Energy prices and energy policy

as determinants of investment in wind energy in Europe

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Abstract

The following thesis sets to find out whether there is a direct relationship between the fuel prices and the level of investment in wind power in the European Union countries. The research is based on six year panel data on the European Union countries. The results of the research are as follows. No direct link has been found between the fuel prices and the investment in wind power. Moreover, wind energy support schemes which are unobserved factors in the model, have been found to have an impact on the investment in wind power capacity. On top of it, GDP per capita has a positive and statistically significant effect on the investment in wind power, suggesting that European countries in the higher income range were more likely to invest in wind power in 2001-2006 rather than those European countries in the lower income range.

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Contents

Introduction

Wind energy industry is very young; it has appeared in 1982, but it has been growing rapidly, at an annual rate of more than 25% for the past 15 years: global installed wind power capacity has increased from 2.5 GW in 1992 to more than 94 GW by the end of 2007 (Morthorst 2009). According to the statistical data of the Global Wind Energy Council, over 50% of the global installed wind power capacity is located in Europe. Seven European countries along with the USA, India and China top the list of countries with largest installed wind power capacity as of 2008 (GWEC 2009). However, the growth of wind industry has been disproportional among the European countries. Germany, Spain and Denmark are leading in the European Union level in terms of absolute capacity installed as of 2007 (22,247, 15,145 and 3,125 Megawatts respectively) (Wind Energy – The Facts).

Figure 1. European cumulative wind power capacity

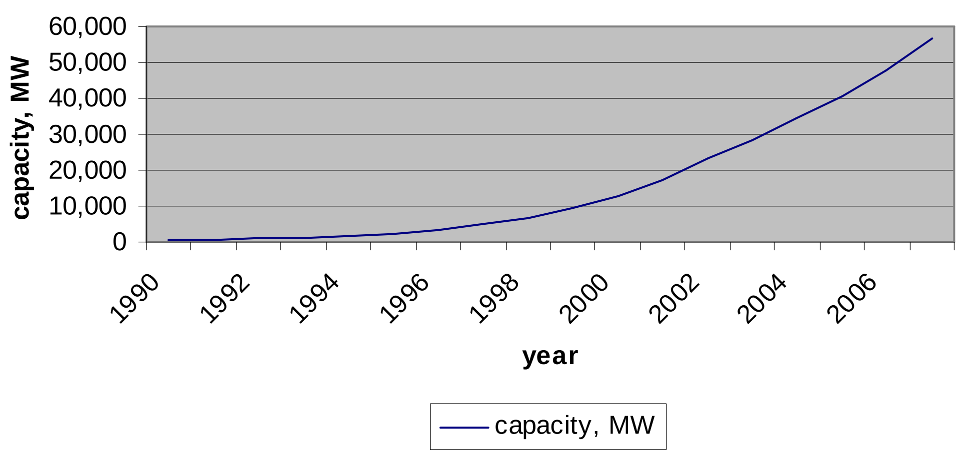
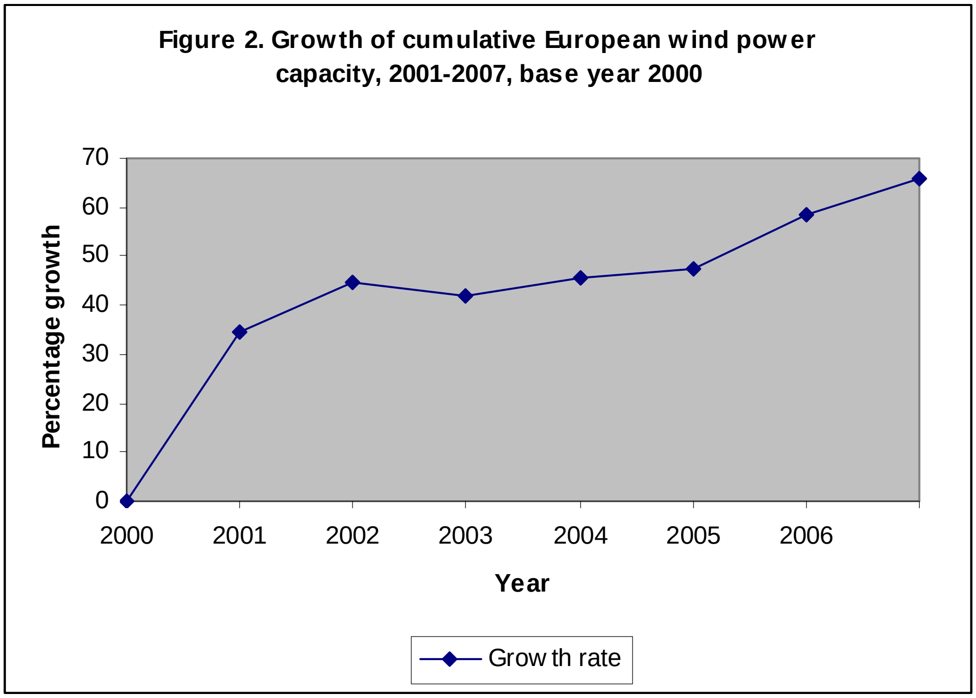


