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Intermittency, backup and overcapacity in wind energy:
Evidence from European countries

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Dissertação para obtenção do Grau de Mestre em
Economia
(2º ciclo de estudos)

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Resumo

Neste estudo, o excesso de capacidade instalada de energia eólica é analisado através de técnicas de dados em painel para um conjunto de 19 países Europeus entre os anos 1998 e 2009. Controlamos para o efeito das fontes convencionais de produção de energia eléctrica, nomeadamente o carvão e gás que são utilizados para *backup* na produção de electricidade quando o vento não é suficiente e a procura tem de ser satisfeita. Controlamos também para o efeito das energias renováveis. Os resultados sugerem que o crescimento de instalação de energia eólica e a densidade populacional contribuem para o aumento do excesso de capacidade de energia eólica. Por outro lado é também medido o efeito do total de políticas energéticas tomadas a nível europeu no âmbito de objectivos energéticos a longo prazo. Contribuímos para o debate sobre a intermitência das renováveis, dando luz sobre este tema e sugerindo possíveis soluções para lidar com o consequente problema do excesso de capacidade.

Palavras-chave

Energias renováveis; intermitência; excesso de capacidade; combustíveis fósseis; políticas energéticas

Resumo alargado

Neste estudo, o excesso de capacidade instalada de energia eólica é analisado através de técnicas de dados em painel para um conjunto de 19 países Europeus entre os anos 1998 e 2009. Os países escolhidos fazem parte de um conjunto de países com objectivos energéticos comuns a longo-prazo, nomeadamente no aumento da quota de energias renováveis para 20% em 2020. Os países incluídos no estudo são os que cumprem os requisitos de disponibilidade dos dados para o tempo e as variáveis em questão. Aplicamos técnicas de dados em painel pois permitem-nos uma inferência estatística mais precisa, através do aumento do número de observações e de graus de liberdade. Por outro lado permite-nos controlar para a heterogeneidade dos indivíduos e das características não observadas dos erros que não são detectáveis em modelos de séries temporais. Esta abordagem com dados em painel sobre o excesso de capacidade no âmbito da intermitência das energias renováveis é inovadora.

No sentido de analisar o excesso de capacidade de energia eólica, escolhemos variáveis de diferentes naturezas, nomeadamente: fontes convencionais de produção de energia

eléctrica; outras fontes renováveis; variáveis de natureza socio-económica; e políticas energéticas. Apesar do forte crescimento das energias renováveis nos últimos anos na Europa, as fontes convencionais de produção de energia eléctrica ainda representam grande parte do portfólio energético. As centrais termoeléctricas movidas a carvão e gás são utilizadas de forma comum para *backup* na produção de electricidade quando o vento não é suficiente e a procura tem de ser satisfeita, como por exemplo em horários de pico. Estas fontes tornam-se, assim, cruciais para ultrapassar o problema da intermitência da energia eólica. Controlamos também para o efeito da energia nuclear e do petróleo dado que também são muito importantes e utilizadas para produção diária.

Verifica-se também o efeito das outras fontes de energia renovável no excesso de capacidade, bem como o crescimento de instalação de energia eólica na contribuição para o aumento do excesso de capacidade. A densidade populacional e o PIB *per capita* são importantes variáveis de natureza socio-económica porque permitem-nos controlar, por um lado, para a dispersão das torres eólicas, dado que países com uma elevada densidade populacional tendem a ter áreas reduzidas para a colocação de eólicas, e por outro lado, controlar para o efeito do nível de vida dos países no excesso de capacidade. As políticas públicas têm sido em geral uma medida muito comum para promover o investimento em energias limpas, por isso, controlamos para o efeito do total dessas medidas nos diferentes sectores no excesso de capacidade.

Pretendemos assim responder às seguintes perguntas: qual a contribuição das fontes de energia convencionais para o excesso de capacidade de energia eólica na Europa? Como podem as políticas públicas mitigar esta ineficiência económica? A não-utilização da capacidade instalada provoca um fenómeno conhecido por excesso de capacidade, é importante conhecer e compreender formas de relativizar essa questão. Pretende-se contribuir para o debate da intermitência das energias renováveis, abordando a questão do excesso de capacidade de energia eólica, e discutindo individualmente as causas e as suas consequências da sua origem e por fim sugerir possíveis medidas para enfrentar este problema.

Após analisar como um todo os diferentes determinantes do excesso de capacidade de energia eólica, os resultados indicam-nos que os combustíveis fósseis, nomeadamente as centrais termoeléctricas movidas a carvão e gás são de facto utilizadas para *backup* na produção de energia, enquanto o petróleo e o nuclear parecem não contribuir de forma directa para esse problema. Por outro lado, é também verificado que países com uma maior densidade populacional têm maior excesso capacidade devido à falta de espaço terrestre para instalação de torres eólicas. Contrariamente, países com um nível de vida superior tem tendência a ter uma maior eficiência na produção de electricidade com energia eólica e portanto menor excesso de capacidade.

Abstract

In this paper, overcapacity of wind energy is analyzed using panel data techniques for a set of 19 European countries for the span of time 1998-2009. We control for the effect of conventional energy sources, namely coal-based and gas-fired power plants. These energy sources are mainly used to backup electricity generation in windless periods and in peak-load times. The effect of other renewable energy sources is also assessed. Results suggest that wind power growth rate and population density raises overcapacity. We also test the total of energy measures taken in Europe under long term energy goals. We extend the debate of renewables intermittency, highlighting the overcapacity issue and suggesting possible solutions to smooth out this problem.

Keywords

Renewable energy; intermittency; overcapacity; fossil fuels; and energy policies

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Acronyms list

AR1	First-order autoregressive error
CBEC	Contract balance maintenance cost
CCGT	Combined cycle gas turbine
CF	Capacity factor
CO2	Carbon dioxide
CHP	Combined heat and power
CSE	Conventional standard errors
EU	European Union
EU27	Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom.
FE	Fixed effects
GDP	Gross domestic product
GHG	Greenhouse gases
GWh	Gigawatts *per* hour
JST	Joint significance test
LM	Breusch-Pagan Lagrange multiplier test
LRT	Linear restriction test
MW	Megawatts
OECD	Organization for economic co-operation and development
OLS	Ordinary least squares
RE	Random effects
RREG	Robust regression
RSE	Robust standard errors
UK	United Kingdom
US	United States
VIF	Variance inflation factor

1. Introduction

The continuous support in renewables, particularly in Europe has raised the debate about the levels of installed capacity. It is well known that all kinds of power plants, namely renewables, can never generate 100% of their maximum capacity due to its intermittent nature. For this reason, there may be too much reserve capacity to meet the variability of electricity demand. European institutions have been making an effort in the last two decades with the goal of offering a diversified energy supply, decarbonizing its production by 20% and increasing the share of renewables to 20% until 2020 (EU directive, 2009). The literature suggests that more effort is required to meet this target, although some countries expect to over-achieve this barrier due to large growth of renewable energy (e.g. Klessman, 2011).

It is widely accepted that renewable energy, namely solar photovoltaic and wind energy, have been one of the most popular solutions in order to meet Europe goals of reducing energy dependence as well as climate change mitigation. However, with the wind energy growth arise the intermittency problem and its socio-economic impact. As a consequence, this issue requires detailed studies due to its quality problems, such as variations in frequency or voltage drops as well as balance issues (Camadan, 2011). Estimating properly the impacts and costs of wind in the energy system is important when planning high penetration levels of wind power (Holttinen et al., 2006). In a European context with large long-term energy goals, the analysis of renewables non-constant production issue is essential for economic players. It is far from new that energy storage costs are still very high, thus not allowing a profound upgrading in the energy grid (Beaudin et al., 2010). Often, the price volatility of raw materials still has strong influence in electricity generation, thus it is important that policymakers focus their efforts to ensure supply security (Bhattacharyya, 2009). Therefore, it becomes necessary to combine other energy sources to backup electricity production from renewables. In order to keep constant energy supply, fossil fuels plants have advantageous start-up and shutdown characteristics, despite its high maintenance costs, and are an effective way to mitigate renewables intermittency (Luickx et al., 2008).

