depend less on fossil sources and seek to lower the geopolitical risks associated with those sources.

We seek to verify the existence of a complementary relationship between economic growth and energy policies that replace existing energy sources and enhance efficiency. As Figure 1 reveals, these efforts have become priorities for many countries in the past decade [3]. However, improving energy efficiency also requires public support, such as public resources devoted to technological upgrades, which we measure as RD&D budgets.

Adopting environmental corrections requires a public intervention that seeks to improve both the environment and the economy. The OECD and European Union have made commitments to reduce GHG emissions. Therefore, energy regulation entails measures that contribute to both energy savings and efficiency [4]. Previous studies analyze the impact of energy efficiency and replacement regulations for

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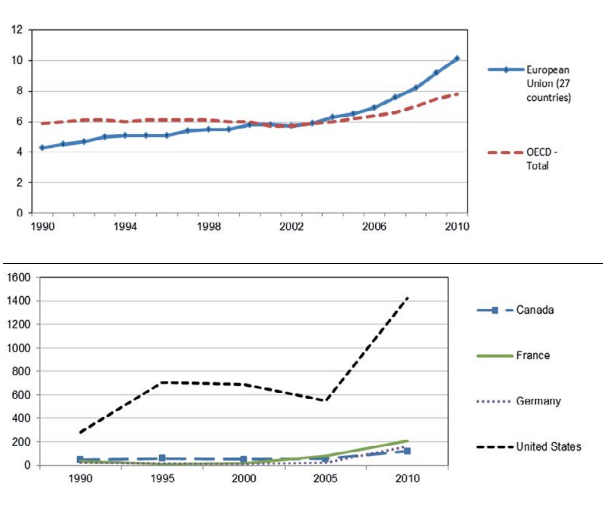

Notes: Panel A shows the contribution of renewable sources to the energy supply. Panel B indicates the public budget for RD&D devoted to energy efficiency, in millions of U.S. dollars (2011 prices and purchasing power parity). Source: OECD (2013).

Figure 1: Evolution of energy consumption and public RD&D budgets for energy efficiency

correcting environmental destruction and indicate positive changes in the environment [5-7].

We investigate instead the impact of technology linked to the energy sector on processes of environmental correction. To analyze this impact, we consider variables associated with energy regulation, with the budget devoted to RD&D in energy efficiency as a proxy variable. On the other hand, we use a variable that seeks to represent energy replacement, due to the impact that renewable sources have on energy consumption. By including these variables in assessing the relationship between income level and contamination, we demonstrate a positive impact on environmental correction [8] highlight the limitations linked to the degree in which a society assumes the internalization of expenses generated by GHG emissions, because every environmental regulation implies an initial cost that society must assume in its entirety. Although in the short term, energy regulation thus should generate a negative impact on costs, in the long term, these measures can contribute to more efficient energy [5,9]. In both the middle and long term, these technological improvements likely reduce plant costs and therefore the ultimate energy costs too [10].

The energy sector operates in a market with imperfect competition, compatible with the existence of financing activities that can generate technological progress [1]. With an endogenous view of economic growth, we can predict a relationship between economic growth and the environment, such that technology advances in the energy sector improve chances to invest in and achieve sustainable growth rates [11].

Theoretical model

Because of its key function in any economic system, the energy sector exerts an influence over disparate areas, including cost structures, environmental destruction, and exterior balance. Studies that analyze the relationship between economic growth and environmental destruction, according to the EKC's analytic scheme, propose a relationship between economic growth and environmental quality [12-14]. This nexus implies that environmental destruction is an increasing function of the level of economic activity, until it reaches a critical level, when higher income levels lead to improved environmental quality, in the shape of an inverted U [13,15].

It provides a systematic explanation for the relation between environment and income [13]. They argue that economic growth affects the environment in three different channels: scale effect, composition effect and technique effect. If we proceed to explain these three effects, the scale effect asserts that even if the structure of the economy and technology, of the countries, does not change, an increase in production will result in decreased environmental quality. Therefore, it could be argued that economic growth through scale effect has a negative impact on the environment. On the other hand, [13] claim that composition effect may have a positive impact on the environment because in the earlier stages of economic development pollution increases as the economic structure changes from agriculture to more resource intensive heavy manufacturing industries; while in the later stages of development pollution decreases as the structure moves towards services and light manufacturing industries. Therefore, composition effect, through this change in the production structure, could lower the harmful effects of economic growth on the environment pollution. Finally, technique effect captures improvements in productivity and adaptation of cleaner technologies, which will lead to an increase in environmental quality.

It describes the evolution of environmental destruction and economic growth. At lower development levels, environmental destruction depends on subsistence resources and limited quantities of biodegradable waste. As economic growth speeds up through agriculture, resource use, and industrialization, extraction rates start to surpass regeneration rates, and waste increases in quantity and toxicity. Then information and services industries appear, together with growing environmental concerns, leading to environmental regulations, a technological upgrade, and more environmental investments, followed by stabilization and a gradual decrease of environmental destruction, where technological innovation has an important role [16,17].

The impact of economic growth on environmental destruction thus may be divided into three parts: composition, scale, and technological effects [18,19] confirm that as economic activity increases, the level of environmental contamination gets corrected, mainly through technological factors. This perspective links the EKC with technological development, because technological effects have greater influences than composition or scale effects.

The composition effect results when the service sector replaces the industrial sector, with its intensive energy consumption and toxic emissions, which should decrease polluting emissions and help to reverse the slope in the curve [20]. The scale effect refers to the margin for new improvements to create increasing returns in terms of reducing contamination [21]. The scale effect generates the upward trend of an EKC when production shifts to industrial production, in the sense that economic development gives the opportunity of investing in information-based industry and services as well as improving production techniques or adopting cleaner technology; being called these effects the composition and technique effect respectively. Both effects can overcome scale effect and generate downward trend of an EKC curve Dinda [25].

Several studies emphasize the significant effect of technology and structural changes on GHG emissions over time [22-24]. Kander [23] and various authors support two fundamental driving forces of an EKC-pattern: structural changes and technical progress [20,25], where composition effect (structural changes) includes the transition of the production process from the production intensive industry to the service sector, which is considered as less-polluting [26]. Technical progress includes any improvement in the production techniques, which result in less use of inputs or/and adoption of less polluting technologies. The technical effect suggests improvements in technology that allows the use of less input per unit of output or the adoption of cleaner technologies that substitute the obsolescence in the production of goods. The development of cleaner techniques is encouraged by investment in environmental RD&D for which a sufficient economic growth is required [27].

The EKC suggests the potential for public intervention in environmental affairs, and energy RD&D are significant for understanding this phenomenon, for this reason, regulation processes in technological innovation offer an additional explanation, backed by the endogenous theory; a change in the income level/environment nexus is due to the improvement in the production process thanks to technological change [11]. Therefore, the technology used to reduce contamination also affects the EKC analysis, such that economic growth alone cannot solve contamination issues. With environmental regulations, the outcomes of the income level-contamination relationship might be achieved even at lower income levels.