Figure 1 above depicts the growth of wind capacity in Europe in absolute terms, measured in MW installed. We can see that wind power capacity in Europe has been growing exponentially from 1990 through 2007; with growth of 227 percent between 2001 and 2007. Growth of cumulative capacity in the EU between 2001 and 2007 compared to base year 2000 is plotted in Figure 2 below.



However, this growth has been unequal: some countries have exceeded the average growth rate compared to base year 2000 (48.4%); some have underinvested in wind energy. Growth of installed capacity in Germany has been faster than average, Spain had a smaller rate of growth. At the same time, in other European countries such as Belgium, Finland and Poland, installations of wind power constitute a few hundred MW. In Luxembourg, Bulgaria, Hungary, the Baltic States and Czech Republic, total installations of wind power are below 100 MW as of 2007, which can be explained by the fact that they have started investing in wind power between year 2000 and 2002, therefore, their wind industry is at its early stage (Wind Energy – The Facts 2009).

Given such dramatic growth of wind industry in Europe, an important question arises as to what was driving this growth. It main determinants have been identified as decreasing production costs of wind electricity, increasing prices of fossil fuels, direct substitutes of wind electricity and effective EU energy policy together with national support schemes for wind industry in member countries.

Although a lot of research has been focused on the decreasing costs of wind electricity and EU renewable energy policy as determinants of growth of wind industry in Europe (Wind Energy – The Facts 2009, The Economics of Wind Energy 2009, OPTRES 2006, Jensen and Morthorst 2006) (this literature is described in Literature Review), to date little research has been done on the effect of fuel prices on the investment in wind power.

Issue of security of energy supply, concerns about the future availability of energy and fuel price volatility are at the agenda of European governments. Moreover, these concerns are coupled with high awareness of the consequences of climate change and the negative contribution of fossil fuels to the global warming due to the emission of Greenhouse Gases. European legislation such as European Union Directive on the promotion of the use of Renewable energy sets a target for European countries to produce 20% of energy from renewable energy sources by 2020. Moreover, the Kyoto Protocol to the United Nations Framework Convention, which stipulates at least 5% (compared against the base year levels – 1990) reduction in the level of emission of the 6 main greenhouse gases by the developed countries over the five-year period 2008-2012 (Europa 2009), has been an important step towards green energy.

The aim of this thesis is to analyze the determinants of growth of European wind industry in order to find out to what extent rising fuel prices or wind energy policies of EU countries have driven the investment in wind energy in Europe. In this thesis, I test the direct empirical relationship between the fuel prices and investment in wind power. However, indirect impact of fuel prices through policies is reasonable as uncertainty about the future of energy markets and the desire of EU countries to diversify their energy supply have a strong impact on forming the renewable energy policies.

