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The Impact of Renewable Energy Sources on Economic Growth and CO2 Emissions - a SVAR approach

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Abstract:

We analyze how an increasing share of Renewable Energy Sources on Electricity generation (RES-E) affects Gross Domestic Product (GDP) and Carbon Dioxide (CO2) emissions using a 3 variable Structural Vector Autoregressive (SVAR) methodology. We used a sample of four countries with different levels of economic development and social and economic structures but a common effort of investment in RES in the last decades. The period considered was 1960 to 2004. The existence of unit roots was tested to infer the stationarity of the variables. Through the impulse response functions (IRF), the SVAR estimation showed that, for all countries in the sample, except for the USA, the increasing RES-E share had economic costs in terms of GDP per capita. There was also an evident decrease of CO2 emissions per capita. The variance decomposition showed that a significant part of the forecast error variance of GDP per capita and a relatively smaller part of the forecast error variance of CO2 per capita were explained by the share of RES-E.

Key Words: *SVAR, Renewable Energy Sources, Economic Growth, CO2 Emissions*

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1. Framework

The Kyoto Protocol set targets for Greenhouse Gas (GHG) emission, particularly Carbon Dioxide (CO2), for industrialized countries. A large share of anthropogenic emissions is due to the energy sector, in concrete, due to the combustion of fossil fuels (Halicioglu, 2009; Soytas and Sari, 2009; Jaccard et al., 2003; Köhler et al., 2006)[4]. Since the Protocol, the replacement of the traditional sources for Renewable Energy Sources (RES) has appeared as a viable solution to reduce emissions, particularly in the electricity sector (Böhringer and Löschel, 2006, Neuhoff, 2005; Stocker et al., 2008). But what are the consequences for economic growth of an increasingly dependence on these sources? Are these sources really effective in reducing emissions?

To evaluate the existence and extent of economic and environmental effects of a growing dependence on RES, we take a sample of four countries with distinct economic and social structures as well as different levels of economic development: Denmark, Portugal, Spain and USA. The single country analysis allows assessing if countries with diverse geographic, economic and social conditions react differently to an increase in the RES share. We use a three variable Structural Vector Autoregressive (SVAR) model which includes the share of RES on Electricity generation (RES-E), CO2 emissions *per capita*, and GDP *per capita*.

The relationship between energy, economic growth and carbon emissions has been treated in the literature using different methodological approaches (see, for example, Payne, 2010; Ozturk, 2010; Halicioglu, 2009; Jalil and Mahmud, 2009; Bowden and Payne, 2009; Narayan et al., 2008; Erbaykal, 2008; Narayan and Prasad, 2007; Stern and Cleveland, 2004; Soytas and Sari, 2003; Ortega-Cerdà and Ramos-Martín, 2003; Aqeel and Butt, 2001;Cheng and Andrews, 1998; Stern, 1993). The results have differed significantly depending on the country, period, variables and method used for the analysis (Ozturk, 2010; Bowden and Payne, 2009; Chontanawat *et al.*, 2008). However, most studies ignored the disaggregation of energy sources, in particular, between renewable and non renewable sources. Some exceptions are Chien and Hu (2008), Sari *et al.* (2008), Chang *et al.* (2009) and Sadorsky (2009a).

To our knowledge, the SVAR methodology has never been used with the variables included in our model and for the countries under analysis.

Our results show that, except for the USA, the increasing share of RES-E had an economic cost. Notwithstanding it has been an effective measure to decrease CO2 emissions. Additionally, we tested the variables for the existence of unit roots and performed forecast error variance decomposition.

[4] According to the European Environment Agency (2008), the energy sector is responsible for about 80% of the Greenhouse Gas (GHG) emissions in Europe.

The article is organized as follows. Section II describes the model; section III depicts the sample used. The empirical results are presented in section IV. Conclusions and policy implications are presented in section V.

2. The Model

In this article we analyze the relationship between the fuel mix for electricity generation, economic growth and CO2 emissions using a SVAR methodology.

