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A decomposition of the effect of renewable energy sources regulation on CO_2 emissions in the EU-15

Abstract

A lot of emphasis is placed by the EU on developing strategies to combat climate change. Recognizing that climate change and energy policies need to be integrated, the EU has developed the climate change and energy package to achieve emission and renewable energy deployment targets. To increase the share of renewables in the energy mix the European Commission promotes a common framework described in relevant directives, coordination of efforts across countries, and the use of policy instruments to promote Renewable Energy Sources (RES). This paper is interested in the effectiveness to reduce emissions of different sources of regulation implemented to promote RES and of the directive 2001/77/EC, the first directive for the promotion of RES. Using panel data on CO_2 emissions from the EU-15 countries the authors decompose the effect on CO_2 emissions of different types of RES promoting regulation, and we differentiate between the pre- and post-directive era. After this decomposition of RES regulation to feed-in tariffs and all other measures, this paper finds that all measures have a positive effect on reducing CO_2 emissions with feed-in tariff measures exhibiting the greatest impact. The authors also find that the implementation of the directive itself has a positive effect on the reduction of CO_2 emissions.

Keywords: CO_2 emissions, fossil fuels, final energy consumption, regulation, renewable energy, feed-in tariffs, EU directive.
JEL classification: Q40, Q42, Q48.

Introduction

The EU places considerable emphasis on developing strategies to combat climate change. Recognizing that climate change and energy policies need to be integrated, the EU has developed the EU climate change and energy package and adopted regulation to achieve its ‘20-20-20’ targets, according to which by 2020 (1) GHG emissions should be reduced by 20% (compared to 1990 levels), (2) the share of renewable energy in the energy mix should be increased to 20%, and (3) energy efficiency should be increased by 20% (European Council, 2009).

Increasing the share of Renewable Energy Sources (RES) in the energy mix across European countries is considered key in reducing GHG emissions, complying with the requirements of the Kyoto protocol, and contributing to global coordinated efforts to fight climate change. An increased share of RES is anticipated to work together with promoting energy preservation and efficient energy use to achieve the target of arriving at a low carbon economy (Commission of the European Communities, 2009, p. 1). To this direction the European Commission recognizes the importance of the regulatory framework and promotes the use of a number of policy measures and instruments (Commission of the European Communities, 2009, p. 27).

The Commission acknowledges the importance of member states’ freedom to choose the instruments and mechanisms to promote the use of RES, and at the same time, the need to coordinate efforts across member states to achieve the common targets. This coordination of efforts starts with the introduction of the 2001/77/EC directive, the first directive introduced for the promotion of the use of RES in the production of energy and is supported by consecutive directives. The 2009/28/EC Directive on the promotion of the use of energy from renewable sources requires member states to submit their National Renewable Energy Action Plans, outlining their strategies to achieve common targets, including the instruments and measures that the countries will adopt to support and develop RES technology and investment (Commission of the European Communities, 2009; Jager-Walday et al., 2011). Among the different instruments used across European countries to promote the use of energy from renewable sources feed-in tariffs are the most widely used instrument among EU member states, according to the International Feed-in Cooperation (2010, p. 1). Feed-in-tariffs are used either as a primary mechanism, or as a supportive mechanism, in combination with other mechanisms, and only four member states do not use them at all as part of their policy to promote RES (International Feed-in Cooperation, 2010).

Global CO_2 emissions have been growing since 2000 (The World Bank, 2007) and are expected to continue growing (IEA, 2011). As Europe’s economy is picking up, emissions are picking up as well (EurActiv, 2011). To be able to meet the ‘20-20-20’ objective it is important to understand what is driving emissions. While a number of factors have been considered relative to this question, we believe that the effect of RES promoting regulation has been overlooked.

We build upon previous work (Alexopoulos, Thomakos & Tzavara, 2012) and look at the effect that RES regulation has on the evolution of CO_2 emissions of EU-15 countries[1]. We decompose RES regulation to feed-in tariffs and all other measures. We do this because of the popularity of feed-in-tariffs, which calls for an investigation of the effect of those on CO_2 emissions as well as for practical reasons, since there were not an acceptable number of observations for analyzing each RES promoting variable separately. All other measures include investment subsidies, quota obligations and green certificates, fiscal measures and bidding systems. Also, given the emphasis placed on a common framework for the promotion of RES, we look at the effect of the activation of the first directive to promote RES in the EU (the 2001/77/EC directive) on CO_2 emissions. We ask whether there is a relationship between different types of RES regulation and CO_2 emissions, assess the efficiency and effectiveness of the regulation on reducing CO_2 emissions and focus in particular on the effectiveness of feed-in-tariffs as well as the common regulatory framework in achieving common emission targets.

We find that both feed-in tariffs as well as the aggregate of all other measures are affecting positively the reduction of CO_2 emissions. Moreover, it appears that feed-in tariffs are more effective than the aggregate of all the other measures in reducing emissions. We also find that the common framework directive 2001/77/EC has a positive effect of reducing CO_2 emissions. In both cases, the efficacy of the instrument is dependent on the energy mix.