Focusing on the EKC interpretation proposed by [19], who propose that decontamination processes depend mainly on technological factors, because consumption generates contamination, energy innovation budgets linked to decontamination should lead to reductions in the level of contamination. As income levels rise, demands emerge for both more consumption and less contamination. Any strategy that seeks to reduce contamination levels thus must assume increasing returns to scale. In turn, we can infer that technological innovation is fundamental to the EKC. The processes of technological innovation make environmental correction possible at lower incomes [28], such that reforms and institutional changes are necessary [29,30]. In a first stage, economic development policies create distortions, such as subsidising energy consumption, and market failures occur [16,25]. In a second stage, distortions disappear and market failures are corrected. Then subsequent stages apply strict environmental policies, and environmental awareness increases. In turn, institutional changes that take place at the same time as economic development can explain the pattern described by the EKC [31,32] admit that better executed measures for environmental correction lower the level of income needed to reach environmental correction. Empirical evidence also confirms the complimentarily of measures to reduce contamination and economic growth, which also lower the income levels required to reach environmental decontamination [33].

Incorporating the effect of technological innovation thus reinforces the endogenous aspect of our hypothesis [11,34]. We can affirm that technological progress conditions the income level-environmental contamination relationship, so that as energy technology improves, replacement with less contaminating energy sources [35] and more efficient processes [36,37] takes place.

Therefore, public promotion in renewable energy sources and the implementation of RD&D policies that improve energy efficiency should contribute positively to environmental correction, on a path of sustainable economic growth. To demonstrate this hypothesis, we use the EKC model, which has been generally accepted for analyzing the relationship between economic growth and environmental destruction; it also can incorporate other variables that might explain environmental corrections [33].

To clarify our hypotheses, we briefly develop some of the most important aspects of the EKC theoretical model. Previous studies cite the relationship between environmental pollution and income levels [16,32,38], and starting with [13], many studies that consider the link between economic growth and environmental destruction suggest an inverted U-shaped relationship. For our empirical study, we begin with the general theoretical framework so that we can identify different relationships between environmental destruction and levels of income [18]:

$$GHG_{it} = \alpha_{it} + \beta_1 GDPpc_{it} + \beta_2 GDPpc2_{it} + \beta_3 GDPpc3_{it} + \beta_4 Z_{it} + e_{it} \quad (1)$$

where GHG refers to pollution or environmental destruction, GDPpc is the level of income per inhabitant, and Zit indicates other influences on environmental pressure. The coefficient α includes the environmental pressure average when income has no special relevance for environmental pressure; the coefficient β represent the relative importance of exogenous variables; and e_{it} is the error term, normally distributed with a 0 average and constant variance. A subindex i indicates the country or region, and t is the moment in time.

As we can see in Figure 2, depending on the value allocated to coefficient β, the EKC can adopt different forms, other than the typical one in Figure 3, which shows how an economy that reaches a certain level of income (highest point) also experiences decreases environmental pollution with continued growth in the level of income:

(1) If $\beta_1>0$, $\beta_2=\beta_3=0$, there is an increasing monotonic relationship,

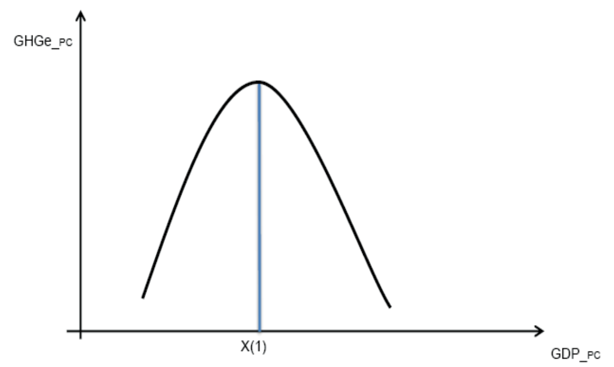

Figure 2: Inverted U-shaped EKC

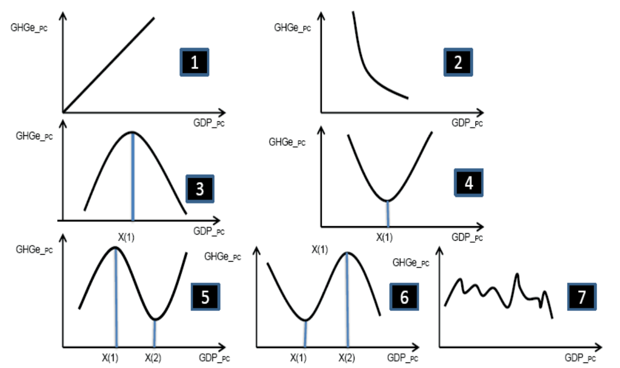

Figure 3: Possible behaviors between environmental pressure and GDP per capita

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such that high levels of income are associated with high levels of pollution.

(2) If $\beta_1<0$, $\beta_2=\beta_3=0$, there is a decreasing monotonic relationship, such that high levels of income are associated with decreasing levels of pollution.

(3) If $\beta_1>0$, $\beta_2<0$ and $\beta_3=0$, and $\beta_3 = 0$, a quadratic relationship in an inverted U-shaped pattern indicates that high levels of income are associated with decreasing levels of pollution, beyond a certain level of income.

(4) If $\beta_1<0,\beta_2>0$, and $\beta_3=0$, there is a quadratic relationship in a U-shaped pattern, in direct contrast with the EKC.

(5) If $\beta_1>0,\beta_2<0$, and $\beta_3>0$, a cubic polynomial reveals an N shape, such that the inverted U hypothesis occurs up to a certain point, after which pollution increases again.

(6) If $\beta_1<0,\beta_2>0,\beta_3<0$, we have a cubic polynomial in an inverted N shape.

(7) If $\beta_1=\beta_2=\beta_3=0$, flat behavior indicates that emissions are not influenced by the level of income.

Among the different shapes of the EKC (Figure 3), we pay special attention to the N-shaped pattern, following the suggestions of Grossman and Krueger [18], Torras and Boyce [21] and Shafik [38] among others. These authors offer some evidence of an N shape but also argue that the last ascending stretch likely implies income levels that are much too high for most regions. Therefore, they largely ignore the cubic form of the function, focusing more on the inverted U-shaped relationship (quadratic form).