The SVAR methodology considers the interactions between all variables and its restrictions are based on economic theory or reveal information about the dynamic properties of the economy investigated. Thus, the SVAR can be used to predict the effects of specific policy actions or of important changes in the economy which is the case of a change in the energy supply mix (Narayan *et al.*, 2008; Buckle *et al.*, 2002).

Our model used Gross Domestic Product (*gdp*), CO2 emissions (*co2*) and the weight of renewable sources on total electricity generation (*rentotal*): $rentotal = \frac{ren}{ren + ther}$

Where *ren* is the electricity generated from RES (hydro power, wind power, geothermal power, photovoltaic, biomass, tidal and wave power) and *ther* is the electricity generation from non-renewable sources[5]. We use electricity because it has gained importance in the energy balances of most industrialized countries and it has a strong penetration of the RES we are interested in. Using the share of RES-E instead of the absolute value may prevent some bias: if there is a positive causality relationship from energy generation to GDP, an increase in energy generation may increase GDP regardless of the source used.

GDP is the main economic growth indicator and is used in most of the studies referred in the literature review as a proxy of income (Sadorsky, 2009a). CO2 is the most important polluting gas, being responsible for 58,8% of the GHG emissions worldwide (Halicioglu, 2009).

All variables are logarithm transformed (Apergis and Payne, 2010; Sadorsky, 2009b; Narayan *et al.*, 2008; Ewing *et al.*, 2007; Lee, 2006; Aqeel and Butt, 2001; Soytas and Sari, 2003; Brischetto and Voss, 1999) and we use the logarithmical differences as a proxy of the growing rates (Robalo and Salvado, 2008; Soytas and Sari, 2006). This guarantees that all variables are stationary.

[5] All variables come from the World Bank database. Variables specification: GDP per capita (constant prices 2000, USD); CO_2 emissions (t per capita). Since we do not have the CO_2 emissions value for 2004, we use the same value of 2003; Electricity generation from non-renewable sources per capita (coal, oil, natural gas and nuclear) (kWh per capita); Electricity generation from renewable sources per capita (hydro, wind, solar, geothermic, biomass and waste). Per capita variables permit a better and least biased comparison among countries with different population dimensions (Aqeel and Butt, 2001).

For the SVAR, 5 lags were used according to the Akaike Information Criterion (AIC). Our constraints are based on technical and empirical evidence. We assume that *gdp* does not affect *rentotal* in the short-run, meaning that *gdp* increases do not alter the energy supply mix structure. When *gdp* increases requiring additional energy generation hydro power and ther[6] respond to that necessity. We assume they increase in the same proportion. Other restrictions are based on the assumption that *co2* has no short-term effect on *gdp* and *rentotal* since there is no direct causality relation[7].

This SVAR identification corresponds to Cholesky decomposition imposing the order *rentotal*, *gdp*, *co2* (from the most to the less exogenous).

3. The Sample

The countries in our sample have different levels of economic development, social and economic structures but have shown a common effort of investment in RES in the last decades.

The USA is the largest world economy for the whole period and provides detailed and reliable data. It was the first country to liberalize its electricity market, in 1978. Besides, it exhibited a diversified electricity generation-mix, with a significant RES share.

Denmark (DK) had a remarkable economic performance through the period. It is a particular case of sustainable economic growth and one of the world's most significant cases of wind power development (Lund, 2009). Our data covers the period before and after Denmark entrance in the integrated marker pool (Nord Pool) in 2000 (Amundsen and Bergman, 2002)[8].

The Iberian Peninsula – Portugal (PT) and Spain (SP) – stands as an example of late energy market liberalization, as well as an (almost) isolated regional market due to the weak interconnections with the rest of Europe. For these countries, market structure remains critical – almost a monopoly in Portugal and a strong duopoly in Spain. Notwithstanding, the Iberian Electricity Market (MIBEL) was created and has been active since 2007. Both countries suffered severe economic growth problems and strong political and structural changes over the last decades. They are also highly dependent on fossil fuels imports.