The difference between maximum capacity in full-time generation and the electricity actually generated in a given period of time causes idle capacity. This issue arises for both renewables due to their intermittency nature, as well as for other conventional sources because they lose importance in energy portfolio. We will focus on wind power overcapacity. Boccard (2009), Fiedler and Bukovsky (2011) and Yang et al. (2012) already addressed this issue and argued that wind energy generation in a year rarely exceeds 25% of its maximum capacity, and therefore we can be in the presence of wind overcapacity due to wind farms idleness. This ratio of the realized electricity output by the maximum capacity is the capacity factor (CF). The energy demand volatility throughout the day, especially the gap in off-peak and peak-load periods is a key factor for this issue. Idle capacity can lead to additional investment into two components: (i) pumped hydro during periods when there is wind overproduction and low grid consumption, and (ii) thermal plants such as coal-based or gas-fired power plants, to backup power when there is lack of wind (Luickx et al., 2008). In fact, these plants may be operating inefficiently, supporting wind power while consumers have to support the secure energy supply costs and Contract Balance Maintenance Costs (CBMC). Systems based on fossil fuels are subsidized for their non-use leading to rising prices to the final consumer.

Although the literature concerning renewables intermittency both from theoretical and case studies is vast, it has not been much focused on appraise of the wind overcapacity and, above all, on the empirical assessment of the overcapacity causes. As consequence, the main aim of this paper is to provide empirical evidence on the drivers that contribute to explain wind power overcapacity. Our objective is to analyze the causes of wind overcapacity. In particular, we will test for its interaction with other energy sources as well as socio-economic drivers and energy measures. This approach is useful to highlight and draw attention of policy makers to the possible wind overcapacity due to intermittent nature of renewables. For this, we address this issue in an innovative way, through an empirical study applying econometric techniques with a panel dataset to deal with energy and socio-economic characteristics of an economic bloc with environmental concerns and long-term energy targets. We follow to answer the question: what contribution gives conventional energy sources to the wind power overcapacity in Europe? How can public policies mitigate this economic inefficiency? The non-use of installed capacity causes a phenomenon known as overcapacity. It is important to know how to avoid this inefficiency. We contribute on the debate of the renewables intermittency addressing the issue of wind overcapacity, stating its consequences and suggest possible measures to cope this problem.

The remainder of this paper is organized as follows: Section 2 focuses on literature and the questions addressed by the research in the renewables intermittency and overcapacity debate. Section 3 characterizes data and methodology. Further, section 4 presents the results, and discussion is provided in section 5. Finally, section 6 reveals the conclusions.

2. Renewables intermittency and overcapacity: the debate

The debate focusing on the renewables intermittency issue is not new actually, but the relevance of this problem requires much more research. Authors such as Albadi and El-Saadany (2010), and Green and Vasilakos (2010) focused on analyzing the main reasons and impacts of non-constant generation of wind energy in markets with large amount of intermittent energy sources. The amount of wind energy generated varies with the natural resources available. Other authors have addressed this subject for some countries in particular. Gonzalez et al. (2004) look through the Ireland case while Gül and Stenzel (2005) discussed extensively for Scandinavia, United (UK) and United States (US).

The approach to intermittency of renewables can be made through the analysis of their capacity factor which is defined as the ratio of average plant output by the maximum possible output over a period of time, generally one year (Denholm et al., 2005). Recently, Boccard (2009) argues that capacity factors depends on: (i) the wind variability; (ii) the shadowing phenomenon which is due to the fact that wind farms compromise the distance between them to save on land cost or to group too many turbines in a limited area with high population density; and (iii) the intensive focus in subsidies policies and too much confidence in public finances may have led to a fast and inefficient wind energy deployment. It can also be observed a seasonal influence to the capacity factor (Acker et al., 2007). This corroborate the assumption of Caralis et al (2008) which analyzed the capacity factors in Greece and suggest that spatial dispersion of wind farms benefits wind power efficiency. Therefore, they concluded that the accumulation of too many wind farms, even in wider regions is not always the best solution. Several other studies regarding capacity factors are resumed by Boccard (2009). Recently, Yang et al. (2011) and Zhang and Li, (2011) analyzed the huge growth of wind power in China that was driven by three main reasons: (i) the perception that China benefits from large wind resources; (ii) the adoption of energy policies that promote incentives and subsidies for the installation of wind power; and (iii) the reduction of wind capital costs. However, this requires more attention about the efficiency of wind turbines allocation in China. In fact, one-third of wind turbines were idle because the recent wind power growth has not been proportional to electricity generation, causing a capacity factor of 16.3% between 2007 and 2010 (Yang et al., 2011).

Hereupon, it is crucial to find means to deal with wind power output variability both in short-term and long-term, in order, to improve large-scale integration of wind energy in Europe. This can be done with additional energy sources to backup power when wind is insufficient or by energy storage devices (Purvins et al., 2011). Another important subject widely discussed in literature is the need to ensure a secure energy supply using a mix of wind jointly with other energy sources, including fossil fuels. Pearce (2009) argues that a solar photovoltaic system with combined heat and power (CHP) overcomes intermittency issue in California without depending on energy storage. Moreno and Martínez-Val (2011) analyses a new scenario where thermal power plants have lost some importance in energy generation (base load) turning into backup systems to substitute renewables. These authors argued that backup with combined cycle gas turbine (CCGT) plants have to grow to 8-9 GW by 2020. Another simple and effective way to smooth wind variability is the interconnection of multiple wind energy sites through the electricity transmission grid. As more turbines are interconnected, they behave more similarly over time as a single wind farm with constant wind speed, thus allowing a constant supply of energy (Archer and Jacobson, 2007).

Regarding the impact of adopted energy policies in the renewables deployment, there are a few studies that provide empirical evidences. Carley (2009) use a variant of the fixed effects model, the fixed effect vector decomposition, and concludes that the total of energy policies in the US does not contribute significantly to the amount of electricity generated from renewable sources. However, for each additional year that a state maintains a policy, it promotes renewables energy growth. In turn, Menz and Vachon (2006) also found that there is a positive relationship between the expansion of wind energy and the adoption of energy policies that promote investment and subsidies, corroborating that this kind of measures is effective in wind installed capacity growth. Regarding European countries, there are also empirical studies that focus in this subject. Recently, Marques and Fuinhas (2012) found that in line with stated above, policies that subsidize the promotion on renewables are effective in promoting renewables. On the other hand, they found that renewables growth is partly from political will in order to meet the European targets in accordance with the EU directive 2009/28/EC.

Wind power installation is strongly influenced by a highly subsidized model based on feed-in tariffs which will last for more than 25 years as stated by Moreno and Martínez-Val (2011). Together with other drivers that promote renewables in a large scale, this creates distortions and increased costs to consumers. Nevertheless, it appears that the targets established in the Europe Agreements will be reach in most EU Member States. However, as stated above, the deployment of wind energy in Europe needs extra attention due to its intermittent nature. It leads us to idle capacity problem. For the best of our knowledge the literature lacks from empirical evidence on this subject. Therefore we consider being useful to shed some light in this question and explain this phenomenon with an innovative approach.

3. Data and methodology

In this section we present the methodology and data, their main characteristics and sources. The wind energy growth in the last decade in Europe was mainly driven by several reasons such as energy demand growth; the commitments made in the GHG reduction under the Kyoto protocol directives; improvements in renewable energy technology; and the reduction of the marginal cost of wind power generation over the past 15 years, approaching to the cost of conventional energy sources (Pechak et al., 2011). For these reasons the origin of wind power expansion in Europe was in the end of the 1990s, and early 2000s. As consequence, due to several lack of data before 1998 for almost all European countries, we work upon a panel data for the span of time 1998-2009, for the countries Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Netherlands, Norway, Poland, Portugal, Spain, Sweden and United Kingdom. These countries are part of a set that share long-term energy goals under the European directives (EU directive, 2009). However not all countries have the same observations due to sporadic missing values leading to an unbalanced panel. Luxembourg was excluded due to several missing data. The remaining countries of EU27 did not provide available data for wind power installed capacity.