This study is structured as follows. The second section of first chapter reviews the literature in this research area. The second chapter provides information on the current trends in the costs of producing wind power, reviews the policy schemes, which exist in the EU to support wind power production and outlines trends in market prices of fossil fuels. Chapter three deals with empirical methodology, describes the data and contains empirical analysis. Chapter four concludes with a summary of main findings.

In the third chapter empirical relationship between the fuel prices in the previous period and level of investment in wind power in the EU in the following period has been tested using Pooled OLS, Fixed Effects and Log-differenced estimation. Results of the estimation show that there is no direct link between fuel prices in the previous period and investment in wind power in the following period. Moreover, unobserved effects in the model which are national energy policies are important for the growth of wind power capacity in Europe. Nevertheless, rising fuel prices have had an indirect impact on investment in wind power, through policies.

1. Literature review

Although there has been a large amount of literature focusing on the development of wind power in Europe, most of which has been quantitative and dealt with economic modeling and forecasting, little econometric research has been done in this area. Moreover, numerous policy studies have been performed to evaluating the effectiveness of support schemes for renewable energy technologies, which currently exist in all of the EU member states and identify the criteria for the design of optimal support schemes. The fact that econometric estimation has not been at the core of this research can be due to the fact that wind industry is very young, was formed in 1982, it exhibited the strongest growth in 2001-2007, and therefore, it is only now that empirical estimation can be applied to the limited data which is available. Data limitation is also due to the fact that wind industry has developed well in only a group of countries: selection of EU countries, China, USA and India. An overview of literature explaining the development of European wind industry is provided below.

An important report which assessed effectiveness of renewable support schemes, OPTRES (2006) concluded that among EU15 countries, Denmark, Spain and Germany had the highest effectiveness of support scheme for wind on-shore, among EU10, Latvia and Estonia had the highest effectiveness. Another conclusion of the report was that although there is progress in employing renewable energy technologies in member states, the support is heterogeneous among the countries, and there are barriers to development of RES which need to be addressed. Such barriers were identified as social, administrative barriers for wind power producers, grid integration and financial barriers (OPTRES 2006). Moreover, Jensen and Morthorst (2006) stressed the importance of creating common regional RES electricity market. This also applies to wind industry: eventual merging of national support schemes would be beneficial for increasing its cost efficiency.

Another study on the economics of wind power stressed the fact that in order for renewable energy technologies to become competitive, conventional power plants must include externalities of their production, pollution of the environment, in their cost function (The economics of Wind Energy 2009).

Quite a few studies were performed to compare the two main support schemes in the EU, feed-in tariffs and quota obligations. Haas et al (2007) and authors of "Wind Energy – The Facts (2009) provide an overview of main support schemes in Europe and assess their efficiency, they say that feed-in tariffs which are long term contracts between producers of wind electricity and power suppliers, can be a great success due to the low risk for investors, at the same time, high administrative barriers may be a serious obstacle for the development of wind energy even if the policy environment is rather stable and the feed-in tariff is high, as in the case of France. Countries which have succeeded in deployment of wind power between 1998-2005 are Denmark, Germany and Spain, which applied feed-in tariffs throughout the whole period. Second main support scheme in the EU, has been found to provide high risk environment to the producers coupled with high magnitude of absolute support level as exemplified by the case of UK and Italy (Haas et al 2007).