Regarding arguments that focus on the problems created by adjusting the model to the data, Grossman and Krueger [18] mention that the EKC could follow an N-shaped pattern, as a statistical result, due to stabilization of the GHG emission levels, or because of a recovery effect, after the initial impact of an oil shock in the 1970s. Moomaw and Unruh [39] argue that developed countries would have experienced a structural transition toward lesser GHG emissions as a consequence of the 1973 crisis, and the cubic form would be the result of adjusting the polynomial curve, not a reflection of an underlying structural relationship. Neumayer [27] agrees that the possibility of returning to a new stretch of increasing contamination holds no importance, because such an increase tends to happen outside the data range or during a final extreme, for which there are few observations. Torras and Boyce [21] argue for the consideration of a path of increasing contamination (N shaped), which could become manifest at reasonably high income levels. Economies might reach a path of increasing contamination due to a scale effect that overcomes the composition and technology effects when the margin for continuous improvement in distribution gets exhausted or when the diminishing returns on technological change reduce contamination through technology depletion. This point of view is also shared by Opschoor and Vos [40], who raise the possibility that, once the technology improvement cannot go further or becomes too expensive, net environmental degradation results from increased incomes. An adequate environment regulation policy could effectively accelerate technology changes capable of decreasing the level of contamination [21].

Methodology and data description

In this section, we propose a model of the relationship of GDPpc and other regulatory variables with GHG emissions per capita, using a data panel for 28 OECD countries during 1993–2010. Estimating models that combine time period and cross-sectional data is a frequent approach in microeconomic studies. Using econometric techniques with panel data is adequate and extremely useful if there are non-observable heterogeneities, in any specific country or during a particular time period. In our case, not every country makes decisions similarly, even if they share the same observable characteristics. Therefore, this analysis considers the existence of specific individual effects in every country, invariable over time, that affect the way every nation makes its decisions. If these latent effects exist and are not taken into account in the model, an issue arises with omitted variables, such that the estimators of the explanatory variables are biased. An important benefit of using panel data is the ability to control the specific effects in every country, whereas a cross-sectional data analysis can neither identify nor control for such individual effects.

The interpretation of a panel data model occurs through its error components. The specification of a regression with panel data is as follows:

$$Y_{it} = \alpha + X_{it}\beta + u_{it} coni = 1,...N;\ t\ = 1,\ ...,\ T, \qquad (2)$$

where i indicates the individual, which in our case is the country (cross-section); t is the time dimension; α is a scale; β offers a vector of K coefficients; and X_{it} is the i-th observation at moment t for the explicative variable K. The error term u_{it} can be broken down as follows:

$$u_{it} = \mu_i + \delta_t + e_{it}$$

The *t*component μ_i represents non-observable effects that differ between countries but not over time. The component δ_t identifies non-measurable effects that vary over time but not between countries. A third component e_{it} refers to a purely random error term. Thus, we consider an error component model, known as one way, in which $\delta_t=0$. This one-way model has three variants, depending on the use of the term μ_i:

1. The simplest case considers $\mu_i=0$: there is no non-observable heterogeneity between countries, and therefore, their behavior remains the same.

2. By attributing to μ_i a fixed and differentiated effect for every country, the linear model is the same for every country but the intercept is specific to each.

3. Treating μ_i as a random, non-observable variable allows for changes between countries but not over time.

A frequent point of contention in studies with panel data is how to treat non-observable heterogeneity, in terms of whether to presume that a random or fixed effect exists. For fixed effects, non-observable heterogeneity is incorporated into the intercept, regardless of the model, so it alters the expected value of the explained or endogenous variable [41]. The specific intercept for each country would indicate, in the case of the EKC, exogenous factors of the process of economic growth of each country that affects the environmental indicator, such as infrastructures of energy replacement or the budget for decontamination. As Greene [41] indicates, "the fixed effects model is reasonable when we can be sure that the differences between units (countries) can be interpreted as a parametric displacement in the regression function."

In the random effect model, non-observable differences get incorporated into the error term, which modifies the variance in the model. Kennedy [42] proposes that the random effects model represents an important inconvenience, because it assumes some random disruptions associated with each country or period of time that are not correlated with the other regressors, which is unlikely. If this

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correlation exists, a random effect model creates a correlation between the disturbance and the regressor, provoking a bias in the estimated coefficients. As Greene [41] warns, with such a correlation, "the treatment of random effects could be inconsistent, due to the omission of variables." To determine if the random effects model is adequate, we use a Hausman test to analyze the possible correlation between the disturbance and regressors. If the null hypothesis of no correlation holds, we may apply the random effects model, and the estimator of possible generalized least squares (GLS) is consistent and efficient [42]. We therefore propose the following equation:

$$GHGIpc_{it} = \alpha_i + \beta_1 GDP_{pc^2_{it}} + \beta_3 GDP_{pc^3_{it}} + \beta_4 PRENEW_{it} + \beta_5 EE_{pc_{it-2}} \ \beta_6 GDP_{pc_{it}} * PRENEW_{it} + \varepsilon_{it} \quad (3)$$

where:

$GHGpc_{it}$ = level of emissions of GHG, measured in millions of tonnes CO_2, per capita in country i and year t [43].

$GDPpc_{it}$ = level of income per capita measured in millions of US dollars, at current prices and current PPPs, for country i and year t [43].

$PRENEW_{it}$ = contribution of renewable energy sources to the final energy consumption for every country, measured in percentages, for country i and year t [43].

$EEpc_{it-2}$ = public expenses on RD&D for energy efficiency, per capita and measured in millions of US dollars, at current prices and current PPPs, for country i and year t – 2. This variable enters the equation with a delay of two time periods, because innovative measures, once adopted, take time to have an effect [33,43].

$GDPpc_{it} \times PRENEW_{it}$=the product of $GDPpc_{it}$ and $PRENEW_{it}$. The coefficient β_6 accompanying this variable measures the dampening effect that variable $GDPpc_{it}$ provokes has on the causal effect of the independent or exogenous variable, $PRENEW_{it}$, and the dependent or endogenous variable, $GHGpc_{it.}$

This equation includes a dampening variable, because it reflects the theoretical assumptions of the EKC model. If a seemingly causal relationship can be established between the independent variable $PRENEW_{it}$ and a response variable $GHGpc_{it}$, we also must consider the potential role of other variables, such as $GDPpc_{it}$ in our case.

Figure 4 contains path diagrams [44] for several situations that incorporate a third variable. The dampening variable alters the magnitude and/or direction of the relationship between the independent variable and the response variable, by amplifying or even inverting their causal effect. It usually reflects a stable, behavioral or contextual characteristic.