Economic research using panel data techniques has some advantages over cross-sectional and time-series datasets (Hsiao, 2006). Panel data allows a more accurate statistical inference, because it gives more informative data and variability, it increases the number of observations and the degrees of freedom. Panel data allow for controlling for individual heterogeneity and unobserved characteristics of errors which are not detectable in time-series or cross-sectional models (Baltagi, 2005). It also brings to researchers a more efficient and stable economic analysis than with conventional cross-sections and time-series.

The aim of this paper is to provide empirical evidence on the drivers that contribute to explain wind power overcapacity and identify empirically the causes for a panel of 19 countries. Boccard (2009) addresses the issue of wind intermittency from the perspective of the capacity factors. We are focused on the importance of intermittency and possible wind overcapacity, but in the non-used wind capacity approach. The study requires the construction of a variable which emulates the wind overcapacity. Given that overcapacity is a concept, to make it operational, we constructed the variable *SWID*.

SWID is our dependent variable and represents the ratio of the non-used installed capacity in a year to the hypothetical maximum energy that could be produced in a year, in a continuous full-power operation. This ratio was computed from raw data, and can be done in two different ways: (i) through idle capacity and (ii) through capacity factor. Accordingly for the way (i) it comes:

$$SWID_{i,t} = \frac{IDLECAP_{i,t}}{TOTCAP_{i,t}}, \qquad (1)$$

Where IDLECAP and TOTCAP are expressed in Megawatts (MW). TOTCAP is the total of wind installed capacity. IDLECAP is computed as follows:

$$IDLECAP_{i,t} = \frac{(WINDCAP_{i,t}*8760)-(TOTENGEN_{i,t}.*1000)}{8760}, \tag{2}$$

In expressions (1) and (2) IDLECAP denotes the non-used capacity of wind power in a year. In other words, IDLECAP represents the difference between wind electricity maximum possible output during the year (8760 hours) and the amount of electricity actually produced. TOTENGEN is the total electricity generated in a year, expressed in GWh.

Regarding option (ii) SWID is also the difference between 1 and the capacity factor (CF) as follows:

$$SWID_{i,t} = 1 - CF_{i,t}, \tag{3}$$

Where capacity factor (CF) is computed as follows:

$$CF_{i,t} = \frac{TOTENGEN_{i,t}}{TOTCAP_{i,t}*8.76}, \tag{4}$$

In expressions (3) and (4) CF is the ratio of realized wind power over maximum capacity in a year. For example, for a country with 19 MW of wind power installed, with 57 GWh of electricity in a year:

$$\frac{(19*8760)-(57*1000)}{8760} \approx 12.4932 \text{ MW}$$

Wind overcapacity ratio (SWID) is given by:

$$\frac{12.4932}{19}*100 \approx 65.75\ \%$$

This indicates that 65.75% of the wind installed capacity was not used during the year, i.e., a capacity factor of 34.25%.

Average SWID values for the span of time 1998-2009 are presented in figure 1. Wind overcapacity average values are in line with capacity factors showed in Boccard (2009). It denotes that Nordic countries (e.g. Norway, Sweden, Finland, Denmark, United Kingdom and Ireland) as well as southern Europe (e.g. Portugal, Spain and Greece) have lower idle capacity values than continental countries. It can be due mainly to higher wind speeds in these regions.

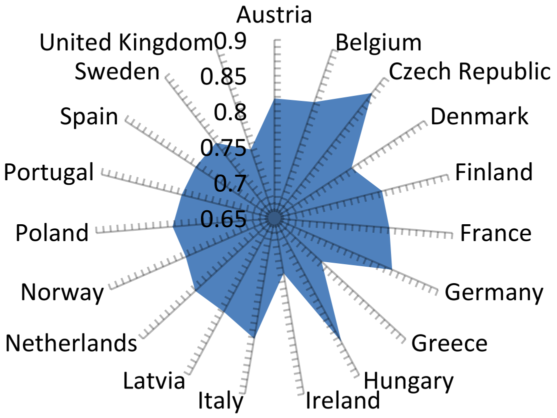

Figure 1 – Average SWID for the span of time 1998 – 2009

Since the values obtained for *SWID* are relatively high, it is surprising that this issue has not been discussed with more emphasis on literature. However, they are in line with other authors who addressed capacity factors such as Boccard (2009) and Yang et al. (2011). For example, in Denmark and Portugal, the average *SWID* is 0.7790 and 0.7840 respectively, according to (4) the CF are 0.2210 and 0.2160. This is in line with the values obtained in Boccard (2009).

The literature, especially the normative one, suggests several causes for wind idle capacity. Following closely this literature, we control for the impact of variables with different natures, namely: conventional energy sources; other renewable sources; socio-economic; and energy policies as follows:

- *Conventional energy sources*. We control for the share of fossil energy sources in total electricity generation across European countries, namely coal-based power plants (*SCOAL*), gas-fired (*SGAS*) and oil power plants (*SOIL*). These variables are largely addressed by literature (e.g. Luickx et al., 2008; Østergaard, 2008; Larraín et al., 2010; and Purvins et al., 2011) since they represent a major source to backup wind energy supply namely coal and gas-fired power plants. Gas turbine power plants are advantageous to backup wind power in windless periods because their start-up times are in the order of a few minutes while for other conventional power plants it may takes several hours (Kehlhofer et al., 2009). In some European countries, these energy sources are also largely used as base load energy production, we expect that these variables has highly significant influence on wind overcapacity. Conventional energy sources also include nuclear power. We control for the impact of nuclear capacity factor (*NUCLEARCF*) to wind overcapacity. Nuclear capacity factor was also computed according to (4). Nuclear power has great relevance in the European energy portfolio, although its capacity factor reduction by 7,9% between 1998 and 2009. The toxic residuals that comes from nuclear power and their difficult treatment as well as disaster risk has recently brings the debate to Germany on reducing its share of nuclear power in electricity generation.

- *Other renewable energy sources*. We control for the effect of capacity factor of hydropower (*HYDROCF*) in the wind idle capacity creation. Hydro capacity factor was computed according to (4). We use the capacity factors of nuclear and hydro power to avoid multicollinearity problems. As stated by Münster and Meibom (2010), to invest in industrial, municipal and renewables waste treatment is in line with the goal of increasing the share of renewables to 20%, as well with other renewables sources like solar photovoltaic. Thereby, we control the effect of waste (*SWASTE*) and solar (*SSOLAR*) shares in electricity generation to assess the influence of other renewables in wind overcapacity. We also control for the rate of growth of wind power installed capacity (*GWWIND*) to control for the new installed power plants effects over the years. We expect that a higher growth rate of wind installed capacity causes a positive effect on overcapacity. This effect is intrinsic to a greater amount of installed capacity of an intermittent energy source.

- *Socio-economic drivers*. In line with Caralis et al. (2008) and Boccard (2009) Population density (*POPDENSITY*) is referred as an important driver of wind intermittency due to its importance in the decision making process of installing new power plants and can be used as a proxy to measure the spatial dispersion of wind farms. Moreover, economic development effect of European countries can be controlled through a common driver, the natural logarithm of GDP *per capita* (*LNGDPPC*), this can control for the standard living influence on overcapacity. We expect that more developed countries have more balanced energy consumption and, in consequence, less overcapacity.

- *Energy efficiency measures and public policies*. There have been several measures taken in Europe for energy efficiency and incentives to renewables. The MURE[1] database provides the necessary information to control for the influence of energy policies in overcapacity. First we use the total of energy policies and measures carried out in a year (*TOTPOL*). We expect that the number of measures may have a positive impact in wind power overcapacity. Moreover, to assess the relationship between wind overcapacity and energy policies, we detached the total number of policies into specific types to control for the impact of each kind of energy measures. According to the MURE database, legislative/normative (*MNORMATIVE*) measures includes mandatory standards for buildings, regulation for heating systems and hot water systems, regulation in the field of building and mandatory standards for electrical appliances; legislative/informative (*MINFORMATIVE*) measures aim to inform about energy efficiency, mandatory standards in buildings and electrical appliances; fiscal/tariffs (*MFISCAL*) includes tax exemptions/reductions in retrofitting investments; financial measures through incentives/subsidies (*MFINANCIAL*) which includes feed-in tariffs, grants and loans. We expect a positive effect of these measures on *SWID*, probably due to its impact in renewables expansion and thus can contribute positively to wind idle capacity; information/education (*MEDUC*) which includes information campaigns by energy agencies

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[1] Database available at http://http://www.muredatabase.org/

and energy suppliers; co-operative measures (*MCOOP*) which includes voluntary programs and finally cross-cutting measures (*MCROSSCUT*) including Eco-tax on electricity/energy consumption or CO2 emissions as well as other eco-taxes. These measures are the cumulative amount of measures taken for household, industrial and tertiary sectors. Table 1 shows the variables, their sources and descriptive statistics.