2. Theoretical framework

2.1. Fuel prices

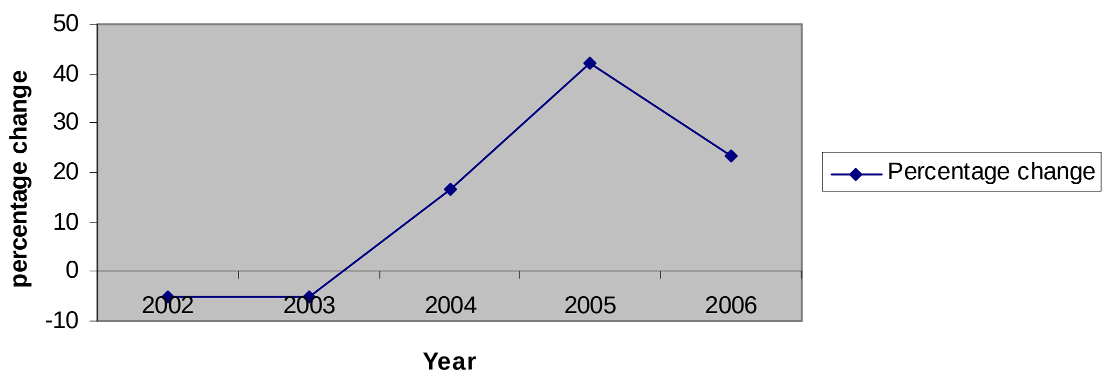
Fuel prices have an important impact on the decisions of policymakers to invest in renewable energy technologies. Rising prices of fossil fuels over the past decade have sparked concerns over the affordable energy supply in the future. Oil and gas markets have several distinct characteristics. Demand for oil and gas is relatively inelastic due to the fact that there is no readily available substitute in the short run, which could satisfy the current level of global energy demand. Moreover, supply of fossil fuels is constrained in the short run, due to the long time needed to develop new capacities.

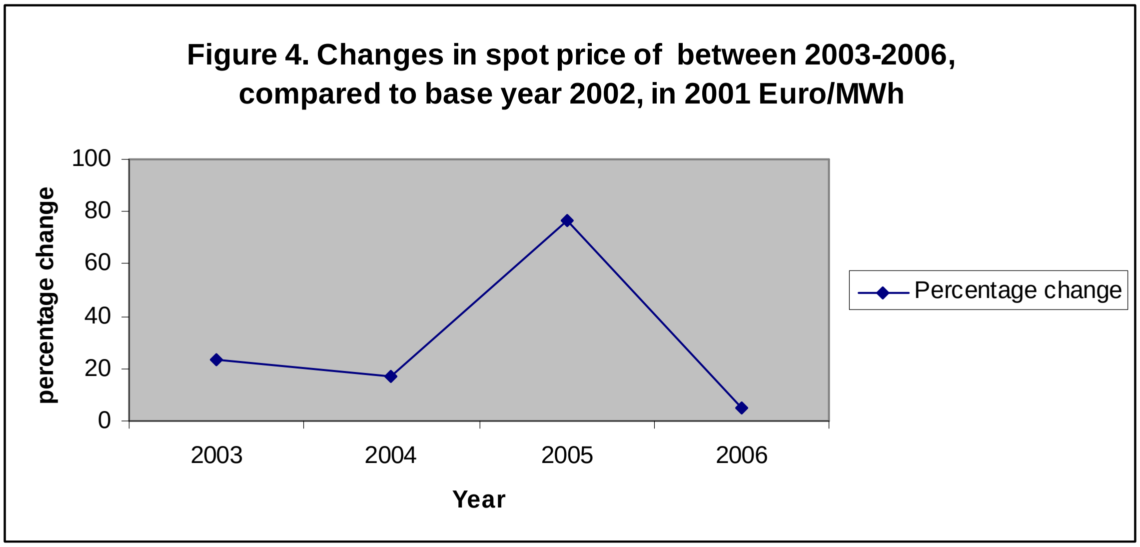
At the same time, current low oil prices discourage investment in exploration and development (Martino and Fiorello 2008). According to the IEA, International Energy Agency (2008), even if nominal values of upstream investment have been rising, most of this investment is aimed at developing reserves, which have declining rates of production. In addition, resource nationalism, which limits the access of international oil companies to the oil resources, has caused the capital to be directed towards exploration and development of high-cost reserves. Therefore, current level of investment in exploration and development is not sufficient to meet future energy demand (IEA 2008).

Figure 3 below shows the evolution of spot prices of Brent Crude, in constant 2001 Euro/bl. Figure 4 shows the evolution of spot price of natural gas, in constant 2001 Euro/MWh. Spot market price for natural gas is available from 2002 only, as the spot market for gas has appeared recently. From the two figures, we can see that the price of gas has followed the pattern of oil price.