We used moderation effects to prove the causal hypotheses [45], such that an estimation of the effect of a dampening variable Z over the relationship X→Y transforms into a multiple regression equation, included along with the X and Z variables, as is the interaction variable X × Z.

$$Y=a+b\,X+c\,Z+d\,XZ+\varepsilon, \quad (4)$$

where XZ is the product of X and Z, coefficient d measures the dampening effect, and coefficient b captures the simple effect of X when Z = 0. A simple modification in the terms of Equation (4) leads to the following model

$$Y=(a+c\,Z)+(b+d\,Z)X+\varepsilon, \quad (5)$$

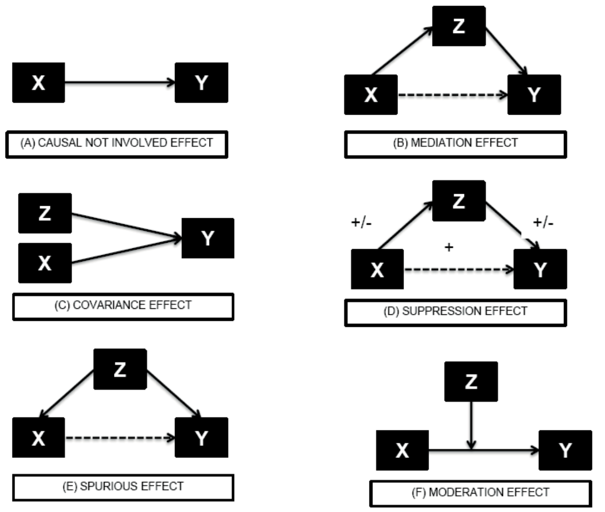

Figure 4: Path diagram of relationships incorporating a third variable

such that the first parenthetical refers to the origin and the second to the slope in the regression line of Y over X for particular values of Z. This presentation of the regression analysis is called multiple dampening regression [46], because it includes the dampening effect of Z. If no anomalies are present, rejecting the hypothesis that d=0 indicates a dampening effect of Z over the relationship X→Y.

To analyze the dampening role of variable Z, which is $GDPpc_{it}$ in our model, over X, or $PRENEW_{it}$, we estimate a linear regression model in two steps, featuring first the dependent variable and then $GHGpc_{it}$. That is, we first include only the direct effects of $PRENEW_{it}$ and $GDPpc_{it}$; then in the second step we incorporate the dampening effect of $GDPpc_{it} \times PRENEW_{it}$. Formally,

Step 1:

$$GHGIpc_{it} = \alpha_i + \beta_1 GDP_{pc_{it}} + \beta_2 GDP_{pc_{it}} + \beta_3 GDP_{pc_{it}} + \beta_4 PRENEW_{it} + \beta_5 EE_{pc_{it}} + \varepsilon_{it} \quad (6)$$

Step 2:

$$GHGpc_{it} = \alpha_i + \beta_1 GDP_{pc_{it}} + \beta_2 GDP_{pc^2_{it}} + \beta_3 GDP_{pc^3_{it}} + \beta_4 PRENEW_{it} + \beta_6 GDP_{pc_{it}} * PRENEW_{it} + \varepsilon_{it} \quad (3)$$

As suggested by [47], to substantiate whether the interaction $GDPpc_{it} \times PRENEW_{it}$ increases the explanatory power of a model that only incorporates direct effects, it is necessary to estimate its incremental power with the following F-test:

$$F\left(k_2 - k_1, N - k_2 - 1\right) = \frac{R_2^2 - R_1^2 /\ \mathrm{k}_2 - k_1}{1 - R_2^2 /\ \mathrm{N} - \mathrm{k}_2 - 1} \quad (7)$$

where $R2_2$ is the determination coefficient for the model that includes the dampening effect with k_2 variables, and $R2_1$ is the determination coefficient for the model that only includes direct effects with k_1 variables.

Finally, to check the paper that plays the public budget in energy efficiency RD&D, carried out for every country as a measure of

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technological innovation, we are going to compare the equation (3) to the equation (8), being able to see this effect by omitting the variable EEit-2 in this last equation.

$$GHGpc_{it} = \alpha_i + \beta_1 GDP_{pc_{it}} + \beta_2 GDP_{pc_{it}^2} + \beta_3 GDP_{pc_{it}^3} + \beta_4 PRENEW_{it} + \beta_6 GDP_{pc_{it}} * PRENEW_{it} + \varepsilon_{it} \quad (8)$$

Results

We first estimate Equation (3) with fixed effects for the cross-sections using a GLS method and correcting for heteroscedasticity in the cross-section. We provide the results in Table 1.

Variable	Coefficient	t-Statistic
C	13640.61***	(46.78255)
GDP_{PC}	0.175087***	(6.652198)
$GDP_{PC\wedge 2}$	-5.52E-06***	(-6.218734)
$GDP_{PC\wedge 3}$	3.59E-11***	(3.721938)
PRENEW	-226.4926***	(-15.85196)
EE_{PC}(it-2)	-0.033953***	(-3.666637)
GDP_{PC}*PRENEW	0.001926***	(6.747269)

Table 1A: Model 1, GLS, without autocorrelation correction

	Country	Effect		Country	Effect
1	Australia	11402.53	15	Korea	-3592.902
2	Austria	-709.9724	16	Luxembourg	13115.03
3	Belgium	-730.4773	17	Netherlands	-752.8087
4	Canada	10261.40	18	New Zealand	8283.067
5	Czech Republic	-130.5850	19	Norway	4524.175
6	Denmark	732.4735	20	Poland	-3392.183
7	Finland	3342.674	21	Portugal	-4483.345
8	France	-4389.840	22	Slovak Republic	-4666.227
9	Germany	-1493.321	23	Spain	-5081.748
10	Greece	-2853.909	24	Sweden	-2179.152
11	Hungary	-6521.241	25	Switzerland	-4390.134
12	Ireland	2167.013	26	Turkey	-7375.579
13	Italy	-4507.509	27	United Kingdom	-3248.558
14	Japan	-3905.292	28	United States	10576.42

Table 1B: Effects Specification: Cross-section fixed (dummy variables)

R-squared	0.988065	Adjusted R-squared	0.987275
F-statistic	1249.383***	Durbin-Watson stat	0.568348

Dependent Variable: GHGPC
Method: Panel EGLS (Cross-section weights)
Sample (adjusted): 1992 2010. Periods included: 19
Cross-sections included: 28 Total panel (balanced) observations: 532
Linear estimation after one-step weighting matrix
Cross-section weights (PCSE) standard errors and covariance (d.f. corrected)

Table 1C: Weighted Statistics

Effects Test	Statistic	d.f.	Prob.
Cross-section F	1301.656837	(27.498)	0.0000
Correlated Random Effects - Hausman Test.			
Test Summary	**Chi-Sq. Statistic**	**Chi-Sq. d.f.**	**Prob.**
Cross-section random	18.950517	6	0.0042

Table 2: Fixed effects tests, with cross-section fixed effects

The estimated equation, applied to the maximum likelihood test for the redundancy of fixed effects, checked if the fixed effects in 28 countries can be considered the same; it also was applied to the Hausman test to discern if the better model was a fixed or random effects one.

The results appear in Table 2 and confirm that the fixed effects model is the best option. The Hausman test rejects the hypothesis that individual effects are correlated with explicative variables at 95%, because the p-value equals 0.004. The maximum likelihood test for the redundancy of fixed effects confirms that fixed effects in the countries are different at more than a 99% likelihood.