Table 1 – Variables definition, sources and summary statistics

Variable	*Definition*	*Source*	*Obs.*	*Mean*	*SD*	*Min*	*Max*
SWID	Ratio of non-used output by the maximum possible output over a year	EUROSTAT	221	0.7956	0.0543	0.5947	0.9912
SCOAL	Ratio of elect. Gen to coal (TWh)/total elect. Gen. (TWh)	IEA	227	0.2940	0.2483	0	0.9636
SGAS	Ratio of elect. Gen to gas (TWh)/total elect. Gen. (TWh)	IEA	227	0.2161	0.1761	0.0015	0.6339
SOIL	Ratio of elect. Gen to oil (TWh)/total elect. Gen. (TWh)	IEA	227	0.0564	0.0770	0.0001	0.4243
NUCLEARCF	Ratio of average plant output by the maximum possible output over a year	IEA	228	0.4324	0.4164	0	0.9659
HYDROCF	Ratio of average plant output by the maximum possible output over a year	IEA	228	0.2884	0.1231	0.0948	0.6223
SWASTE	Ratio of elect. Gen to waste (TWh)/total elect. Gen. (TWh)	IEA	227	0.0308	0.0348	0	0.1486
SSOLAR	Ratio of elect. Gen to solar (TWh)/total elect. Gen. (TWh)	IEA	227	0.0004	0.0018	0	0.0210
GWWIND	Yearly growth rate of wind installed capacity	EUROSTAT	223	50.5234	98.1664	-7.1429	1000
POPDENSITY	Population density (people/km2)	World Bank, World Developement Indicators Database	228	139.6083	115.6765	14.5655	489.6442
LNGDPPC	Logarithm of Gross Domestic Product Per Capita	World Bank, World Development Indicator Database	228	9.7194	0.6774	7.9737	10.6431
TOTPOL	Total of Accumulated Number of RE Policies and Measures	MURE DATABASE	228	29.8553	18.9586	0	82

MNORMATIVE	Accumulated Number of RE Policies and Measures – Normative/Legislative	MURE DATABASE	228	6.9035	6.0468	0	36
MFISCAL	Accumulated Number of RE Policies and Measures – Tariff/fiscal	MURE DATABASE	221	1.0905	1.8367	0	7
MINFORMATIVE	Accumulated Number of RE Policies and Measures – Legislative/informative	MURE DATABASE	228	3.2807	3.2434	0	13
MFINANCIAL	Accumulated Number of RE Policies and Measures – Incentives/subsidies	MURE DATABASE	228	8.6754	7.0079	0	26
MEDUC	Accumulated Number of RE Policies and Measures – Educational	MURE DATABASE	228	5.5526	4.7159	0	22
MCOOP	Accumulated Number of RE Policies and Measures – Co-operative	MURE DATABASE	218	2.7456	3.0511	0	16
MCROSSCUT	Accumulated Number of RE Policies and Measures – Cross-cutting	MURE DATABASE	228	1.6404	3.5199	0	16

Notes: MURE DATABASE stands for MURE (Mesures d'Utilisation Rationnelle de l'Energie) II Database; Co-ordinated by the Institute of Studies for the Integration of Systems and the Fraunhofer Institute for Systems and Innovation Research ISI. IEA stands for International Energy Agency Data Services and EUROSTAT stands for Eurostat Statistics Database available at http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database with the code nrg_113a.

We analyzed the panel dataset structure, which generally has complex nature of terms errors composition. Several methods have been applied: (i) a visual analysis of data; (ii) test for first-order autocorrelation in panel data; (iii) test for the presence of groupwise heteroskedasticity; and (iv) contemporaneous correlation. We carry out econometric analysis using the Stata v11.2 software.

The correlation matrix (table A.1 in appendix) values suggest that correlation coefficients are low and do not suggest the existence of collinearity among the variables. Notwithstanding, we performed the Variance Inflation Factor (VIF) test for multicollinearity among variables. Individual values are below 5 for all individual tests and 2.36 for mean VIF (table A.1 in appendix), which reinforces that multicollinearity among variables is not a problem.

As part of empirical research using panel dataset techniques, it reveals accurate to perform tests in order to define which estimators are more suitable to the analysis. In accordance, several tests were conducted to detect common panel phenomena in errors structure. We implement the Wooldridge test with a normal distribution N(0,1) in Ordinary Least Squares (OLS) estimator to detect serial correlation in the idiosyncratic errors of panel-data, with the null hypothesis of no first-order autocorrelation (Wooldridge, 2002). To test the presence of groupwise heteroskedaticity modified Wald statistic was applied in the residuals of a fixed effect (FE) regression model, which assumes homoskedaticity across cross-sections. The modified Wald Test has χ^2 distribution and tests the null hypothesis of: $\sigma_i^2 = \sigma^2$

for $i = 1, \ldots, N$ where $\sigma^2$is the variance of i country, following Greene (2000). Moreover, as stated by Marques and Fuinhas (2012) if we consider that Europe countries are guided by common energy guidelines, there may be signs of contemporaneous correlation in our panel. To detect presence of contemporaneous correlation, i.e., test for cross-section independence, we apply Pesaran (2004), Frees (1995 and 2004) and Friedman (1937) statistics. Pesaran, Frees and Friedman statistics test the null hypothesis of cross-section independence; Pesaran test for cross-sectional dependence and follows a standard normal distribution; Frees statistic test uses Frees Q-distribution; Friedman uses Friedman's chi-square distributed statistic. Frees and Friedman uses only observations available for all cross-sectional units. Hausman's statistics test the null hypothesis of difference of coefficients between fixed-effects and random-effects to be not systematic.

The generic model to estimate is:

$$SWID_{i,t} = \alpha + \sum_{k=1}^{k} \beta_k X_{k,i,t} + d_t + \varepsilon_{i,t} \tag{5}$$

This model assumes that the error term is $\varepsilon_{\mathrm{it}} = \alpha_{\mathrm{i}} + \mathrm{u}_{\mathrm{i,t}}$ with α_{i} uncorrelated with the regressors and $\varepsilon_{\mathrm{it}}$ homoskedastic with no serial correlation. d_{t} is the dummy for time. Ordinary least squares estimator (OLS) reveals to be consistent when there is no presence of multicollinearity among the explanatory variables and when the regressors are exogenous. It is optimal when there is no serial auto-correlation following $V(\varepsilon) = \sigma_{\varepsilon}^2 \mid NT$ and when the error are homoscedastic following$E(\varepsilon) = 0$. Therefore, in our case it may be useful to benchmark results of our panel estimation. Moreover, we apply the panel fixed-effects (FE) and random-effects estimators (RE). Using the FE estimator appears to be appropriate in studying the impact of variables that vary over time. It explores the different variables within groups that have its own characteristics, in our case European countries. FE estimator assumes that something time-invariant within groups can affect the dependent variable and cannot be correlated with other groups. In turn, RE assumes that variation across groups is random and not correlated to the dependent and independent variables.

Specification tests reveal that according to the Wooldridge test value (3.48), we do not reject the null hypothesis of no first-order autocorrelation; therefore it is not appropriate to apply autoregressive (AR1) estimator. Modified Wald test value (749.41) suggests rejection of the null hypothesis of errors homoscedasticity within cross-sections; therefore we are in the presence of errors heteroskedasticity. What concerns to the presence of contemporaneous correlation, with exception to the Pesaran's test for random-effects, generally the null hypothesis of no contemporaneous correlation was not rejected, suggesting that there is no presence of cross-sectional dependence across European countries. This is not surprising given the technical nature of our research through wind overcapacity analysis and its interaction with other energy sources instead of common policy guidelines.