Oil has developed into an internationally traded global commodity. Due to the physical properties of natural gas, it has higher transportation costs and lower energy density than oil. For these reasons, its price follows the pattern of a substitute fuel, and price changes follow price changes of oil. Liquefied Natural Gas, LNG, which is equivalent to oil in terms of transportation flexibility, has appeared on the world markets relatively recently. LNG can be transported in tankers and its supply can be redirected easily by changing the movement route of tankers.

Figure 3. Changes in the spot price of Brent crude between 2002-2006, compared to base year 2001, in 2001 Euro/bl





2.2. *Costs of wind power*

About 75% of the total investment cost in wind industry is comprised of the cost of turbine itself, foundation, electrical equipment, grid-connection, etc. Wind power is a zero fuel technology; most of the costs which investors in wind industry face are fixed costs, which can be calculated with a relatively high degree of certainty. Therefore, fluctuations in the fuel prices have no impact on wind power generation costs, whereas fuel costs comprise a large share of the total costs of conventional power technologies, which are, therefore, exposed to fuel price volatility risk. Conventional power production is very fuel cost intensive and it produces large amounts of GHG emissions. Therefore, it makes sense to gradually replace a substantial proportion of electricity consumption currently produced from fossil fuels by renewable energy, and wind power as well. It is important to consider that wind turbines have a good record of low CO_2 emission associated with their entire lifetime, emissions resulting from manufacturing, installation and maintenance of wind turbines over the life-cycle of 20 years are offset after three to six months of operation, as production of wind electricity is not causing any emissions in itself (Wind Energy – The Facts 2009[1]).

Costs of wind power have been largely affected by the rapid development of the wind industry in Europe. Over the period from 1985 until 2006, total wind energy costs of inland wind turbines in Denmark have decreased from about 0.11 Euro/kWh to a little more than 6 Euro/kWh, in constant 2006 prices, whereas costs of wind turbines located at coastal sites decreased from about 0.09 Euro/kWh to less than 0.06 Euro/kWh (The Economics of Wind Energy). Figure 5 below plots the development of total wind energy costs per unit of electricity produced, by turbine size, in €cent/kWh of energy produced, in constant 2006 prices.

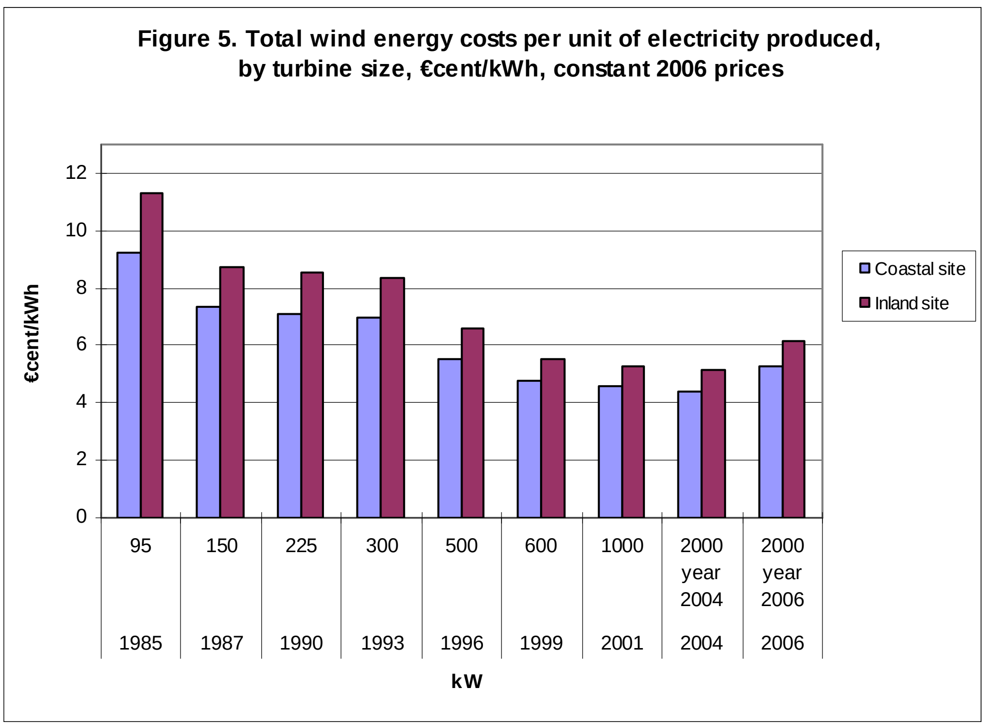


Figure 5. Total wind energy costs per unit of electricity produced, by turbine size, €cent/kWh, constant 2006 prices