After determining that Equation (3) must be estimated as a fixed effects model, we next checked if the interaction term (GDPPC × PRENEW) increased the explanatory power of the model compared with a model that included only direct effects. Therefore, we estimated Equations (3) and (6) and calculated the F-test proposed by [47]. We provide the results of the estimated equations and the value of the F-test in Table 3.

The F-test results [47] indicate that Model 1, which includes the interactive effect of GDPpct over PRENEWt (GDPPC × PRENEW) significantly increases the explanatory power of the model ($p<.05$) compared with a model that only incorporates the direct effects of GDPpct and PRENEWt on GHGpct.

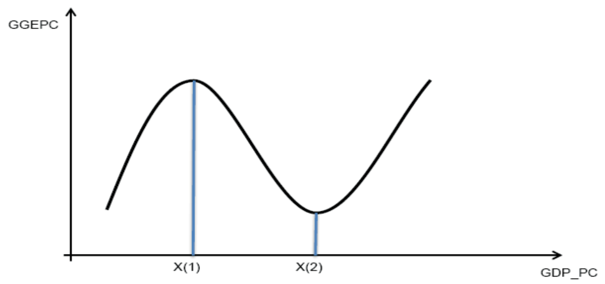
We also corrected the estimated model (Table 4) by introducing a type 1 autoregressive structure, AR(1), to deal with the autocorrelation issue.

Discussion of the Results

The estimation of the coefficients reveals that $\beta_1>0, \beta_2<0$, and $\beta_3>0$, indicating a cubic shape in the N-shaped EKC. In economic terms, this result indicates that during a first segment of per capita income, the level of contamination increases until income reaches a level X_1, at which the GHGpc emission level starts descending until income reaches the X_2 level, at which point it returns to a situation in which environmental destruction increases again. The coefficients β_1, β_2, and β_3 also allow us to calculate the turning points in the cubic model (Figure 5).

The estimation of the turning points for the cubic model used the following formulation [48]:

$$Xj = \frac{-\beta_2 \pm \sqrt{\beta_2^2 - 3\beta_2\beta_2}}{3\beta_2}, \forall j = 1,2 \quad (9)$$



Note: The coefficients $\beta_1>0, \beta_2<0$, and $\beta_3>0$ indicate a cubic polynomial in an N-shaped EKC. The first turning point is at per capita income X_1= \$20.813; the EKC returns to a path of increasing contamination at per capita income of X_2= \$60.353.

Figure 5: Cubic shape of the EKC for model 1, including turning points

Where X_1 represents the first breaking point and X_2 is the second. After this point, economic growth produces again an increase in the rate of environmental destruction.

On the basis of GDP per capita (US$ per capita, current prices, current PPPs), we grouped countries into categories, using the value of breakdown points X_1 ($20.813) and X_2 ($60.353). As we show in Table 5, of the 28 analyzed countries, three are below the first turning point: Turkey, Poland, and Hungary. They have not yet reached the segment of decontamination. Only Luxembourg is again in an ascending stretch, as justified by the productive structure of that country and its high level of income.

Model Main effects			Model Main Effects+ Dampening Effect		
Variable	**Coefficient**	**t-Statistic**	**Variable**	**Coefficient**	**t-Statistic**
C	13340.29***	(46.43206)	C	13640.61***	(46.78255)
GDP_{PC}	0.164359***	(6.384656)	GDP_{PC}	0.175087***	(6.652198)
$GDP_{PC\wedge 2}$	-4.63E-06***	(5.285217)	GDP_{PC}^2	-5.52E-06***	(-6.218734)
$GDP_{PC\wedge 3}$	3.26E-11***	(3.430349)	GDP_{PC}^3	3.59E-11***	(3.721938)
PRENEW	-176.7468***	(-14.39896)	PRENEW	-226.4926***	(-15.85196)
$EE_{PC(-2)}$	-0.043772***	(-4.66623)	EE_{PC}(it-2)	-0.033953***	(-3.666637)
			GDP_{PC}*PRENEW	0.001926***	(6.747269)

Effects Specification: Cross-section fixed (dummy variables)			
Weighted Statistics			
R-squared	0.987432	R-squared	0.988065
Test dampening variables			
Test Jaccard et al. [47]	**Statistic**	**Prob.**	
F(1, 524)	27.797	0.0000	

Dependent Variable: GHGPC
Method: Panel EGLS (Cross-section weights)
Sample (adjusted): 1992 2010 Periods included: 19
Cross-sections included: 28 Total panel (balanced) observations: 532
Linear estimation after one-step weighting matrix
Cross-section weights (PCSE) standard errors and covariance (d.f. corrected)

Table 3A: Model 1 estimated in two steps

Variable	Coefficient	t-Statistic
C	12875.44***	(20.65307)
GDP_{PC}	0.159404***	(3.140695)
$GDP_{PC\wedge 2}$	-5.15E-06***	(-3.428679)
$GDP_{PC\wedge 3}$	4.23E-11***	(2.934046)
PRENEW	-173.3516***	(-9.235741)
GDP_{PC}*PRENEW	0.001585**	(2.52662)
$EE_{PC(-2)}$	-0.027006**	(-2.073095)
$AR_{(1)}$	0.793472***	(31.57743)

Table 4A: Model 1, Autocorrelation correction

	Country	Effect		Country	Effect
1	Australia	12014.24	15	Korea	-1729.752
2	Austria	-713.2349	16	Luxembourg	9080.499
3	Belgium	-374.1385	17	Netherlands	-376.0481
4	Canada	10126.16	18	New Zealand	7549.119
5	Czech Republic	-73.50324	19	Norway	2386.024
6	Denmark	671.3640	20	Poland	-2938.868
7	Finland	3432.149	21	Portugal	-4263.669
8	France	-4274.519	22	Slovak Republic	-4535.553
9	Germany	-1287.903	23	Spain	-4319.392
10	Greece	-2126.656	24	Sweden	-2865.076
11	Hungary	-5967.128	25	Switzerland	-4687.121
12	Ireland	2512.733	26	Turkey	-7250.932
13	Italy	-3977.798	27	United Kingdom	-3222.681
14	Japan	-3318.836	28	United States	10530.52

Table 4B: Effects Specification: Cross-section fixed (dummy variables)

R-squared	0.99622	Adjusted R-squared	0.995946
F-statistic	3635.889	Durbin-Watson stat	2.028925
Inverted AR Roots	0.79		

Dependent Variable: GHGPC
Method: Panel EGLS (Cross-section weights)
Sample (adjusted): 1993 2010; Periods included: 18
Cross-sections included: 28 Total panel (balanced) observations: 504
Iterate coefficients after one-step weighting matrix
Cross-section weights (PCSE) standard errors and covariance (d.f. corrected)
Convergence achieved after 24 total coef iterations

Table 4C: Weighted Statistics

The first three coefficients β_i determine the cubic shape of the EKC; the behavior of the remaining coefficients also helps explain the GHGpc emission level. For example, β_4, which represents the substitution of traditional sources with renewable sources of energy (PRENEW), has a negative sign, indicating that as the importance of renewable energy sources increases, the level of GHGpc emissions declines. The adoption of energy regulatory measures that mandate replacing traditional sources (more polluting) with renewable sources that improves levels of environmental correction.