4. Results

To test if the RE estimator is more suitable than OLS estimator, we provide the Breusch-Pagan Lagrange multiplier (LM) test. The results from the LM test value reveals that we reject the null hypothesis of variances across groups is equal to zero, so there is a significant difference across groups, accordingly the RE estimator is more suitable than Pooled OLS. Moreover, to choose the most appropriate estimator between FE and RE, we apply the Hausman test where the null hypothesis assumes that difference in coefficients is not systematic, thus accepting RE over FE estimator (Greene, 2008). The Hausman's test value indicates that the null hypothesis is not rejected, thus the errors α_i uncorrelated with the regressors. Therefore, it seems that differences across countries have influence on SWID, and then the panel RE estimator is more appropriate than FE to our analysis.

Our estimations from pooled OLS (*I* and *II*), panel FE (*III* and *IV*) and panel RE effects (*V* and *VI*) are presented in table 2. All models are presented with conventional standard errors (CSE) and Robust Standard errors (RSE) to deal with the presence of heteroskedasticity. As further evidence of results robustness, it reveals also suitable to apply the robust regression (RREG – model *XX* in the appendix A.2) estimator to cope with possible outliers from our dataset (Huber, 1973). In models *IV* and *VI* the error term of the equation is $\varepsilon_{it} = \alpha_i + u_{i,t}$. It is assumed that the regressors are not correlated with α_i and therefore our reference model to results discussion is RE estimator (model - *VI*).

Table 2 – Regression results - Dependent Variable $SWID_{i,t}$

Ind. Variables	OLS		FE		RE	
	CSE(I)	*RSE(II)*	*CSE(III)*	*RSE(IV)*	*CSE(V)*	*RSE(VI)*
$SCOAL_{i,t}$	-0.0402** (0.0161)	-0.0402** (0.0182)	-0.0696 (0.1264)	-0.0696 (0.0651)	-0.0381** (0.0177)	-0.0381** (0.0192)
$SGAS_{i,t}$	-0.0768*** (0.0234)	-0.0768*** (0.0255)	-0.1174 (0.1330)	-0.1174 (0.0660)	-0.0692*** (0.0253)	-0.0692*** (0.0253)
$SOIL_{i,t}$	-0.0442 (0.0479)	-0.0442 (0.0739)	-0.2819** (0.1382)	-0.2819*** (0.0673)	-0.0646 (0.0508)	-0.0646 (0.0731)
$NUCLEARCF_{i,t}$	-0.0086 (0.0101)	-0.0086 (0.0137)	0.0893 (0.0785)	0.0893 (0.0619)	-0.0070 (0.0110)	-0.0070 (0.0142)
$HYDROCF_{i,t}$	0.0118 (0.0362)	0.0118 (0.0402)	-0.1466 (0.0825)	-0.1466** (0.0621)	0.0049 (0.0386)	0.0049 (0.0415)
$SWASTE_{i,t}$	0.2878*** (0.1084)	0.2878*** (0.0836)	-0.1588 (0.3438)	-0.1588 (0.3102)	0.2666** (0.1174)	0.2666** (0.0849)
$GWWIND_{i,t}$	0.0002*** (0.0000)	0.0002*** (0.0001)	0.0002*** (0.0000)	0.0002*** (0.0001)	0.0002*** (0.0000)	0.0002*** (0.0000)

$SSOLAR_{i,t}$	1.2293 (1.8236)	1.2293 (1.0963)	1.5059 (2.0191)	1.5059 (0.8716)	1.1403 (1.8146)	1.1403 (0.9527)
$POPDENSITY_{i,t}$	0.0002*** (0.0000)	0.0002*** (0.0000)	0.0021 (0.0014)	0.0021 (0.0011)	0.0001*** (0.0000)	0.0001*** (0.0000)
$LNGDPPC_{i,t}$	-0.0300*** (0.0063)	-0.0300*** (0.0076)	0.0878 (0.0563)	0.0878 (0.0511)	-0.0290*** (0.0068)	-0.0290*** (0.0081)
$TOTPOL_{i,t}$	0.0008*** (0.0002)	0.0008*** (0.0003)	0.0009** (0.0004)	0.0009*** (0.0003)	0.0008*** (0.0002)	0.0008*** (0.0002)
CONSTANT	1.0650*** (0.0617)	1.0650*** (0.0746)	-0.2911 (0.6436)	-0.2911 (0.6077)	1.0593*** (0.0666)	1.0593*** (0.0805)
N	218	218	218	218	218	218
R2	0.4316	0.4316	0.3623	0.3623		
Wald test (χ^2)					136.63***	
F (N(0,1))	7.09***		4.82***			
LM (χ^2)					11.76***	
Hausman test (χ^2)			30.93			

Notes: OLS - Ordinary Least Squares. RE – Random Effects. FE – Fixed Effects. CSE – Conventional standard errors. RSE – Robust standard errors. Models in shading highlight RSE. The F-test has normal distribution N(0,1) and tests the null hypothesis of non-significance of all estimated parameters. The Wald test has χ^2distribution and tests the null hypothesis of non-significance of all coefficients of independent variables. LM test has χ^2 distribution and tests the null hypothesis of non-relevance of individual effects in RE model. Hausman test has χ^2distribution and test the null hypothesis of difference in coefficients to be not systematic between two selected estimators. Standard errors are reported in brackets. All estimates were controlled to include the time effects, but they are not reported for simplicity. ***, **, denote significance at 1 and 5% significance levels respectively for both coefficient estimators and test statistics.

Given the LM and Hausman test results, the most consistent and appropriate estimator is the random-effects with robust standard errors (model *VI*). Results from table 2 reveal consistency among coefficients signs, although some differences between significance levels. The effect of *SCOAL* and *SGAS* are negative and highly statistically significant. In contrast, the effect of *SOIL* does not appear to be significant. These results may reveal that overcapacity arises from intermittency, which in turn must be overcome by other electricity sources such as coal and gas to backup wind power, but oil is not usually used for this purpose, and therefore, this difference in significance of the coefficients may be a sign of our model robustness.

NUCLEARCF, *HYDROCF* and *SSOLAR* coefficients verify that there is no statistical relationship between the use of nuclear, hydro and solar energy with overcapacity of wind power. The effects of variables *GWWIND*, *POPDENSITY*, *LNGDPPC* and *TOTPOL* are positive and statistically significant and thus leading us to conclude that they are important drivers explaining wind overcapacity. Other energy policies have not been omitted. But none of them have shown a direct effect on idle capacity excepting *MNORMATIVE* and *MFISCAL*. It is important to note that we chose to not consider the legislative/informative policies because they are closely related to normative policies but in the informative side, and could create collinearity problems due to their identical nature. It is relevant to note that grants/subsidies class of policies, including feed-in tariffs for investment in renewable energy, combined heat and power plants and investment in energy efficient in build renovation have no influence in explaining idle capacity.

We provide exclusion tests for explanatory variables in which the estimators do not reveals a statistical significance and thus do not influence *SWID*. The results are shown in Appendix A.2. Indeed the models keep robustness among the estimators for all coefficients with or without disaggregated energy policies. These set of variables has no influence both on the ratio of non-used wind capacity (*SWID*) as in the remaining model. Therefore we opted to present these results in appendix due to space constraints.

5. Discussion

Renewable energy sources, namely wind and solar, are linked to the intermittency phenomenon. To deal with it, we must deeply analyze the causes and consequences of wind overcapacity. We consider that the factors may be conventional energy sources, other renewables, socio-economic and energy policies. The results allow us to explore and discuss them individually to clarify this issue and propose some policy suggestions.

For fossil fuels, two effects could be noted about their relation to wind overcapacity. It would be accurate to accept coal, gas and oil to have a positive or negative effect in wind overcapacity. It is important to note that *SOIL* can reflect the robustness of our model, because, generally, oil is not the main backup source for renewables. Therefore, we consider that the oil power plants are mainly used in base load electricity generation and have no relation with wind overcapacity. An increase in share of energy production using fossil fuels would cause a substitution effect in the electricity generation process due to less use of wind energy, in consequence idle capacity will be greater and lead to a positive effect in wind overcapacity. But in the European context, the literature (Snyder and Kaiser, 2009; and Michakal, 2011) shows us a significant wind power growth in last years.