1. Literature review

The literature looking at factors affecting CO_2 emissions is extensive. Earlier literature starts from looking at the link between economic development and CO_2. At the center of this literature is the well-known Environmental Kuznets Curve (EKC) hypothesis, according to which emissions initially increase with output, eventually this increase slows down and then emissions decrease as output increases, so that the relationship between the two takes the form of an inverted U-curve. The literature does not always confirm the EKC, so the idea that higher economic development will put downward pressure to emissions is not a universal finding. There is a number of studies looking to confirm or reject the EKC hypothesis – see for example, Stern (2004), Dinda (2004), Dinda and Coondoo (2006), Coondoo and Dinda (2002), Managi and Jena (2008), Tamazian and Rao (2010), Jaunky (2011), Zhang (2011).

Energy consumption is a driver of economic development and at the same time economic development is key to more efficient energy consumption patterns (Wolde-Rufael, 2006; Narayan and Singh, 2007; Narayan, Narayan and Prasad, 2008; Ozturk, Alsan and Kalyoncu, 2010; Belloumi, 2008; Mehrara, 2007; Freitas and Kaneko, 2011). Given the relationship between energy consumption and economic development and the fact that economic development is a driver of CO_2 emissions, more recent literature confirms that there is a link between output, energy consumption and CO_2 emissions (Liaskas et al., 2000; Ang, 2007; Ang, 2008; Apergis and Payne, 2009; Halicioglu, 2009; Soytas and Sari, 2009, Marrero, 2010; Pao and Tsai 2010). The form of the relationship between CO_2 emissions, energy consumption and output as well as the direction of causality depends on a number of factors, such as for example, estimation methods, variables included in empirical models, the spread of data, geographical focus.

This later literature also looks at other drivers of CO_2 emissions. For example, Halicioglu (2009) looks at the impact of foreign trade, and finds that there is an effect of foreign trade on emissions, but this is of smaller magnitude compared to output and energy consumption. Liaskas et al. (2000) look at changes in the composition of the industrial sector and find that the effect of the restructuring is ambiguous and "a shift towards less energy-intensive sectors" (p. 393) does not necessarily translate to a reduction in CO_2 emissions. Liaskas et al. (2000) also include a decomposition of the energy mix in their analysis and confirm that the energy mix affects the evolution of CO_2 emissions, a result also confirmed by Marrero (2010), who also considers the effect of the energy mix on emissions. Soytas and Sari (2009) look at the link between CO_2 emissions, output and energy consumption, "controlling for gross fixed capital investment and labor" (p. 1667) in order to assess energy and environmental concerns in conjunction with growth concerns.

To the best of our knowledge, the only study which looks at the effect of RES regulation on CO_2 emissions is Alexopoulos, Thomakos and Tzavara (2012). The authors use data on emissions, on the fossil fuel mix used for energy production and the final energy consumption mix and construct a new variable to account for national regulation to promote RES in the EU-15 countries. The effect of RES regulation is

[1] We consider the EU-15 member states, before the recent enlargement of the EU, because of issues of data availability. It is important to stress out that the current discussion on environmental policy affects all of the EU-27 member states, and potential environmental gains are to be expected when RES-related regulation changes the energy mix and the CO_2 emissions to them and not just the EU-15 group. We would like to thank the unknown reviewer(s) for making a point on this issue.

captured by a binary dummy which captures the introduction of new measures in EU-15 countries and which accounts for all possible RES regulation measures. This new variable aggregates all RES promoting measures and this earlier study does not go into any investigation of effect on CO_2 emissions of different types of measures. The authors find that RES regulation does have a negative and significant effect on emissions and that this effect depends on the composition of the fuel mix. Also, the introduction of RES regulation seems to introduce some evidence of convergence on the composition of the fuel mix among the EU-15 and some evidence of divergence in terms of how energy is used across EU-15.

To our knowledge, while there is literature focusing on the mix of policies in relation to promoting penetration of RES in Europe (see for example Meyer, 2003; Haas et al., 2004; Rowlands, 2005; Held, Ragwitz and Haas, 2006; Ringel, 2006; Jacobsson et al., 2009; Jager-Waldau et al., 2011), these studies do not look at RES policies relative to achieving emission targets. Our current study builds upon our earlier study and aims to (1) decompose the effect of RES regulation into the feed-in-tariff effect and all other measures effect; and (2) look at the effect of a common policy to promote and support the use of RES for the production of energy across the EU-15 of CO_2 emissions. With this we aim to shed more light to earlier findings about the effect of RES regulation on CO_2 emissions and to inform the debate about instruments and measures used to promote the use of RES, maintaining the focus on how the mix of policy is going to help in the direction of reducing CO_2 emissions.

2. Data

In what follows we use panel data on CO_2 emissions, the fossil fuel mix used for energy production, and the final energy consumption mix for the EU-15 countries over 1980-2009 or 1990-2009 when the final energy consumption is included. We also construct three new variables on regulation pertaining to RES promotion, discussed below in more detail. These variables are constructed from individual country sources and correspond to specific regulatory measures. In this way we can examine in great detail the efficacy of different policy instruments on emissions.