The coefficient β_5 has a negative sign, indicating that an increase in public budgets devoted to RD&D for improving energy efficiency also reduces the level of GHGpc emissions. This result can be interpreted in relation to the scale effect indicated by [21] to justify a cubic shape for the EKC. The variable EEPC(-2) (technological innovation) behaves like a solution to the scale effect; if progress is not achieved through technological improvements to correct environmental destruction, decreasing technological returns reestablish an upward path in the level of GHGpc emissions with respect to GDPpc. The results obtained when we incorporate public budgets devoted to RD&D in energy efficiency (EEPC(-2)) thus are compatible with our hypothesis that it is necessary to undertake measures to improve energy efficiency, whether to correct environmental destruction or prevent it. When there is a N-shaped relationship between the indicator of environmental destruction and per capita income, without measures to improve the technology and maintain technological advances with increasing returns, a point occurs at which decreasing technological returns force economies back to a state of increasing environmental destruction.

In our model, the GDP per capita is a dampening element of energy replacement, using the variable GDPPC × PRENEW. The positive sign of coefficient β_6 associated with the variable GDPPC × PRENEW indicates that energy replacement influences the level of GHGpc emissions and is affected by the income level. In other words, energy replacement is moderated by the economic cycle.

In Table 6 we isolated the effect of energy efficiency, by omitting the variable EEPC (-2), to see how the EKC behaves (Model 2) and check if the turning points adjust to the omission of the regulatory variable.

From these estimations, we first observe from the omission of the variable (EE_{PC}(-2)) that the turning points change (X_3 and X_4). As we show in Figure 6, the income requirements to reach reduced GHGpc levels decrease ($X_3<X_1$), so regulatory measures that require energy efficiency impose an initial extra cost. For the turning point of increasing contamination part, we also observe that omitting measures of RD&D dedicated to energy efficiency led to a lower income threshold ($X_4 < X_2$). Therefore, applying energy innovation measures results in a departure from the decreasing technological returns that lead to the reversion to the upward path of the EKC [21].

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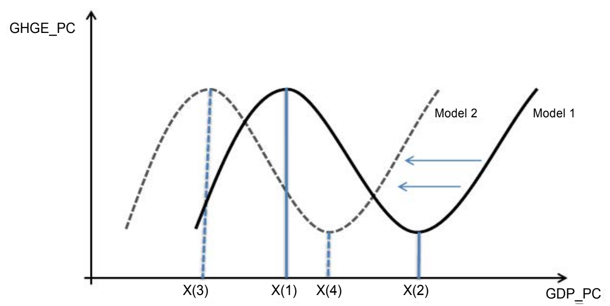
<US$20.813,1525		US$20.813,1525–US$60.353,1202		>US$60.353,1202	
Turkey	US$ 15.775,42	Slovak Republic	US$23.284,73	Luxembourg	US$ 85.583,01
Poland	US$ 20.033,79	Czech Republic	US$25.413,38		
Hungary	US$ 20.625,12	Portugal	US$25.621,68		
		Greece	US$27.539,14		
		Korea	US$28.828,80		
		New Zealand	US$29.316,82		
		Spain	US$31.573,45		
		Italy	US$32.340,58		
		Japan	US$34.088,02		
		France	US$35.413,59		
		United Kingdom	US$35.827,11		
		Finland	US$36.032,09		
		Germany	US$37.680,13		
		Belgium	US$37.834,02		
		Canada	US$39.050,29		
		Sweden	US$39.247,01		
		Austria	US$40.410,97		
		Denmark	US$40.616,16		
		Ireland	US$41.038,30		
		Australia	US$41.068,27		
		Netherlands	US$41.673,19		
		United States	US$46.614,91		
		Switzerland	US$48.700,59		
		Norway	US$57.454,48		

Table 5: Classification of countries according to income level per capita millions of US dollars, current prices, current PPPs



Model 1: X1=US$20.813, 1525; X2= US$60.353,1202
Model 2: X3=US$20.020; X4=US$59.912, 0029

Figure 6: Comparison of turning points for Models 1 and 2

The public budget in RD&D for energy efficiency is a discretionary variable, used by the agent in charge of energy regulation, so this analysis suggests that the regulating agent could maintain or increase energy RD&D policies, to avoid decreasing technological returns. According with [49] the technical effects extent to which the total effect dominate depends on the incentives faced by policy makers. In this regard Stern 2004 explains that in fast growing middle income countries, scale effect which increases pollution dominates the time related effects, which try to capture technological change both on input and output sides. On the other hand, in advanced economies, generally, growth rates are low, so that technological change may overcome the scale effect. As [50] argue, "The quality of the environment and technology are public goods, which makes government involvement necessary in order to keep a market economy in a socially optimal trajectory" [51]. Concurs, even while noting the questions remaining about a theory of growth with environmental considerations. But economic growth and policies that improve energy efficiency have positive impacts on environmental correction and simultaneously avert the part in the N-shaped form of the EKC that moves back to increasing contamination.

For its part, Table 7 shows the effect that the incorporation, or not, for the variable public budget in energy efficiency RD&D, causes on the level per capita GHG emissions, as a result of the changes that occur as a result of the unobservable characteristics of the countries i, collected by the coefficient αi of equations (3) and (8), belonging to the models 1 and 2 respectively. Thus, the average decrease of 1.5% of the set of countries, stimulated by the unique characteristics of each country, it is clear empirical evidence on the existence of a positive externality, as a result of the efforts in energy innovation undertaken.

Conclusions and Policy Implications

The relationship between income and economic inequality, which was first stated by [52], has been reinterpreted in an environmental economics literature since 1990s, under the name of Environmental Kuznets Curve (EKC). This study focuses on an analysis of the EKC and seeks to enrich existing literature by incorporating auxiliary variables associated with environmental regulation measures. Our study point out the positive effects of technological improvements on environmental quality [53].

The results of the estimated model are consistent with our hypothesis about a positive impact of RD&D measures in energy efficiency, as well as measures supporting the replacement of energy sources; have for strategies that seek to reduce contaminant emissions. Incorporating a variable that links energy replacement with economic growth reveals a dampening effect. We also confirm that the direct impact on the level of greenhouse gas emissions in 28 countries that replace traditional energy sources with renewable ones is less than might be expected, because it depends on the level of per capita income. This finding implies that in countries with a high levels per capita income, not all greenhouse gas emissions are offset by replacing traditional energy sources with renewable ones, which helps explain the N-shaped curve.