The results show a negative effect of coal and gas shares in overcapacity, i.e., there is a decrease in wind power overcapacity as coal and gas are most frequently used. This effect may arise due to four main reasons. First, a greater use of fossil fuels as base load power generation may involve less use of wind energy and, in consequence, there may be a reduction of wind idle capacity. Second, in line with wind energy intermittency issue there is the need to ensure a stable energy supply. Therefore, when considering a higher economy dependence on fossil fuels, we assume that coal and gas power plants are mainly used to support backup of renewable energy in peak-load periods. In these periods energy production is simultaneously based on renewables and fossil fuels to supplant electricity demand, leading to wind overcapacity reduction. Note that fossil fuels power plants are capable to rapidly start-up to ensure electricity supply with high demand variations (Isla, 1999 and Luickx et al., 2008). Third, some regions still have low shares of wind power. In these regions, fossil fuels are largely used as base load production. Usually, the first sites for wind energy allocation are the most efficient ones, as they have higher wind speeds. Thus, there is greater capacity factor and in consequence an overcapacity reduction. Four, the coefficient signs sustain a lobbying effect in electricity production industry, in line with the literature (e.g. Marques et al., 2010). In fact, the lobbying effect leads to more stringent energy policies, intensifying the energy market on fossil fuels (Fredriksson et al., 2004). This effect restricts renewables growth; therefore, wind overcapacity tends to be lower, since wind power is installed in optimum sites.

Nuclear power represents a large share of electricity generation in some European countries. It allows the production of a large amount of energy in a single plant as well as cheaper than many other fossil fuels such as oil. Moreover, nuclear power cannot generate electricity according to demand needing, but rather in full-power operation (Dittmar, 2011). This supports its use in base load power generation and its widespread use in Europe. However, nuclear power cannot backup renewable energy intermittency due to limitations of the electricity generation start-up times in the short run. For these reasons, nuclear energy appears to be not statistically significant in explaining wind power overcapacity.

Regarding hydropower, as in the case of nuclear energy, there is not direct link between hydro power and wind overcapacity given the stable and mature characteristics of hydro which is primary used for base load energy production. In Europe, in 2000, the share of hydro accounted for about 23% of total energy produced, and decreased to 17% in 2009. Hydropower is a well-developed renewable energy source, with extensive use in Europe for electricity production (Balat, 2006). The technology is well developed and stable. Hydropower can be used in conjunction with wind power. In fact, wind power with pumped hydro power stations hybrid systems can be useful to meet electricity demand in peak-load periods. In low demand periods, excess electrical capacity of wind farms is used to pump water to an elevated reservoir to later be re-used and produce electricity (Dursun and Alboyaci, 2010). This could help to mitigate overcapacity effects, but the results also revealed no influence on overcapacity. As pumped-hydro system is not a common energy production source, moreover, it is not always combined with wind, thus it is acceptable that there is no direct effect of hydropower in wind overcapacity. Moreover, this energy source mainly reflects the output of large dams and small hydro that are more recently been used to backup renewables.

Solar energy deserves our attention since it is a widely used renewable energy source in Europe; however, the results show that solar energy does not reveal to be statistically significant in explaining wind overcapacity. The use of solar and wind energy simultaneously through hybrid systems of energy is an increasingly popular and advantageous solution because their integration makes them more efficient and can be integrated with conventional sources (Nema et al., 2009). Promoting such systems more especially in remote areas may be a solution in reducing idle capacity. A successful case is the recent investment in southern Spain in solar thermal plants with a capacity of 300MW at its completion in 2013. These plants use different available technologies as power towers, parabolic trough with heat storage, sterling dish and concentrated and non-concentrated solar power. With this, the power plants can operate without sunlight and with a total capacity of 7.5 hours. This may be a solution to be followed by European partners namely in regions where land space and natural resources allows this investment.

With the fast growth of wind energy installed capacity in Europe, renewables have sizeable share in the energy networks, changing the European energy paradigm (Michalak, 2011). The effect of growth rate of wind installed capacity is positive and highly significant, as expected because with the strong wind power expansion, also rises idle capacity. The share of waste is also statistically significant. In fact, with the growth of waste processing for energy production, there appears to be a substitution of wind energy. Investment in waste processing to produce electricity seams to overlap wind energy.

The efficient allocation of wind parks should be widely discussed. Accordingly, diversify wind turbines allocation can be a solution because it smooth out wind idle capacity, thus the players involved should give a special attention to this subject since the results are consistent with this assumption; there is more wind idle capacity as countries have higher population density. The installation of offshore wind farms can be a solution to deal with the constraints caused by regions with high population density. Offshore wind farms have a steadier and efficient energy production due to higher wind speeds in sea. Generally, population is more concentrated in continental areas with low wind speeds. Therefore, the offshore characteristics can help to overcome the population density effect in the overcapacity creation.

The relationship between economic development and renewables growth is also an important driver in the idle capacity analysis. In general, it is suggested that economic growth is a driver toward renewable energy expansion. However, Chang et al. (2009) concludes with a panel data analysis across all OECD countries that there is no direct relationship between economic growth and renewables development. Notwithstanding, countries with high economic growth rates in the previous year can support prices of investing in renewables. Therefore developed countries tend to invest more in renewables even though, as consequence, it increases electricity prices in the final consumer. In literature there is no consensus of the GDP impact on the renewables deployment. Furthermore, Marques et al. (2010) concluded that the effect of GDP in renewables may vary depending on the level of existing share of renewables. In this paper, we focus only in wind power overcapacity. Economic growth rate and GDP assumptions revealed to be not significant. Thus, the logarithm of GDP per capita shows a negative effect in wind overcapacity. Eventually, it proves that countries' population with highest standard living, benefits for more efficient and advanced wind power plants.

Energy measures are considered an effective method that EU Member States should implemented to increase the share of energy from renewable sources (EU directive, 2009). The literature (Gan et al., 2007; and Johnstone et al., 2010) suggests that investment incentives, incentive taxes, feed-in tariffs, voluntary programs as well as R&D policy support are the main measures that support renewables deployment. Our results show that the total of energy policies contributes to the overcapacity increase. It can be explained by the impact of these policies in renewables deployment which sometimes is disproportionate and inefficient, taking into account only the players political will and not the promotion of an efficient energy grid. In table A.2 of the appendix the results from disaggregated policies such as legislative/normative, more specifically, regulatory and efficiency policies in household, industry and tertiary sectors create overcapacity of wind power. Further, these policies are really effective and are linked to more efficiency and consumption savings in these sectors. In a context of wind energy growth, reducing energy consumption in buildings logically implies more idle capacity. Moreover, fiscal and tariff policies which included the value added tax reduction in retrofitting investments have the opposite effect due to improved and more efficient power plants. Retrofit investments help to upgrade the electricity system, replacing old power plants to reduce system's energy use and improve efficiency in energy production.

This work contributes to the analysis of intermittency issue on another aspect, the overcapacity of renewables. Wind energy has been very important in order to meet the Energy 2020 goals and therefore deserves a review of the implicit economic consequences. Policy makers should pay more attention to advantages and consequences to avoid an immoderate and blindly decision making process. It is evident that advancement of wind power overcapacity in Europe has consequences for the energy system as a whole and creates economy distortions. Thus it is important to analyze energy networks and consumption patterns in Europe in order to place side by side GHG emissions reduction with an efficient electricity supply. The energy portfolio diversification is a key issue to establish equilibrium between fossil and renewables for electricity generation, but it can be very complex and requires political and scientific intervention in several areas. In Europe, the main sources of electricity generation are not completely homogenous but there is a pattern regarding main use of fossil fuels, combined with nuclear and hydropower as well as the recent commitment to renewables (Bhattacharyya, 2009). Our results suggest that regulation in buildings reduce energy consumption and therefore creates overcapacity. Policy makers must be aware that renewables growth has to be proportional to electricity consumption patterns. To mitigate this problem, micro-production incentives seem to be a solution to balance domestic consumption with network energy supply. Furthermore, installed players must not resist to retrofitting investment, promoting more efficient technologies to maximize wind farms capacity factors. Off-shore sites are a good alternative because they have a much higher capacity factor than on-shore wind farms.