The data on fossil fuel consumption mix and total CO_2 emissions for the period of 1980-2009, are available from the US Energy Information Administration (EIA, 2011). The final energy consumption data are available from Eurostat (2011). For our RES regulation variables data are derived from the German Federal Ministry for the Environment, Nature Conservation and Nuclear safety (2011) and from the Energy Research Center of the Netherlands (2011). We identify all the possible legislative actions for the promotion of renewables and categorize RES regulation into two categories. The first category includes feed-in tariffs (*RESRFIT*). The term feed-in tariff is used both for regulated, minimum guaranteed prices per unit of produced electricity to be paid to the producer, as well as for premiums in addition to market electricity prices. The second category (*RESROTH*) includes all other kinds of promotional measures, such as investment subsidies to overcome the barrier of high initial investment, fiscal measures like rebates on energy taxes, lower VAT rates, tax exemption for green funds etc., quota obligations that impose a minimum electricity production or consumption from RES and the bidding systems. Finally we construct a third variable (*DIRDUM*) that consolidates the EU 2001/77/EC directive, the first European directive for the promotion of RES, which introduces a common framework for the promotion of RES.

We put our regulation variables into binary form and we denote each one by a dummy D_{it}, which takes the value of 1 when a RES-promoting measure, of the first or the second or the third kind, becomes and stays active at year t in country i, and zero otherwise. Each dummy effectively acts as a structurally-defined sample splitting device, before and after regulation, and allows us to compare the efficacy of *RESRFIT* and *RESROTH*, as well as the common framework variable *DIRDUM*.

Our other variables are as follows. We use CO_{2it} to denote CO_2 emissions, and PC_{it}, CC_{it}, NGC_{it} and TFC_{it} to denote fossil fuel consumption per major category, i.e. petroleum, coal and natural gas consumption and their aggregate. Finally, we use TEC_{it} to denote the aggregate of the total final energy consumption from all major categories (households, industry, transport, services and other). For all the variables (except the RES dummies) we take natural logarithms and their differences (growth rates), the latter being denoted with the letter Δ in front of each variable.

Table 1 presents some summary statistics, which give a preliminary understanding on the cross country differences and the effects of the use of RES regulation in the form of feed-in tariffs, all other measures and the common framework directive. Table 1 presents country averages for the growth rates of the different variables in the analysis. It also includes results from three types of statistics: an F-test for the hypothesis of equal growth rates (F-test all) and a re-application of the same test using data before and after the implementation of the RES regulation of the three different types considered in each country.

In Table 1 we have preliminary evidence on the efficacy of RES regulation: looking at the emissions variable in column one we can see that the cross-country differences in average emissions were significant before the enactment of regulation, decomposed in *RESRFIT* and *RESROTH* but become insignificant after it. The same is the case with *DIRDUM* variable. The findings in Table 1 suggest that the role of RES regulation in achieving a common path on CO_2 emissions across the EU-15 countries is probably quite significant.

Furthermore, we find that when we look at *RESROTH* there are significant differences in the use of fossil fuel consumption across countries before the enactment of regulation but there are no such differences after, while the opposite is the case for total final energy consumption. But when we look at *RESRFIT* and *DIRDUM*, we see that the effect of cross-country differences becoming insignificant after the introduction of RES regulation carries over to total energy consumption as well as fossil fuel consumption. Note that there appears to be a stronger effect from regulation on the growth of natural gas and coal consumption but not on petroleum consumption – a result that will re-appear later in our analysis.

Table 1. Mean growth rates per country

Country	ACO_2	APC	ACC	ANGC	ATFC	AIEC
AU	0,74%	0,53%	-1,64%	1,7S%	0,31%	1,66%
BE	0,04%	0,53%	-433%	1,70%	-0,21%	0,45%
DTV	-0,93%	-1,91%	-1,24%	16,46%	-0,93%	0,5 8%
71	-0,20%	-1,01%	-0,67%	5,36%	-0.36%	0,59%
FR	-0,72%	-0,73%	-4,16%	1,96%	-0,S3%	0,75%
DE	-1,11%	-0,81%	-2,63%	0,76%	-172%	-0,35%
EL	2,27%	1,54%	3,52%	14,91%	3,02%	1,95%
IE	2,17%	2,00%	2,00%	5,90%	2,08%	2,58%
IT	0,32%	-0,81%	0,26%	3,59%	0,47%	0,62%
LUX	-0,33%	3,0S%	-10,94%	2,7S%	-0,35%	1,10%
XL	0,74%	1,33%	2,39%	0,49%	1,11%	1,08%
PI	3,02%	1,94%	6,53%	32,34%	3,29%	2,36%
ES	1,81%	1,36%	-1,30%	10,56%	1.37%	2,36%
SE	-1,63%	-1,55%	-1,44%	10,90%	-1,38%	0,12%
UK	-0,57%	-0,12%	-3.13%	2,0S%	-0.66%	0.07%
RESRFIT						
F-test all	0.03	0.03	0.01	0.00	0.05	0,11
F-test before	0,00	0,01	0.04	0,00	0.01	0.01
F-test after	0.95	0.02	0,46	0.09	0,54	0,85
RESROTH						
F-test all	0.03	0.03	0.01	0.00	0.05	0.11
F-test before	0.00	0.01	0,17	0.00	0.00	Û.S3
F-test after	0.35	0.02	0.04	0.01	0,13	0.09
DIRDUM						
F-test all	0.03	0.03	0.01	0.00	0.05	0,11
F-test before	0.01	0.01	0.01	0.00	0.01	0.04
F-test after	0,99	0.15	0.96	0.10	0.82	0.85