Our model illustrates the importance of environmental regulation measures for keeping countries on a decreasing path of GHGpc emissions, even when they reach high income levels. Energy efficiency can reduce the scale effect and thus avoid a return to a path of increasing contamination. Measures that encourage technological innovation can efficiently prevent the trap of falling into decreasing technological returns.

	Model 1		Model 2	
Variable	Coefficient	t-Statistic	Coefficient	t-Statistic
C	12875.44***	(-20.65307)	13051.47***	(-20.63341)
GDPPC	0.159404***	(-3.140695)	0.142859***	(-2.787977)
GDPPC^2	-5.15E-06***	(-3.428679)	-0.00000476***	(-3.142448)
GDPPC^3	4.23E-11***	(-2.934046)	3.97E-11***	(-2.726043)
PRENEW	-173.3516***	(-9.235741)	-177.2406***	(-9.415447)
EEPC(-2)	-0.027006**	(-2.073095)	-----------	
GDPPC*PRENEW	0.001585**	(-2.52662)	0.001661***	(-2.62011)
AR(1)	0.793472***	(-31.57743)	0.798384***	(-32.00162)

Table 6A: Comparison of Models 1 and 2

Country	Effect Model 1	Effect Model 2
Australia	12014.24	12048.31
Austria	-713.2349	-685.0008
Belgium	-374.1385	-351.6284
Canada	10126.16	10132.94
Czech Republic	-73.50324	-64.51851
Denmark	671.364	683.5756
Finland	3432.149	3264.315
France	-4274.519	-4258.264
Germany	-1287.903	-1252.366
Greece	-2126.656	-2081.145
Hungary	-5967.128	-6135.383
Ireland	2512.733	2486.194
Italy	-3977.798	-3950.154
Japan	-3318.836	-3362.222
Korea	-1729.752	-1697.4
Luxembourg	9080.499	9071.614
Netherlands	-376.0481	-431.3826
New Zealand	7549.119	7642.968
Norway	2386.024	2397.62
Poland	-2938.868	-2934.635
Portugal	-4263.669	-4190.479
Slovak Republic	-4535.553	-4534.448
Spain	-4319.392	-4267.3
Sweden	-2865.076	-2884.846
Switzerland	-4687.121	-4713.941
Turkey	-7250.932	-7244.756
United Kingdom	-3222.681	-3193.221
United States	10530.52	10505.55

Table 6B: Effects Specification

R-squared	0.99622	0.996181
Adjusted R-squared	0.995946	0.995913
F-statistic	3635.889***	3715.115***
Durbin-Watson stat	2.028925	2.004533

Table 6C: Weighted Statistics

Our analysis results show how advances in energy technology over the time seem to be the key of improved environmental quality. For this reason the energy policies should focus the attention toward measures of innovation to reduce the social costs that energy intensity causes on economic systems, where environmental regulations aims provide incentives for innovation and adoption of better abatement technologies. This study also point to the need for greater nuance in policy approaches aimed at energy innovation. Our results indicate that advances in energy efficiency are necessary to improve environmental quality. One of the most important results that can be driven from the EKC analysis is that correction of environmental quality cannot wait until per capita incomes rise. This study shows that pollution will not disappear automatically with economic growth. This leads us to conclude that there is a strong need for each country to develop specific policies in energy efficiency RD&D to combat environmental pollution. Future researches should focus on expanding the knowledge base requires to support policies that address the drivers of environmental degradation.

References

1. Grossman G, Helpman E (1991) Innovation and Growth in the Global Economy, MIT Press, Cambridge, MA.
2. World Commission for Environment and Development, 1987. Our Common Future, Oxford University Press.
3. EU Commission (2009) Directive 2009/28/EC of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, Official Journal of the European Union L 140, 5 June 2009, 16-47, Brussels.
4. Brock WA, Taylor MS (2004) Economic Growth and the Environment A Review of Theory and Empirics. Handbook of Economic Growth Chapter 28, suppl part Estudios de Economía Aplicada B 1749-1821.
5. Cantos JM, Balsalobre D (2011) Las energías renovables en la Curva de Kuznets Ambiental Una aplicación para España. Estudios de Economía Aplicada 29: 1-32.
6. Iwata H, Okada K, Samreth S (2010) Empirical study on the environmental Kuznets curve for CO_2 in France The role of nuclear energy. Energy Policy 38: 4057-4063.

Country	Effect Model 1 (*)	Effect Model 2 (**)	% Decrease	Country	Effect Model 1 (*)	Effect Model 2 (**)	% Decrease
Australia	24889.7	25099.8	-0.8%	Korea	11145.7	11354.1	-1.8%
Austria	12162.2	12366.5	-1.7%	Luxembourg	21955.9	22123.1	-0.8%
Belgium	12501.3	12699.8	-1.6%	Netherlands	12499.4	12620.1	-1.0%
Canada	23001.6	23184.4	-0.8%	New Zealand	20424.6	20694.4	-1.3%
Czech Republic	12801.9	12987.0	-1.4%	Norway	15261.5	15449.1	-1.2%
Denmark	13546.8	13735.0	-1.4%	Poland	9936.6	10116.8	-1.8%
Finland	16307.6	16315.8	-0.1%	Portugal	8611.8	8861.0	-2.8%
France	8600.9	8793.2	-2.2%	Slovak Republic	8339.9	8517.0	-2.1%
Germany	11587.5	11799.1	-1.8%	Spain	8556.0	8784.2	-2.6%
Greece	10748.8	10970.3	-2.0%	Sweden	10010.4	10166.6	-1.5%
Hungary	6908.3	6916.1	-0.1%	Switzerland	8188.3	8337.5	-1.8%
Ireland	15388.2	15537.7	-1.0%	Turkey	5624.5	5806.7	-3.1%
Italy	8897.6	9101.3	-2.2%	United Kingdom	9652.8	9858.2	-2.1%
Japan	9556.6	9689.2	-1.4%	United States	23406.0	23557.0	-0.6%
Average rate per countries (-1, 5%)							

Notes: (*) Effect 1 model (equation 3), reflects the level per capita GHG emissions (e.t. CO2) generated by the characteristics of each lend out, due to the public budget in energy efficiency RD&D. (**) Effect model 2 (equation 8), reflects the per capita GHG emissions (e.t. CO_2) generated by the characteristics of each lend out, without considering the public budget in energy efficiency RD&D.