Our annual data covered the period 1960 to 2004[9]. The implementation of the model with a reduced number of observations, in spite of suffering from limitations, was in line with other contributions (Soytas and Sari, 2009; Narayan *et*

[6] Hydro power is a peak load technology. Peaking power plants are electricity plants that generally run only when there is a high demand, known as peak demand.
[7] We are able to assume this because our period does not include the emission trade system.
[8] The Nord Pool started in 1996, with the integration of the Norwegian and Swedish power markets. In 1998 it included Finland, and in 2000, Denmark power market was integrated as well.
[9] Quarterly data would have allowed a more refined analysis including namely the influence of weather conditions and activity effects, but was unavailable for some variables.

al., 2008). This time span covered the most relevant events in the energy sector, from the creation of OPEC (Organization of the Petroleum Exporting Countries) in 1960, to the oils shocks in 1973 and 1979 and the counter-shock in 1986, as well as the energy market liberalization for all countries in our sample and the emergence of environmental concerns. It was a period characterized by high oil prices volatility leading to different fuel choice dynamics.

4. Empirical Results

4.1. Unit Root Tests

We use the Augmented Dickey-Fuller (ADF) and the Phillips-Perron (PP) tests to analyze the existence of unit roots in the variables in levels and in first difference. Although the results depend on the test used (ADF or PP) and on the trend specification we provide some generic conclusions.

Table 1. Unit Root Tests for the Series in Levels

	ADF test								PP test								
	Ct and No Trend				Ct and Trend					Ct and No Trend				Ct and Trend			
Variable	lags	t-stat	Prob		lags	t-stat	Prob		Variable	lags	t-stat	Prob		lags	t-stat	Prob	
gdp_dk	0	-2,59	0,102	**	1	-3,06	0,128	**	gdp_dk	1	-2,64	0,093	**	2	-3,44	0,059	**
gdp_pt	6	-2,50	0,123	**	5	-2,39	0,377	**	gdp_pt	2	-2,70	0,082	**	2	-1,72	0,723	**
gdp_usa	2	-1,09	0,711	**	1	-4,39	0,006	-	gdp_usa	17	-1,80	0,375	**	11	-2,37	0,389	**
gdp_es	1	-1,60	0,476	**	1	-2,59	0,289	**	gdp_es	4	-3,24	0,024	-	4	-3,61	0,041	-
co2_dk	0	-3,61	0,009	-	0	-3,35	0,072	**	co2_dk	2	-3,63	0,009	-	1	-3,35	0,071	**
co2_pt	1	-1,92	0,319	**	0	-2,11	0,527	**	co2_pt	2	-2,14	0,231	**	2	-1,94	0,618	**
co2_usa	1	-3,24	0,024	-	1	-2,89	0,177	**	co2_usa	1	-2,52	0,117	**	0	-2,07	0,547	**
co2_es	0	-3,26	0,023	-	0	-1,98	0,594	**	co2_es	3	-3,02	0,041	-	3	-1,98	0,597	**
rentotal_dk	3	-0,96	0,76	**	3	-2,46	0,34	**	rentotal_dk	5	-0,03	0,951	**	4	-2,02	0,577	**
rentotal_pt	5	-1,60	0,47	**	5	-1,06	0,92	**	rentotal_pt	3	-2,72	0,078	**	4	-3,84	0,024	-
rentotal_ USA	2	-2,10	0,25	**	0	-1,59	0,78	**	rentotal_ USA	9	-2,15	0,228	**	4	-1,42	0,841	**
rentotal_es	6	-0,53	0,87	**	6	-2,46	0,35	**	rentotal_es	4	-1,44	0,555	**	3	-3,25	0,088	**

** indicates the level of significance at 5%.

Both the ADF and the PP tests examine the null hypothesis of a unit root against the alternative hypothesis stationarity.

Optimal lag length selected using Akaike's information criterion (AIC) is given in the first column.