Source: The Economics of Wind Energy

[1] Wind Energy – The Facts is a report on all financial and economic aspects of wind power. It is main European publication on wind energy by the European Wind Energy Association, a consortium of 603 members, comprised of research institutes, wind turbine manufacturers, electricity providers, national wind and renewable energy technology associations and other parties involved in wind power industry.

Case of Denmark is provided due to limited data availability, it must be noted that Germany also experienced a decrease in costs, but at a slower rate. As can be seen from the figure above, turbines have been growing in size and costs were decreasing over time. Larger turbines have an improved cost-effectiveness. Increasing the hub height of the turbines automatically increases their productivity, as wind is stronger at higher altitudes. Moreover, there has been an improvement in the techniques to evaluate wind speed which has positive consequences for the siting of newly installed turbines. In Germany and Denmark, as most of the windy and productive sites are already occupied, there are projects aimed at decommissioning of old, smaller capacity turbines in order to replace them with higher capacity, more efficient new turbines, a term referred to as "repowering" (Wind Energy – The Facts 2009).

Over the period of the study, 2001-2006, costs have been decreasing until 2005, and in 2005-2006 they were higher than average. These patterns become clear when one considers the fact that demand for wind electricity rose exogenously in 2005 and 2006 (Wind Energy – The Facts 2009), which caused higher investment level in wind energy in those years compared to previous years. Another important report on the economic aspects of wind energy, "The Economics of Wind Energy" (2009), published by European Wind Energy Association in March of 2009, informs the reader that between 2001 and 2004, growth of wind power capacity was less than expected, this drove down the price of wind power installations, which went up between 2005 and 2008 together with the costs of wind electricity, as demand for wind turbines grew together with demand for wind electricity. Increase in costs was also caused by insufficient production capacity of sub-suppliers of wind turbine components.

Due to the fact that country level data was not available for costs of wind electricity, I was not able to include the costs into the empirical analysis. However, the decrease of costs of wind electricity over time, not only during the period 2001-2004 (as in 2005 they increased), has made wind power production more competitive with the conventional power production and contributed greatly to the development of wind industry in Europe.

2.3. The European Union Wind Energy policy

The European Union countries implement domestic support schemes for wind power producers. Following "Wind Energy – The Facts (2009), there are several major schemes, both price driven and quantity driven. Main price driven schemes include fixed and premium feed-in tariffs. Fixed feed-in tariff is a fixed price which wind power producers are paid according to long-term contracts. Premium feed-in tariffs differ in the sense that the amount to be added to the electricity price is fixed, therefore, the total price which wind power producer will receive, which is a combination of electricity price plus a premium, is less predictable due to the volatility of electricity prices. Quantity driven mechanism includes tendering system for investment grants and Tradable green certificate systems. Tenders are organized for defined amount of capacity; winner will receive a guaranteed tariff for a specified period of time. Tradable green certificate systems operate in such a way that the government sets quota for the amount of power supply in the country which should be produced from renewable sources. Therefore, utility companies, wind power producers, wholesalers or any other parties involved must either supply or purchase a certain proportion of their electricity from the renewable energy sources. By doing so they collect certificates. And if they do not fulfill the quota, they are penalized.