Table 7: Effect of the variable EEPC in GHGpc levels due to the characteristics of the countries

7. Turner K, Hanley N (2011) Energy efficiency, rebound effects and the Environmental Kuznets Curve. Energy Economics 33: 722-741.
8. Agostini L, Padilla J (2010) La promoción de las energías renovables: La experiencia española, Electricidad Verde. Energías Renovables y Sistema Eléctrico 517-541.
9. Río PD, Labandeira X, Linares P (2009) La interacción del sistema europeo de comercio de emisiones con otros instrumentos de política. Papeles de Economía Española 121: 211-223.
10. Collado EF (2009) Energía solar fotovoltaica, competitividad y evaluación económica, comparativa y modelos, Tesis doctoral. UNED
11. Gradus R, Smulders S (1993) The trade-off between environmental care and long term growth pollution in three prototype growth models. Journal of Economics 58: 25-51.
12. Ekins P (1997) The Kuznets curve for the environment and economic growth examining the evidence. Environment and Planning A 29: 805-830.
13. Grossman G, Krueger E (1991) Environmental Impacts of a North American Free Trade Agreement. NBER Working Paper 3914.
14. Stern DI, Common MS, Barbier EB (1996) Economic growth and environmental degradation The Environmental Kuznets Curve and sustainable development. World Development 24: 1151-1160.
15. Selden T, Song D (1995) Neoclassical growth, the j curve for abatement, and the inverted u curve for pollution. Journal of Environmental Economics and Management 29: 162-168.
16. Panayotou T (1993) Empirical test and policy analysis of environmental degradation at different stages of economic development. Working Paper, 238, Technology and Environment Programme, International Labour Office, Geneva, 1993.
17. Andreoni J, Levinson A (2001) The simple analytics of the environmental Kuznets curve. Journal of Public Economics 80: 269-286.
18. Grossman G, Krueger E (1995) Economic growth and the environment. Quarterly Journal of Economics 110: 353-377.
19. Andreoni J, Levinson A (1998) The Simple Analytics of the Environmental Kuznets Curve NBER. Working Papers 6739.
20. Hettige H, Mani M, Wheeler D (2000) Industrial pollution in economic development the environmental Kuznets curve revisited. Journal of Development Economics 62: 445-476.
21. Torras M, Boyce J (1998) Income, inequality, and pollution a reassessment of the Environmental Kuznets Curve. Ecological Economics 25: 147-160.
22. Lindmark M (2002) An EKC-pattern in historical perspective: carbon dioxide emissions, technology, fuel prices and growth in Sweden 1870-1997. Ecological Economics 42: 333-347.
23. Kander A (2005) Baumol's disease and dematerialization of the economy. Ecological Economics 55: 119-130.
24. Tol RSJ, Pacala SW, Socolow RH (2009) Understanding long-term energy use and carbon dioxide emissions in the USA. Journal of Policy Modeling 31: 425-445.
25. De Bruyn S, Sander M, Heintz RJ (1999) The environmental Kuznets curve hypothesis, in Van Den Bergh, Jeroen C. J. M ,ed. Handbook of Environmental and Resource Economics, Cheltenham and Northampton, Edward Elg.
26. Panayotou T (1997) Demystifying the environmental Kuznets curve turning a black box into a policy tool. Environment and Development Economics 2: 465-484.
27. Neumayer E (1998) Is economic growth the environment's best friend? Journal of Environmental Law and Policy 2: 161-176.
28. Arrow K, Bolin B, Costanza R, Dasgupta P, Folke C, et al. (1995) Economic growth, carrying capacity, and the environment. Science 268: 520-521.
29. Stagl S (1999) Delinking economic growth from environmental degradation? A literature survey on the Environmental Kuznets Curve Hypothesis. Working Paper Series of the Research Focus Growth and Employment in Europe Sustainability and Competitiveness 6.
30. Unruh GC, Moomaw WR (1998) An alternative analysis of apparent EKC-type transitions. Ecological Economics 25: 221-229.
31. Jones L, Manuelli R (1995) A Positive Model of Growth and Pollution Controls. NBER Working Papers 5205.
32. Selden TM, Song D (1994) Environmental Quality and Development Is There a Kuznets Curve for Air Pollution Emissions? Journal of Environmental Economics and Management 27: 147-162.
33. Cantos JM, Balsalobre D (2013) Incidencia del gasto público en I+D+i energético sobre la corrección medioambiental en España. Estudios de Economía Aplicada 31: 93-126.
34. Bergh JC, Van Den JM, Nijkamp P (1994) Dynamic macro modelling and materials balance Economic environmental integration for sustainable development. Economic Modelling 11: 283-307.
35. Stokey L (1998) Are there limits to growth? International Economic Review 39: 1-31.
36. Bovenberg LA, Smulders S (1995) Environmental quality and pollution-augmenting technological change in a two-sector endogenous growth model. Journal of Public Economics 57: 369-391.
37. Verdier T (1993) Environmental pollution and endogenous growth A comparison between emission taxes and technological standards. Fondazione Eni Enrico Mattei. Discussion Paper 57.
38. Shafik N (1994) Economic development and environmental quality an econometric analysis. Oxford Economic Papers 46: 757-773.
39. Moomaw W, Unruh G (1997) Are environmental Kuznets curves misleading us? The case of CO_2 emissions. Environment and Development Economics 2: 451-463.
40. Opschoor JB, Vos HB (1989) Economic Instruments for Environmental Protection, OECD, Paris.
41. Greene WH (1999) Análisis econométrico, Prentice Hall, Madrid, 3ª edición.
42. Kennedy P (1998) A Guide to Econometrics, Blackwell Publishers.
43. OECD (2013) IEA Energy Technology RD&D Statistics, http//www.oecd.org/statistics/
44. Kenny D (1979) Correlation and causality, New York Wiley.
45. Wu AD, Zumbo BD (2008) Understanding and using mediators and moderators. Social Indicators Research 87: 367-392.
46. Aguinis H (2004) Regression Analysis for Categorical Moderators, Guilford Press, New York.
47. Jaccard J, Turrisi R, Wan C (1990) Interaction Effects in Multiple Regressions, University Paper Series on Quantitative Applications in the Social Sciences 72. Newbury Park, Sage Publications.
48. Diao X, Zeng S, Tam C, Tam V (2009) EKC analysis for studying economic growth and environmental quality a case study in China. Journal of Cleaner Production 17: 541-548.
49. Heerink N, Mulatu A, Bulte E (2001) Income inequality and the environment: aggregation bias in environmental Kuznets curves. Ecological Economics 38: 359-367.
50. Martínez M, Sánchez M (1998) Crecimiento económico y calidad medioambiental. Estudios Economía Aplicada 9: 103-118.
51. Xepapadeas A (2005) Economic growth and the environment, in K. G. Mäler, J. R. Vincent ,ed. Handbook of Environmental Economics 3: 1219-1271.
52. Kuznets S (1955) Economic growth and income inequality. American Economic Review 45: 1-28.
53. EU Commission (2006) Directive 2006/32/EC of the European parliament and of the council on energy end-use efficiency and energy services and repealing council directive 93/76/EEC. 5 April 2006.