RES regulation appears to have a 'convergence' effect on the composition of the fuel mix across EU-15 countries, and this effect preserves whether we are looking at feed-in tariffs or at all other measures taken across countries. This is a positive effect on a common energy policy in the production mix of all the EU-15 countries, and is in-line with the results on the effects on natural gas and coal, which point towards increased substitutability effects. On the other hand, looking at energy consumption, we observe evidence of 'convergence' on final energy consumption after the introduction of both feed-in-tariffs and the common framework directive. But when we look at the aggregate of all other measures except feed-in tariffs (*RESROTH*) we find evidence of 'divergence' on final energy consumption. What this might indicate is that when we are looking at final energy consumption, the policy mix plays a role and points to the direction of further research.

3. Methodology

We next construct empirical models to assess the effects of the three kinds of regulatory measures on CO_2 emissions. We anticipate a positive effect from RES regulation on reducing CO_2 emissions – after accounting for the main sources of emissions (fossil fuel mix and the final energy consumption mix). Our decomposition of RES regulation allows us to compare different sources and approaches to regulation.

We use panel estimation methods and three different types of models, following a top-down approach via testing. For understanding better the effect on emissions we use a decomposition of the fuel mix but an aggregate for energy consumption. We use a similar methodological approach to our earlier work (Alexopoulos, Thomakos and Tzavara, 2012).

Our first model includes the D_{it} variable and the components of the fossil fuel mix, along with the interactions that capture the effects of changing regulation:

$$CO2_{it} = c_i + \delta_0 D_{it} + \gamma_1 PC_{it} + \delta_1 D_{it} PC_{it} + \gamma_2 CC_{it} + \\ + \delta_2 D_{it} CC_{it} + \gamma_3 NGC_{it} + \delta_3 D_{it} NGC_{it} + \varepsilon_{it}. \quad (1)$$

If the type of regulation has an emissions reducing effect, then we should have $\delta_j < 0$ for all j = 0, 1, 2, 3. We estimate this equation in log-levels and in log-differences using either pooled least squares (LS), fixed effects (FE) or random effects (RE), based on specification testing[1].

Our second model includes the aggregates of the fossil fuel consumption and the final energy consumption:

$$CO2_{it} = c_i + \delta_0 D_{it} + \gamma_1 TFC_{it} + \delta_1 D_{it} TFC_{it} + \\ + \gamma_2 TEC_{it} + \delta_2 D_{it} TEC_{it} + \varepsilon_{it}. \quad (2)$$

Estimation of the model and interpretation of the parameter estimates is the same as in the first model.

Finally, our third model is based on an "error correction" approach. For this, we consider two cases. In the first case we consider three variables as having a common-trend and build the single-equation component of a full system as in:

$$\Delta CO2_{it} = c_i + \delta_0 D_{it} + \alpha\left(CO2_{i,t-1} - \beta_1 TEC_{i,t-1} - \beta_2 TFC_{i,t-1}\right) + \\ \alpha_D D_{it}\left(CO2_{i,t-1} - \beta_{1D} TEC_{i,t-1} - \beta_{2D} TFC_{i,t-1}\right) + \varepsilon_{it}. \quad (3a)$$

The cointegrating component has switching coefficients and therefore the contribution of the RES regulation can be assessed here as well: we expect that the speed-of-adjustment coefficients $\alpha < 0$ and $\alpha_D < 0$ are both negative and we have that $\alpha > \alpha + \alpha_D$, i.e. the speed of adjustment is faster after the enactment of the RES regulation. In the second approach we remove the emissions from the right-hand side and look at energy consumption and fossil fuel consumption as in:

$$\Delta CO2_{it} = c_i + \delta_0 D_{it} + \alpha\left(TEC_{it} - \beta TFC_{it}\right) + \\ + \alpha_D D_{it}\left(TEC_{it} - \beta_D TFC_{it}\right) + \varepsilon_{it} \quad (3b)$$

and we interpret the coefficient in the same way as in equation (3a).

Each of the above equations is estimated three times, once using the regulation variable for *RESRFIT*, then again using the regulation variable for *RESROTH* and finally using the directive variable *DIRDUM*. We present these separate estimations but we also present results that correspond to tests of statistical significance of the differences from the use of the two measures, as well as the common framework directive. We discuss these tests in the next section.

4. Results and discussion

Our estimation results are reported in Tables 2 and 3. In Table 2 we have the results based on the model of equation (1) while in Table 3 we have the results based on the models of equations (2), (3a) and (3b). For each model we present three different, corresponding panels (where each panel corresponds to the use of the new regulation variables *RESRFIT*, *RESROTH* and *DIRDUM*, respectively).