European Union Directive on the promotion of the use of Renewable energy, which was originally adopted in 2001, later amended in 2003 and March 2009, sets a target for the European Union countries to produce 20% of energy from renewable energy sources by 2020. Moreover, it is stipulated in the Directive that the 20% target must be allocated among the EU countries according to their starting points in development of renewable energy sources (RES) and their potentials. According to the Directive, countries must set domestic targets for different RES technologies, and maintain a properly functioning national support schemes for RES (European Union Directive on Renewable Energy 2009). Second important policy at the European level which had an impact on the development of renewable electricity, was "White Paper for a Community Strategy and Action Plan, Energy for the Future: Renewable Sources of Energy", adopted by the European Commission in December or 1997, which set a target of 12% of the gross inland consumption of energy in the EU to come from RES (OPTRES 2006). This legislation has helped the national governments to pursue wind energy development policy, successful examples being Denmark, Germany and Spain.

3. Empirical model

3.1. Empirical methodology

Main determinants of the development of wind industry in Europe were identified as technological advancement and economies of learning and scale, associated with decreasing wind power production costs; prices of fossil fuels as substitutes for wind electricity and, last but not least, renewable energy policies in the European Union member countries. The purpose of this chapter is to describe the empirical analysis performed in this study in order to determine the effect of fuel prices and energy policy on the level of investment in wind generating capacity in European countries. In the previous chapters, reader has been introduced to the topic of this thesis, and given information on the development of wind industry, trends exhibited by the costs of wind electricity and renewable energy policy of EU and its member countries, along with the information of the main trends in the prices of fossil fuels. This chapter is constructed as follows: this section describes the methodology used in the analysis, second section describes the data, and third section deals with the results of empirical estimation and their interpretation.

Data is available for spot prices of fuels and end user prices of electricity and natural gas. There are used as explanatory variables to estimate the effect on investment in wind power. Wind electricity is used by both the household and industrial consumers. In household sector, it is used for general heating and water heating purposes, as part of the electricity purchased from the grid or as locally produced wind electricity. Large industrial consumers, which generate electricity for their needs, from fossil fuels, also substitute for wind electricity, if it is profitable for them to do so rather than produce electricity.

Wind energy policies in EU member countries have a substantial effect on investment in wind energy, they act as unobserved factors in the model. Fixed effects, energy policies, have an important effect on the regressand. Countries with systematic, properly designed and well enforced policies, have succeeded in deploying wind power. At the same time, policies are correlated with GDP per capita, which is included in the model, due to the fact that high-GDP countries in the EU are historically investing more in renewable energy technologies than low-GDP countries. According to Wooldridge (2003), when the unobserved effects which are correlated with the dependent variable, are also correlated with an independent variable in the model, two estimation methods can be used to eliminate the fixed effects – fixed effects estimation and first differenced estimator. I estimate the model using Pooled OLS first, then I turn to fixed effects estimation, and then use log-differenced estimator. Log-differenced estimator is preferred over first difference due to the fact that such growth variable as GDP is included in the model, which is normally used in logarithmic form. Results of log-differenced estimator can be interpreted as elasticities.

In this thesis, the model estimated is a linear regression of natural logarithm of cumulative installations of wind power in European Union countries on natural logarithm of spot prices of crude oil, natural gas and steam coal, fixed to 2001 base prices, as well as constant 2001 values of natural gas and electricity prices, charged to industrial consumers (without taxes) over the period 2001-2006. Moreover, the natural logarithm of gross electricity generation from wind is also used as a regressand to test the robustness of results.

3.2. Data description

This study uses longitudinal data for 20 European Union countries over the period of 2001-2006, a total of 120 observations. Variables of interest are the level of investment in wind energy in the given countries and prices of fossil fuels in the European Union and its member states. The years 2001-2006 were selected for the study as they exhibited the largest growth in terms of new wind power generating capacity installed in Europe, and country level data is available for this period for the wind power capacity installed. Out of 27 European Union countries, Cyprus, Malta and Slovenia had zero cumulative and yearly capacity installed as of 2007, therefore, were excluded from the empirical analysis; moreover, in countries like Bulgaria, Romania, Slovakia and Latvia, the level of wind power installations was very low at the beginning of the period and it exhibited no change in half of the years. Moreover, natural gas and electricity prices for end users were missing for half of the years in most of these countries. Including these countries in the regressions does not change the empirical results; therefore, they have been excluded due to the reasons outlined above. The list of the countries included in the study is provided in the Table 1 below. Gross electricity generation from wind is also used as dependent variables in the model, to estimate the effect of different fuel prices.