The importance given to other installed fonts is affected and redirects them to other functions. Once, hydropower had a great share in energy grid, although not cease to have, it is declining in most countries. It appears that fossil fuels power plants namely as coal-based and gas-fired may be used to backup electric power generation from wind to ensure a secure energy supply. However, this implies higher costs for systems based on fossil fuels for their non-use leading to rising prices to consumers. In Europe, traditionally systems are still largely based on these sources. Therefore, policy makers and authorities should be aware and combine these systems to mitigate renewables intermittency. Depending on the installation area, the natural resources available and the demand characteristics, hybrid systems can be developed and optimized to respond to the needs of the area (Erdinc and Uzunoglu, 2012). The optimal design of hybrid systems based on renewable energy can improve economically the energy supply and reduce overcapacity of renewables. Energy policies should take into account subsidies promoting more combined cycle gas turbine power plants (CCGT) to mix several energy sources in areas with low wind capacity factors. With a more open market to private investment and the recent energy network unbundling process, energy market regulation is an essential implement in controlling inefficient investments. Thus, we can reach European goals in line with a more efficient energy supply as well as a cost reduction to final consumers.

6. Conclusions

This paper is focused on a panel of 19 European countries for the span of time 1998-2009, to address the issue of intermittency of renewables, specifically wind energy. It is important to understand the causes of overcapacity that may arise from non-constant electricity generation. To the best of our knowledge, the analysis of wind overcapacity was never been made with panel data techniques. This paper sought to contribute on the debate of wind energy intermittency and its relationship with other conventional energy sources, renewables, socio-economic drivers and energy policies in the context of an economic bloc with common long-term energy guidelines.

Our results showed that fossil fuels, namely coal-based and gas-fired power plants are actually used to backup electricity generation, while oil and nuclear does not appear to contribute statistically to the wind overcapacity. These results may indicate the robustness of our model, as oil and nuclear power are generally used for base load energy generation and therefore has no direct relationship with wind overcapacity.

Other renewables like hydropower and solar photovoltaic seem to have no relationship to wind overcapacity, as opposed to industrial, municipal and renewables waste which are increasingly used in Europe. The results evidence that there may be a substitution effect of wind, and thus increases the overcapacity. Moreover, it seems that population density is a factor toward greater wind overcapacity. In fact, countries with higher population density tend to have less land area available to install properly wind farms with optimal distance between them. On the contrary, countries with a higher living standard tend to be more efficient in generating electricity with wind power and therefore cause less overcapacity. Regarding, public policies and energy measures, the results indicate that may have a positive effect in increasing overcapacity due to an inefficient deployment of wind power.

Despite all the advantages of renewables, particularly in the context of Kyoto protocol to reduce GHG emissions, the renewables intermittency is still a barrier to make an energy portfolio exclusively based on renewables. Globally our model suggests that there are many factors pro-overcapacity. We must reverse this trend and adopt measures that could lead to that way. As showed in this paper, wind energy fast growth also increases the need for a more intensive use of fossil fuels in European countries, where coal and gas are widely used as backup sources to electric power generation. With the intensive advance of new wind farms in optimal sites, reaching the share of renewables could become a problem and compromise energy efficiency due to optimal sites exhaustion. Accordingly, it is crucial to pay attention and focus on new ways of wind power installation, to minimize the intermittency effects. Policy makers have a central role in this issue and should promote the implementation of energy policies which favor the support retrofitting investment, regulating energy consumption patterns and encouraging regular hours of consumption.

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Appendix A.1 – Correlation Matrix and variance Inflation Factor (VIF)

	SWID	*SCOAL*	*SGAS*	*SOIL*	*NUCLEARCF*	*HYDROCF*	*SWASTE*	*GWWIND*	*SSOLAR*	*POPDENSITY*	*LNGDPPC*	*MNORMATIVE*	*MFISCAL*	*MFINANCIAL*	*MEDUC*	*MCOOP*	*MCROSSCUT*
SWID	1																
SCOAL	-0.0365	1															
SGAS	-0.1244	-0.1455	1														
SOIL	-0.2115	0.0710	0.2375	1													
NUCLEARCF	0.2218	-0.1512	-0.0172	-0.4296	1												
HYDROCF	0.0557	-0.4607	-0.2358	-0.2613	0.1269	1											
SWASTE	0.0412	-0.0863	0.0188	-0.2497	0.2778	0.4466	1										
GWWIND	0.4853	-0.0079	-0.1081	-0.0593	-0.0462	-0.0219	-0.1532	1									
SSOLAR	0.0203	-0.0003	0.0637	-0.0357	0.1309	-0.0880	0.0184	-0.0723	1								
POPDENSITY	0.1344	0.1529	0.5052	-0.0721	0.3865	-0.3300	-0.0177	-0.0968	0.0592	1							
LNGDPPC	-0.1772	-0.3668	0.0691	-0.0704	0.1725	0.3844	0.3010	-0.2477	0.0294	0.1445	1						
MNORMATIVE	0.0936	-0.2008	0.2193	0.1654	0.0503	-0.1347	-0.0908	-0.1090	0.4542	0.1375	0.2511	1					
MFISCAL	-0.0087	-0.1839	0.2779	-0.2763	0.4015	-0.1103	0.0589	-0.0683	-0.0680	0.5570	0.3284	0.1434	1				
MFINANCIAL	-0.1705	-0.1179	-0.0270	-0.3426	0.5317	0.1690	0.0880	-0.0178	0.1358	0.2150	0.2488	0.3877	0.3986	1			
MEDUC	-0.0832	-0.2672	0.0633	-0.3603	0.1555	0.3154	0.2520	-0.0749	0.0879	-0.0983	0.3927	0.1509	0.2376	0.4939	1		
MCOOP	-0.0080	-0.1613	0.2452	-0.2366	0.4922	0.3567	0.5535	-0.1681	0.0922	0.2422	0.4507	0.1037	0.3808	0.3564	0.3814	1	
MCROSSCUT	0.0634	0.0865	-0.0564	-0.2202	0.2274	0.1750	-0.0224	-0.0820	0.2490	0.2750	0.3259	0.0897	0.1559	0.4795	0.3185	0.2131	1
VIF		2.33	2.42	1.81	2.76	2.92	1.95	1.11	1.64	3.47	2.22	2.37	2.41	3.29	2.19	2.66	2.16
1/VIF		0.4292	0.4140	0.5522	0.3630	0.3423	0.5131	0.8993	0.6092	0.2881	0.4514	0.4226	0.4150	0.3040	0.4556	0.3758	0.4621
Mean VIF										2.36							

Appendix A.2 – Regression results with disaggregated variables - Dependent variable $SWID_{i,t}$