A first direct result is that, for both the feed-in tariffs as well as for all other measures, all the interaction-term estimates, save that on petroleum consumption, are negative and statistically significant. That is, the estimates of the parameters $\hat{\delta}_0, \hat{\delta}_2, \hat{\delta}_3$ are all negative, as required for an emissions-reducing effect. In the case of the common framework directive, $\hat{\delta}_0, \hat{\delta}_2$ are negative and significant and the natural gas interaction estimate is positive but very close to zero. In all three cases, our RES variables put upward pressure to emissions through the use of petroleum. What this says is that the fuel mix plays an important role in determining the effectiveness of RES regulation towards achieving emissions targets. One important fact is that petroleum takes a larger share of fossil fuel consumption (World Resources Institute, 2006) and that among fossil fuels, world subsidies to oil consumption in 2010 were almost double of those for coal and natural gas combined (IEA, 2011). The latter suggests that if RES are to play a role in achieving emission targets, then policy promoting RES should work hand-in-hand with energy policy.

Second, in Table 2 the magnitude of the estimates of petroleum consumption are larger than the combined magnitude of coal and natural gas consump-

[1] In FE and pooled LS estimation we use GLS with cross-section weights or cross-section SUR weights. In all estimations we report robust standard errors.

tion, i.e. we see that $\hat{\gamma}_1 > \hat{\gamma}_2 + \hat{\gamma}_3$. Third, in Table 2, the combined estimates of the parameters after RES regulation are either zero or slightly positive, i.e. we see that $\hat{\delta}_1 + \hat{\delta}_2 + \hat{\delta}_3 \approx 0$. Note that the effect of the feed-in tariffs (panel A) is larger in magnitude than the effect of all other regulation measures (panel B). This effect is also larger in magnitude than the combined effect of our previous work, where RSE regulation was aggregated in one variable, showing the importance and efficacy of feed-in tariffs. A formal test (not presented here) shows that in the presence of the feed-in tariffs the effect of the other regulation measures becomes insignificant. Also, if we compare the effect of the common framework directive (panel C) with that of our previous work where all RES promoting measures were combined in one variable (Alexopoulos, Thomakos and Tzavara, 2012) we find that it is larger in magnitude than that of the combined RES measure.

The results are the following. The presence of the any RES regulation measure as well as the directive contributes to a fixed reduction in the level of emissions. Furthermore, RES regulation reduces or keeps (almost) unchanged in the case of *DIR-DUM*, the marginal contribution of the use of coal and natural gas. However, the marginal contribution to emissions from the use of petroleum is increased and all estimates are still positive after the RES regulation enactment (either in the form of feed-in tariffs or in the form of all other measures, or in the form of the common framework directive). Note how this last result on the effect of petroleum is relevant to our earlier discussion surrounding Table 1.

Table 2. Estimation results for equation (1)

Panel A: *RESRFIT*				
Explanatory variables		FE in levels	LS in diff/s	RE in levels
c	Estimate	-3,65	0,00	-2,27
	t-statistic	-13,01	1,21	--4,82
D	Estimate	-18,00	0,00	-0,36
	t-statistic	-3,60	0,72	-4,46
PC or ΔPC	Estimate	0,57	0,44	0,44
	t-statistic	22,54	11,33	9,45
$D \times PC$ or $D \times \Delta PC$	Estimate	0,10	0,10	0,13
	t-statistic	8,75	1,28	7,32
CC or ΔCC	Estimate	0,20	0,22	0,18
	t-statistic	23,91	17,92	17,08
$D \times CC$ or $D \times \Delta CC$	Estimate	-0,07	-0,02	-0,07
	t-statistic	-12,87	-1,10	-7,82
NGC or ΔNGC	Estimate	0,049	0,03	0,07
	t-statistic	12,47	3,57	10,74
$D \times NGC$ or $D \times \Delta NGC$	Estimate	-0,02	-0,00	-0,03
	t-statistic	-4,10	-0,77	-3,57
Tests and diagnostics				
$N \times T$		423	408	423
R^2		0,99	0,47	0,78
$S = D \times PC + D \times CC + D \times NGC$ or $S = D \times \Delta PC + D \times \Delta CC + D \times \Delta NGC$		0,01	0,07	0,03
p-value of test $S = 0$		0,00	0,37	0,00
p-value of test for redundant fixed effects		0,00	0,65	n.a.
p-value of test for correlated random effects		n.a.	n.a.	0,00
Panel B: *RESROTH*				
Explanatory variables		FE in levels	LS in diff/s	RE in levels
c	Estimate	-3,40	0,00	-1,55
	t-statistic	13,65	0,20	-3,67
D	Estimate	-0,14	0,00	-0,20
	t-statistic	-3,19	1,44	-3,37
PC or ΔPC	Estimate	0,53	0,39	0,36
	t-statistic	23,00	12,84	9,10
$D \times PC$ or $D \times \Delta PC$	Estimate	0,10	0,20	0,11
	t-statistic	9,13	3,20	6,98
CC or ΔCC	Estimate	0,22	0,24	0,18

Table 2 (cont.). Estimation results for equation (1)