Table 2. Unit root tests for the series in first differences

	ADF test									PP test							
	Ct and No Trend				Ct and Trend					Ct and No Trend				Ct and Trend			
Variable	lags	t-stat	Prob		lags	t-stat	Prob		Variable	lags	t-stat	Prob		lags	t-stat	Prob	
Δgdp_dk	0	-6,30	0,000	-	0	-6,62	0,000	-	Δgdp_dk	1	-6,30	0,000	-	0	-6,62	0,000	-
Δgdp_pt	4	-2,10	0,248	**	5	-2,88	0,180	**	Δgdp_pt	3	-3,69	0,008	-	2	-4,07	0,013	-
Δgdp_usa	1	-5,18	0,000	-	1	-5,22	0,001	-	Δgdp_usa	15	-5,24	0,000	-	20	-6,25	0,000	-
Δgdp_es	0	-3,48	0,014	-	0	-3,53	0,049	-	Δgdp_es	1	-3,46	0,014	-	2	-3,45	0,058	**
Δco2_dk	3	-4,14	0,002	-	3	-4,55	0,004	-	Δco2_dk	2	-7,24	0,000	-	1	-7,57	0,000	-
Δco2_pt	0	-8,14	0,000	-	0	-8,53	0,000	-	Δco2_pt	1	-8,14	0,000	-	2	-8,61	0,000	-
Δco2_usa	0	-4,76	0,000	-	0	-4,97	0,001	-	Δco2_usa	0	-4,76	0,000	-	1	-5,01	0,001	-
Δco2_es	1	-3,34	0,019	-	0	-6,03	0,000	-	Δco2_es	4	-5,65	0,000	-	3	-6,11	0,000	-
Δrentotal_dk	2	-1,90	0,330	**	2	-1,72	0,722	**	Δrentotal_dk	4	-5,36	0,000	-	4	-5,45	0,000	-
Δrentotal_pt	1	-7,94	0,000	-	6	-6,25	0,000	-	Δrentotal_pt	3	-9,81	0,000	-	3	-9,98	0,000	-
Δrentotal_ USA	1	-5,70	0,000	-	1	-6,14	0,000	-	Δrentotal_ USA	6	-5,99	0,000	-	14	-8,38	0,000	-
Δrentotal_es	0	-8,03	0,000	-	3	-4,53	0,004	-	Δrentotal_es	3	-8,11	0,000	-	0	-8,36	0,000	-

** indicates the level of significance at 5%.

Both the ADF and the PP tests examine the null hypothesis of a unit root against the alternative hypothesis stationarity.

Optimal lag length selected using Akaike's information criterion (AIC) is given in the first column.

Generally, the tests indicate that GDP per capita has unit roots, i.e., is non stationary in levels for all countries. Since it becomes stationary after one difference, GDP *per capita* has only one unit root. This is consistent with other studies, for instance, Lee and Chang (2007). The same pattern is observed for *co2* and *rentotal*.

4.2. Impulse Response Function Analysis

The IRF shows how a residual shock to one of the innovations in the model affects the contemporaneous and future values of all endogenous variables (Robalo and Salvado, 2008). Consequently, it plots the responses of *gdp* and *co2* to a shock in *rentotal* for all countries.[10]

[10] We have also performed the test for the USA using the installed capacity instead of electricity generation and obtained similar results.