Ind. Variables	OLS				FE				RE				RREG	RREG
	CSE(VII)	*CSE(VIII)*	*RSE(IX)*	*RSE(X)*	*CSE(XI)*	*CSE(XII)*	*RSE(XIII)*	*RSE(XIV)*	*CSE(XV)*	*CSE(XVI)*	*RSE(XVII)*	*RSE(XVIII)*	*(XIX)*	*(XX)*
$SCOAL_{i,t}$	-0.0320** (0.0162)	-0.0380** (0.0179)	-0.0320** (0.0111)	-0.0380** (0.0158)	-0.0614 (0.1289)	-0.0739 (0.1299)	-0.0614 (0.0789)	-0.0739 (0.0719)	-0.0317 (0.0167)	-0.0380** (0.0179)	-0.0317*** (0.0114)	-0.0380** (0.0158)	-0.0130 (0.0115)	-0.0229 (0.0125)
$SGAS_{i,t}$	-0.0703*** (0.0224)	-0.0676*** (0.0251)	-0.0703*** (0.0177)	-0.0676*** (0.0223)	-0.0767 (0.1348)	-0.0996 (0.1367)	-0.0767 (0.0661)	-0.0996 (0.0693)	-0.0692*** (0.0231)	-0.0676*** (0.0251)	-0.0692*** (0.0179)	-0.0676*** (0.0223)	-0.0696*** (0.0159)	-0.0700*** (0.0176)
$SOIL_{i,t}$	-0.1247** (0.0488)	-0.1219** (0.0508)	-0.1247 (0.0600)	-0.1219** (0.0577)	-0.2299 (0.1359)	-0.3022** (0.1411)	-0.2299** (0.0877)	-0.3022*** (0.0747)	-0.1267** (0.0497)	-0.1219** (0.0508)	-0.1267** (0.0606)	-0.1219** (0.0577)	-0.1351*** (0.0346)	-0.1424*** (0.0356)
$NUCLEARCF_{i,t}$	0.0034 (0.0092)	0.0020 (0.0115)	0.0034 (0.0124)	0.0020 (0.0142)	0.0850 (0.0791)	0.0837 (0.0811)	0.0850 (0.0587)	0.0837 (0.0651)	0.0037 (0.0095)	0.0020 (0.0115)	0.0037 (0.0125)	0.0020 (0.0142)	-0.0028 (0.0065)	-0.0067 (0.0081)
$HYDROCF_{i,t}$	0.0335 (0.0356)	0.0173 (0.0404)	0.0335 (0.0387)	0.0173 (0.0457)	-0.1241 (0.0818)	-0.1599 (0.0834)	-0.1241 (0.0648)	-0.1599** (0.0632)	0.0315 (0.0364)	0.0173 (0.0404)	0.0315 (0.0392)	0.0173 (0.0457)	0.0270 (0.0253)	0.0015 (0.0284)
$SWASTE_{i,t}$	0.3054*** (0.1044)	0.3469*** (0.1179)	0.3054*** (0.0682)	0.3469*** (0.0899)	-0.1836 (0.3496)	-0.1975 (0.3490)	-0.1836 (0.2983)	-0.1975 (0.2968)	0.3015*** (0.1075)	0.3469*** (0.1179)	0.3015*** (0.0692)	0.3469*** (0.0899)	0.3410*** (0.0740)	0.3598*** (0.0827)
$GWWIND_{i,t}$	0.0002*** (0.0000)	0.0002*** (0.0000)	0.0002*** (0.0001)	0.0002*** (0.0001)	0.0002*** (0.0000)	0.0002*** (0.0000)	0.0002*** (0.0001)	0.0002*** (0.0001)	0.0002*** (0.0000)	0.0002*** (0.0000)	0.0002*** (0.0001)	0.0002*** (0.0001)	0.0003*** (0.0000)	0.0003*** (0.0000)
$SSOLAR_{i,t}$	-2.2002 (1.9280)	-2.8232 (2.1182)	-2.2002 (1.6162)	-2.8232 (1.9352)	1.1918 (2.1039)	0.3340 (2.2847)	1.1918 (1.0282)	0.3340 (0.9220)	-2.0828 (1.9270)	-2.8232 (2.1182)	-2.0828 (1.5621)	-2.8232 (1.9352)	-1.7028 (1.3661)	-2.3226 (1.4871)
$POPDENSITY_{i,t}$	0.0002*** (0.0000)	0.0002*** (0.0000)	0.0002*** (0.0000)	0.0002*** (0.0000)	0.0015 (0.0015)	0.0022 (0.0016)	0.0015 (0.0012)	0.0022 (0.0012)	0.0002*** (0.0000)	0.0002*** (0.0000)	0.0002*** (0.0000)	0.0002*** (0.0000)	0.0002*** (0.0000)	0.0002*** (0.0000)
$LNGDPPC_{i,t}$	-0.0245*** (0.0059)	-0.0264*** (0.0067)	-0.0245*** (0.0059)	-0.0264*** (0.0072)	0.0728 (0.0559)	0.0851 (0.0563)	0.0728 (0.0524)	0.0851 (0.0512)	-0.0243*** (0.0061)	-0.0264*** (0.0067)	-0.0243*** (0.0060)	-0.0264*** (0.0072)	-0.0276*** (0.0042)	-0.0278*** (0.0047)
$MNORMATIVE_{i,t}$	0.0031*** (0.0006)	0.0031*** (0.0007)	0.0031*** (0.0010)	0.0031** (0.0011)	0.0008 (0.0011)	0.0009 (0.0011)	0.0008 (0.0005)	0.0009 (0.0006)	0.0031*** (0.0006)	0.0031*** (0.0007)	0.0031*** (0.0010)	0.0031*** (0.0011)	0.0030*** (0.0004)	0.0030*** (0.0005)
$MFISCAL_{i,t}$	-0.0050** (0.0022)	-0.0050** (0.0024)	-0.0050** (0.0022)	-0.0050** (0.0020)	0.0066 (0.0043)	0.0017 (0.0051)	0.0066 (0.0035)	0.0017 (0.0035)	-0.0049** (0.0023)	-0.0050** (0.0024)	-0.0049** (0.0022)	-0.0050** (0.0020)	-0.0041*** (0.0016)	-0.0042** (0.0017)
$MFINANCIAL_{i,t}$		0.0001 (0.0007)		0.0001 (0.0007)		0.0001 (0.0011)		0.0001 (0.0008)		0.0001 (0.0007)		0.0001 (0.0007)		-0.0001 (0.0005)
$MEDUC_{i,t}$		-0.0001 (0.0009)		-0.0001 (0.0007)		0.0004 (0.0013)		0.0004 (0.0011)		-0.0001 (0.0009)		-0.0001 (0.0007)		-0.0006 (0.0007)
$MCOOP_{i,t}$		0.0001 (0.0015)		0.0001 (0.0012)		0.0015 (0.0028)		0.0015 (0.0016)		0.0001 (0.0015)		0.0001 (0.0012)		0.0011 (0.0011)
$MCROSSCUT_{i,t}$		0.0012 (0.0012)		0.0012 (0.0008)		0.0050** (0.0024)		0.0050*** (0.0008)		0.0012 (0.0012)		0.0012 (0.0008)		0.0012 (0.0008)
CONSTANT	1.0006*** (0.0564)	1.0251*** (0.0651)	1.0006*** (0.0512)	1.0251*** (0.0692)	-0.0636 (0.6406)	-0.2684 (0.6538)	-0.0636 (0.6284)	-0.2684 (0.6256)	1.0003*** (0.0580)	1.0251*** (0.0651)	1.0003*** (0.0525)	1.021*** (0.0692)	1.0238*** (0.0399)	1.0377*** (0.0457)
N	218	218	218	218	218	218	218	218	218	218	218	218	218	218
R2	0.4772	0.4809	0.4772	0.4809	0.3554	0.3750	0.3554	0.3750					0.6920	0.7093
Wald test (χ^2)									171.31***	176.91***				
F (N(0,1))	8.09***	6.80***			4.44***	3.99***							19.92***	17.93***

Exclusion tests to MFINANCIAL, MEDUC, MCOOP and MCROSSCUT

JST		0.34		0.76		1.36		10.63***		1.34		3.02		0.86
LRT		0.66		0.85		2.08**		3.78***		0.66		0.85		1.30

Notes: OLS - Ordinary Least Squares. RE – Random Effects. FE – Fixed Effects. RREG – Robust Regression. CSE – Conventional standard errors. RSE – Robust standard errors. Models in shading highlight RSE. The F-test has normal distribution N(0,1) and tests the null hypothesis of non-significance of all estimated parameters. The Wald test has χ^2 distribution and tests the null hypothesis of non-significance of all coefficients of independent variables. JST - Joint Significance Test. JST is a Wald (χ^2) test with the null hypothesis of $H_0: \beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$, with $\beta_1, \beta_2, \beta_3, \beta_4$ representing the coefficient of ***MFINANCIAL***, ***MEDUC***, ***MCOOP*** and ***MCROSSCUT***, respectively. LRT - Linear Restriction Test has the null hypothesis of: $H_0: \beta_1 + \beta_2 + \beta_3 + \beta_4 = 0$. Standard errors are reported in brackets. All estimates were controlled to include the time effects, but they are not reported for simplicity. ***, **, denote significance at 1 and 5% significance levels respectively.