Panel B: *RESROTH*				
	t-statistic	26,86	12,77	16,60
$D \times CC$ or $D \times \Delta CC$	Estimate	-0,07	-0,07	-0,06
	t-statistic	-9,89	-2,92	-5,49
Panel A: *RESRFIT*				
Explanatory variables		FE in levels	LS in diff/s	RE in levels
NGC or ΔNGC	Estimate	0,05	0,08	0,08
	t-statistic	11,37	4,20	13,56
$D \times NGC$ or $D \times \Delta NGC$	Estimate	-0,024	-0,05	-0,03
	t-statistic	-5,64	-3,59	-4,60
Tests and diagnostics				
$N \times T$		423	408	423
R^2		0,99	0,47	0,74
$S = D \times PC + D \times CC + D \times NGC$ or $S = D \times \Delta PC + D \times \Delta CC + D \times \Delta NGC$		0,01	0,08	0,02
p-value of test $S = 0$		0,00	0,25	0,00
p-value of test for redundant fixed effects		0,00	0,61	n.a.
p-value of test for correlated random effects		n.a.	n.a.	0,00
Panel C: *DIRDUM*				
Explanatory variables		FE in levels	LS in diff/s	RE in levels
c	Estimate	-1,97	0,00	-2,13
	t-statistic	-3,97	2,04	-4,64
D	Estimate	-0,24	-0,00	-0,24
	t-statistic	-3,67	1,90	-3,67
PC or ΔPC	Estimate	0,42	0,46	0,42
	t-statistic	8,68	12,39	9,38
$D \times PC$ or $D \times \Delta PC$	Estimate	0,09	0,02	0,09
	t-statistic	6,12	0,26	5,77
CC or ΔCC	Estimate	0,18	0,23	0,18
	t-statistic	21,03	16,52	21,77
$D \times CC$ or $D \times \Delta CC$	Estimate	-0,08	-0,05	-0,08
	t-statistic	-9,01	-2,63	-8,75
NGC or ΔNGC	Estimate	0,07	0,03	0,08
	t-statistic	8,97	5,65	8,85
$D \times NGC$ or $D \times \Delta NGC$	Estimate	0,01	0,15	0,01
	t-statistic	2,95	7,16	2,29
Tests and diagnostics				
$N \times T$		423	408	423
R^2		0,99	0,19	0,77
$S = D \times PC + D \times CC + D \times NGC$ or $S = D \times \Delta PC + D \times \Delta CC + D \times \Delta NGC$		0,02	0,13	0,02
p-value of test $S = 0$		0,00	0,11	0,00
p-value of test for redundant fixed effects		0,00	0,61	n.a.
p-value of test for correlated random effects		n.a.	n.a.	0,00

A possible explanation for the higher estimate(s) of *RESRFIT*, in comparison to that of *RESROTH*[1], is that it is the most effective measure in the reduction of CO_2 emissions. However, feed-in tariffs are also the most popular measures among European countries and that might be what is implied by our results – note though that popularity of a particular measure does not make it *ex ante* most suitable in reducing emissions. There seems to be wide agreement among many observes that feed-in tariffs are more effective in promoting RES use than other instruments and measures (Meyer, 2003; Lauder, 2004; Rowlands, 2004; Held, Ragwitz and Haas, 2006; Mendonca, 2007). Even more so, there is evidence that removing feed-in tariffs from the policy mix and leaving the promotion of renewables to other policy measures, has slowed down the development

[1] Also compared to that of the aggregate RES variable in our previous work.

of RES (Lauber, 2004; Rowlands, 2004; Mendoca, 2007). This effectiveness of feed-in tariffs in promoting the development of RES sources seems to be reflected in the evolution of CO_2 emissions as well. Being effective relative to one target (the promotion of RES), feed-in tariffs seems to be effective relative to the other target as well, resulting in a cut down of emissions.

The dynamics that we observe working together in our models are: on the one hand, increased demand for energy which maintains positive marginal rates from all fossil fuel components and, on the other hand, a marginal effect of RES regulation from the use of fossil fuels. In the case of both *RESRFIT* and *RESROTH*, we observe a reduction in the marginal effects from the use of coal and natural gas and an increase in the marginal effect from the use of petroleum. In the case of the *DIRDUM*, this reduction is only observed from the use of coal, while there is an increase in the marginal effect from the use of petroleum and a (almost) neutral effect from the use of natural gas. In order to understand the direction and magnitude of these effects, one should consider (1) the small share of RES in the production (fuel mix) and consumption of energy (Eurostat, 2011) and (2) that because of its nature, energy produced from RES is used to cover only peak energy demands while most of the base load demands are covered by thermal (fossil fuel) power stations. Thermal power stations that depend on fossil fuels are still being used to cover the higher demand for energy resulting from higher economic growth[1] and demand of higher standards of living and technology. As a result of these observations, RES regulation, be it in the form of feed-in tariffs or in the form of all other measures, is expected to reduce the *rate of increase* of CO_2 emissions before actually reducing emissions.

We turn next to the estimation results in Table 3, from our second group of models, in equations (2) and (3a), (3b). Panels A, B, C of Table 3 capture the effects of *RESRFIT*, *RESROTH* and *DIRDUM* respectively. Starting from the model in equation (2), when we estimate it in first differences, we find that while the marginal contributions, before the RES regulation enactment, from the growth rates of total fuel mix and total energy consumption are positive, those signs become negative only for total energy consumption after the RES regulation enactment (*RESRFIT*, *RESROTH*, *DIRDUM*), and in the case of *RESROTH* those marginal contributions are of equal magnitude, i.e. we find that $\hat{\delta}_1 + \hat{\delta}_2 = 0$. These opposite signs tell us that in terms of rates of change the primary effect of the different types of RES-regulation goes through the aggregate of final energy consumption and not the fuel mix consumption.