Fig. 1. Accumulated response of gdp to *rentotal*

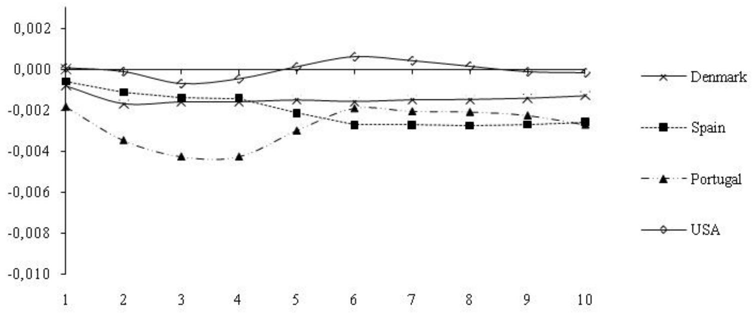
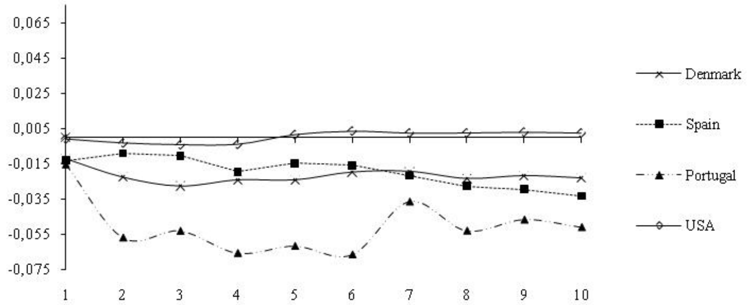


Fig.2. Accumulated response of co2 to *rentotal*



The IRF show that increasing *rentotal* generally decreases *gdp* and *co2*. *gdp* and *co2* behaviour jointly, but *co2* effects (in percent points) are more significant than *gdp* effects. Additionally, it is noticeable that countries with different characteristics respond similarly to RES-E increases.

In concrete, in the USA, a positive shock in *rentotal* decreases *gdp* and *co2*, but after 5 periods the effect becomes positive. However, this effect is always close to zero. Portugal has the strongest *gdp* and *co2* decrease until the 5th period. After the 6th period Spain has the strongest *gdp* negative effects. Spain and Denmark show close and negative responses to the positive shock on *rentotal*.

The gdp decrease may be explained by additional generation costs imposed by RES-E (except large hydro). Another possible explanation is highlighted by Robalo and Salvado (2008). They show that, for Portugal, a positive oil price shock, which may be associated with an increase in RES-E, negatively impacts *gdp*.

4.2. Impulse Response Function Analysis

The variance decomposition indicates how much of the forecast error variance of each variable can be explained by exogenous shocks (changes) to the variables in the same VAR model (Ewing *et al*., 2007). We focus on the forecast error of *gdp* and *co2*.

Table 3. Generalized forecast error variance decomposition results

		Denmark			Potugal		
		DLRENTOT	DLGDP	DLCO2	DLRENTOT	DLGDP	DLCO2
DLGDP	1	16,985	83,015	0,000	34,737	65,263	0,000
	2	32,153	67,615	0,232	36,979	62,996	0,025
	3	30,986	66,735	2,278	39,114	60,226	0,660
	4	26,806	58,263	14,931	39,018	60,226	0,755
	5	25,838	56,644	17,518	43,388	54,186	2,425
	6	24,636	55,164	20,200	45,818	51,928	2,254
	7	24,611	55,011	20,378	45,805	51,942	2,253
	8	24,613	55,013	20,375	45,537	51,643	2,820
	9	24,543	54,821	20,636	44,917	52,085	2,998
	10	24,656	54,564	20,780	45,348	51,662	2,989
DLCO2	1	7,955	6,621	85,425	5,893	8,660	85,446
	2	12,151	5,832	82,017	25,845	10,318	63,837
	3	13,125	6,048	80,828	25,150	11,526	63,325
	4	13,411	6,461	80,128	26,328	12,050	61,622
	5	12,474	6,169	81,356	26,090	12,004	61,907
	6	13,025	6,141	80,834	26,220	11,983	61,797
	7	12,857	6,373	80,770	33,446	10,845	55,709
	8	13,356	6,509	80,135	35,345	10,583	54,071
	9	13,273	6,417	80,310	35,181	10,820	53,999
	10	13,328	6,443	80,228	35,117	10,768	54,115

Table 3. Generalized forecast error variance decomposition results (cont'd)

		Spain			USA		
		DLRENTOT	DLGDP	DLCO2	DLRENTOT	DLGDP	DLCO2
DLGDP	1	9,089	90,911	0,000	0,120	99,880	0,000
	2	10,650	88,672	0,678	0,905	98,679	0,417
	3	10,059	83,629	6,313	7,998	91,164	0,838
	4	9,209	84,417	6,374	8,666	90,051	1,282
	5	14,136	80,168	5,695	14,017	83,894	2,089
	6	17,324	77,042	5,633	17,522	79,922	2,556
	7	17,217	76,568	6,215	17,772	79,461	2,767
	8	17,164	76,634	6,203	18,739	78,365	2,896
	9	17,171	76,630	6,200	19,679	77,422	2,899
	10	17,295	76,463	6,242	19,693	77,363	2,945
DLCO2	1	16,177	21,514	62,309	0,836	52,388	46,776
	2	16,349	26,006	57,645	6,910	52,914	40,175
	3	13,168	39,750	47,082	7,943	52,363	39,694
	4	16,099	43,210	40,691	7,763	50,925	41,312
	5	16,583	40,962	42,455	30,533	38,627	30,841
	6	14,365	48,966	36,669	31,464	37,835	30,701
	7	15,498	48,870	35,633	31,774	37,285	30,942
	8	16,365	49,264	34,371	31,559	37,303	31,137
	9	16,472	49,169	34,358	31,415	37,074	31,511
	10	16,760	49,237	34,002	31,496	37,100	31,404

Portugal has the largest share of gdp variation explained by rentotal, reaching over 45% after the 6th period. The other countries also show considerable values, ranging from 32% in Denmark for the second period, 17% after the 6th period in Spain and more than 19% after the 9th period in the USA. For this last country, the longer the horizon, the larger the impact of rentotal on gdp variations.

The contribution of co2 to the variation of gdp is relatively small for all countries except Denmark, where it reaches over 20% after the 6th period. In fact, for Denmark the impact of *rentotal* on *gdp* variations reaches the maximum in the second period and decreases after that as the weight of co2 increases.

Variations in *co2* are more explained for rentotal than for gdp in Portugal (reaching 35%) and Denmark (reaching 13%). On the other hand, for Spain and the USA, variations in *gdp* are the main responsible for variations in *co2*. For the USA, in the first periods after the shock, *gdp* explains over 50% of *co2* variation. Nevertheless, the longer the horizon, the larger the impact of *rentotal* on *co2* variations. The same happens for Portugal.

5. Concluding Remarks and Policy Implication

In this article we used a three variable SVAR model to study the impact of an increasing share of RES-E on GDP and CO2 emissions. The country sample was selected according to criteria related to economic performance and RES share on the electricity generation-mix.

To our knowledge, our results are not directly comparable to any other study because of the methodology used, the variables included in the model and the aim of the analysis.

The unit root tests indicate that the variables are non stationary and have one unit root. The IRF generally show that a positive shock on the *rentotal* decreased *gdp* and *co2*. It is seen that countries with different characteristics have similar responses to increases in the RES-E share. Finally, the variance decomposition showed that a significant part of the forecast error variance of GDP *per capita* and a relatively smaller part of the forecast error variance of CO2 *per capita* were explained by the share of RES-E.

An increase in the RES-E share may initially harm economic growth, except for the USA, but contribute to the CO2 emissions reduction. The Danish, Portuguese and Spanish Governments may need to complement RES support with other policies, such as demand-side management and energy conservation, in order to achieve environmental goals at the least cost. For the USA, the RES support may be least costly.

Notwithstanding, technical change is making RES cheaper and the economic cost may disappear as these sources become economically competitive. They are still being developed at the present moment and, until 2004, they were not as significant as the UE targets require.

Our results may seem controversial, but, as referred before, the results concerning the relationship between the environments, the economy and energy depend widely on the countries studied, the period covered and especially on the methodology applied.

It would be interesting to extend the period and the country sample in future research and eventually, perform a panel analysis. Nonetheless, this article provides some useful insights on the relationship between RES, economic growth and the environment.

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