The same result comes forth for the levels estimated equation. Thus, on this (fuel and energy consumption) aggregate level, the effect of RES-regulation primarily goes through the energy demand side. This is true both for feed-in tariffs and for all other measures, as well as for the common framework directive. This is an indication that RES regulation is a driver towards more rational use of energy. The implication of this is that energy preservation and energy efficiency policies implemented in different countries should work together with RES promoting policies, as it seems that the effect of one could boost the effect of the other.

Table 3. Estimation results for equations (1), (2) and (3)[1]

Panel A: *RESRFIT*					
Explanatory variables and parameters		LS in diff/s	FE in levels	EC #1	EC #2
c	Estimate	0,00	-6,69	-0,84	0,09
	t-statistic	2,45	34,25	-3,68	10,39
D	Estimate	-0,00	-0,40	-0,48	-0,09
	t-statistic	-1,62	-9,30	-9,48	-5,86
TFC or Δ*TFC*	Estimate	0,46	0,37		
	t-statistic	23,50	6,48		
D × *TFC* or *D* × Δ*TFC*	Estimate	0,21	0,06		
	t-statistic	7,075	8,69		
TEC or Δ*TEC*	Estimate	0,51	0,70		
	t-statistic	19,48	12,10		
D × *TEC* or *D* × Δ*TEC*	Estimate	-0,14	-0,02		
	t-statistic	-3,54	-3,47		
α	Estimate			-0,38	-0,01
	t-statistic			-17,24	-10,11
α_D	Estimate			0,48	0,43
	t-statistic			9,36	4,84

[1] Results where GDP growth was included as an additional explanatory variable were discussed in our previous work.

Table 3 (cont.). Estimation results for equations (1), (2) and (3)

Panel A: *RESRFIT*					
Explanatory variables and parameters		LS in diff/s	FE in levels	EC #1	EC #2
$ß$	Estimate				0,01
	t-statistic				7,89
$ß_D$	Estimate				0,45
	t-statistic				3,29
$ß_1$	Estimate			0,17	
	t-statistic			6,72	
$ß_{1D}$	Estimate			-0,02	
	t-statistic			-3,57	
$ß_2$	Estimate			0,79	
	t-statistic			6,42	
$ß_{2D}$	Estimate			1,33	
	t-statistic			4,21	
Tests and diagnostics					
$N \times T$		285	300	285	300
R^2		0,66	0,95	0,18	0,05
$S = D \times TFC + D \times TEC$ or $S = D \times \Delta TFC + D \times \Delta TEC$		0,07	0,03	n.a.	n.a.
p-value of test $S = 0$		0,00	0,00	n.a.	n.a.
p-value of test for redundant fixed effects		0,09	n,a,	0,00	0,00
p-value of test for correlated random effects		n.a.	0,03	n.a.	n.a.
p-value of test $TFC = TEC$		0,25	0,00	n.a.	n.a.
p-value of test $ß = ß_D$ or $ß_1 = ß_{1D}$ and $ß_2 = ß_{2D}$		n.a.	n.a.	0,62	0,71
Panel B: *RESROTH*					
Explanatory variables and parameters		FE in diff/s	RE in levels	EC #1	EC #2
c	Estimate	-0,01	-6,42	-0,40	-0,59
	t-statistic	-98,55	-15,93	-0,64	1,27
D	Estimate	0,001	-0,19	-0,48	-0,10
	t-statistic	74,70	-2,707	-3,12	-1,61
TFC or ΔTFC	Estimate	0,49	0,397		
	t-statistic	519,86	10,67		
$D \times TFC$ or $D \times \Delta TFC$	Estimate	0,18	0,084		
	t-statistic	168,60	5,937		
TEC or ΔTEC	Estimate	0,70	0,65		
	t-statistic	280,28	20,96		
$D \times TEC$ or $D \times \Delta TEC$	Estimate	-0,17	-0,07		
	t-statistic	-79,80	-4,47		
α	Estimate			-0,18	-0,11
	t-statistic			-2,40	-4,15
α_D	Estimate			0,07	1,41
	t-statistic			0,16	4,50
$ß$	Estimate				-0,01
	t-statistic				-1,74
$ß_D$	Estimate				1,63
	t-statistic				3,16
$ß_1$	Estimate			0,16	
	t-statistic			0,64	
$ß_{1D}$	Estimate			-0,07	
	t-statistic			-4,10	
$ß_2$	Estimate			0,68	
	t-statistic			4,83	
$ß_{2D}$	Estimate			0,35	
	t-statistic			2,70	

Table 3 (cont.). Estimation results for equations (1), (2) and (3)

Panel B: *RESROTH*					
Explanatory variables and parameters		LS in diff/s	FE in levels	EC #1	EC #2
Tests and diagnostics					
$N \times T$		285	300	285	300
R^2		0,66	0,94	0,17	0,15
$S = D \times TFC + D \times TEC$ or $S = D \times \Delta TFC + D \times \Delta TEC$		0,00	0,01	n.a.	n.a.
p-value of test $S = 0$		0,00	0,04	n.a.	n.a.
p-value of test for redundant fixed effects		0,00	n.a.	0,00	0,00
p-value of test for correlated random effects		n,a,	0,08	n.a.	n.a.
p-value of test $TFC = TEC$		0,00	0,00	n.a.	n.a.
p-value of test $ß = ß_D$ or $ß_1 = ß_{1D}$ and $ß_2 = ß_{2D}$		n.a.	n.a.	0,14	0,76
Panel C: *DIRDUM*					
Explanatory variables and parameters		FE in diff/s	RE in levels	EC #1	EC #2
c	Estimate	-0,00	-7,07	0,04	0,01
	t-statistic	>500	-20,44	0,05	3,76
D	Estimate	-0,00	-0,17	0,19	-0,11
	t-statistic	-328	-3,80	1,73	-3,69
TFC or ΔTFC	Estimate	0,46	0,39		
	t-statistic	>500	6,50		
$D \times TFC$ or $D \times \Delta TFC$	Estimate	0,28	0,04		
	t-statistic	>500	5,15		
TEC or ΔTEC	Estimate	0,78	0,72		
	t-statistic	>500	18,76		
$D \times TEC$ or $D \times \Delta TEC$	Estimate	-0,33	-0,03		
	t-statistic	>500	-5,52		
α	Estimate			-0,23	-0,11
	t-statistic			-3,43	-4,15
α_D	Estimate			0,03	0,01
	t-statistic			1,87	3,45
$ß$	Estimate				
	t-statistic				
$ß_D$	Estimate				
	t-statistic				
$ß_1$	Estimate			0,50	
	t-statistic			1,65	
$ß_{1D}$	Estimate			0,89	
	t-statistic			2,93	
$ß_2$	Estimate			-0,05	
	t-statistic			0,21	
$ß_{2D}$	Estimate			0,20	
	t-statistic			0,77	
Tests and diagnostics					
$N \times T$		285	300	285	300
R^2		0,67	0,95	0,14	0,04
$S = D \times TFC + D \times TEC$ or $S = D \times \Delta TFC + D \times \Delta TEC$		-0,05	0,01	n.a.	n.a.
p-value of test $S = 0$		0,00	0,00	n.a.	n.a.
p-value of test for redundant fixed effects		0,00	n.a.	0,00	0,00
p-value of test for correlated random effects		n.a.	1,00	n.a.	n.a.
p-value of test $TFC = TEC$		0,00	0,00	n.a.	n.a.
p-value of test $ß = ß_D$ or $ß_1 = ß_{1D}$ and $ß_2 = ß_{2D}$		n.a.	n.a.	0,22	n.a.

Turning, finally, to the estimation results from the error correction models we can see that the emissions-reducing effect of RES-regulation goes through again, although the results are not as cohesive with the specific measures as it was with the combined measure of our earlier work. The estimates of the $\hat{\delta}_0$ terms are again negative and significant, with the exception of the *DIRDUM* in model (3a). The estimated speed-of-adjustment estimates $\hat{\alpha},\hat{\alpha}_D$ in both models are negative before the enactment of regulation but turn positive after the enactment, however, with decreased magnitude or they become less significant when we consider the individual measures. This is in contrast with our earlier results in Alexopoulos, Thomakos and Tzavara (2012), compared to the new results in Table 3 (panels A and B). This could be interpreted as some form of evidence that the dynamic adjustment (and not just the transition to new equilibrium values) towards lower levels of emissions requires a combination of regulation measures so that it can happen faster.

Conclusions

In this study we look at the effectiveness of different sources of RES promoting regulation relative to reducing CO_2 emissions. We also look at the effect of the first EU directive to promote renewable sources (2001/77/EC) on the evolution of CO_2 emissions. To do this we use data from the EU-15 countries on CO_2 emissions, the fuel mix and final energy consumption and use panel-based estimation methods. To capture the effect of RES regulation, we construct two new variables which account for all RES regulation measures taken across EU-15 countries, grouping RES regulation into two categories: (1) feed-in tariff measures; and (2) all other measures. We also construct a third variable which captures the effect of 2001/77/EC directive for the promotion of the use of RES, which introduced a common framework for the promotion of RES across European countries. This study aims at shedding more light on the question of how RES regulation affects the evolution of CO_2 emissions. There is an open debate in the literature regarding the effectiveness of different policy instruments and measures in achieving the promotion of RES. Also, RES are considered as key to the implementation of international agreements for the reduction of GHG to the direction of combating climate change (Commission of the European Communities, 2009; European Wind Energy Association, 2011). For these reasons, we believe that it is important to understand the role of RES regulation and of the different policy instruments in reducing CO_2 emissions.

To sum up, our findings that our three types of regulation to promote RES put downward pressure on CO_2 emissions, suggest that the focus of attention of EU policies on RES regulation is in the right direction. This suggests that there is need to focus research on the different aspects of how RES can affect CO_2 emissions. Some other aspects of this problem which we are investigating further to this research include a deeper look into the cross-country differences on RES-regulation, the inclusion of other explanatory variables and the generation of emission simulation scenarios based on the efficacy of RES and other types of regulation.

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