In addition, data on GDP per capita of the EU countries for the same time period was used to control for the level of economic development of the countries. Most of the wind power capacity is located in developed countries, such as Germany, Denmark and UK, which fall into the higher range of GDP per capita. Therefore, it is important to control for GDP per capita of the economies when estimating the effect of main variables on the wind capacity installed and electricity generation from wind.

Data on both the cumulative and annual installation of wind power capacity in the European Union member countries measured in Megawatts (MW) has been obtained from the "Wind Energy – The Facts" (2009) publication, a major European publication on wind energy. It is a report of the European Project financed by the Intelligent Energy – Europe programme of the Executive Agency for Competitiveness and Innovation that runs from November 2007 to October 2009. Data on gross electricity generation from wind for years 2001-2006 in Gigawatt-hour (GWh) was obtained from the website of European Commission's Directorate-General for Energy and Transport. Maximum value of cumulative capacity in the sample is 20,622 MW and minimum is zero MW.

Prices of substitute fuels for wind electricity, which are coal and gas, are used in the analysis. At the same time, due to physical properties of natural gas, namely its lower energy density and higher transportation and storage costs (in the case of Liquefied Natural Gas (LNG)) compared to crude oil, gas acts as a substitute fuel and its price follows the pattern of crude oil price (Putting a Price on Energy 2007). Therefore, the crude oil price is used in this analysis as well. Historical spot prices of Brent Crude (US$/bl), which is a benchmark for European crude oil, steam coal (US$/ton) and natural gas (US$/ for years 2001-2006 have been obtained from Enerdata, French energy consulting and information services company. Nominal prices of crude oil and coal were converted to Euro, using yearly average exchange rates obtained from Eurostat, deflated to base year 2001 using Harmonized Index of Consumer Prices (HICP), a harmonized consumer price index for all European Union countries and an official measure of consumer price inflation in the Euro area. HICP values were obtained from Eurostat, Statistical Office of the European Communities. The spot price of natural gas is available from 2002 for National Balancing Point (NBP), gas trading market in the UK, the largest trade market for gas in Europe

(Harris 2006). Spot price in nominal Euro per MWh was converted to real 2001 base prices using HICP deflator. Spot prices of crude oil, natural gas and coal do not vary by country, nevertheless, they will be used in the analysis in order to see the effect of their change with respect to the growth of wind power generation capacity.

Furthermore, nominal natural gas (Euro/GJ) and electricity prices (Euro/kWh) for industrial consumers (excluding taxes) which vary by countries were obtained from Eurostat for years 2001-2006 and converted to real 2001 base prices using HICP deflator.

Nominal values of GDP (in USD) and population levels for the countries in the sample were obtained from the World Development Indicators (WDI) Database of the World Bank, available on the website of the World Bank. For each country and year, nominal values of GDP were divided by the population level, converted to Euro using annual averages of exchange rates obtained from Eurostat and deflated to base year 2001 using HICP. The main statistical values of variables used in the analysis along with their brief description are provided in Table 2 below.

Table 1. EU Countries included in the sample

Austria	Ireland
Belgium	Italy
Czech Republic	Lithuania
Denmark	Luxembourg
Estonia	Netherlands
Finland	Poland
France	Portugal
Germany	Spain
Greece	Sweden
Hungary	United Kingdom

Table 2. Variables

Number	Name of the variable	Description	Mean	Standard deviation	Observations
1	Cumulative capacity	Cumulative wind power capacity, 2001-2006, MW	1598	3709	120
2	Ln (cumulative capacity)	Natural log of cumulative wind power capacity, 2001-2006, MW	5.56	2.2	113
3	Dln (cumulative capacity)	Log-difference of cumulative wind power capacity, 2001-2006, MW	0.36	0.38	93
4	Oil price	Spot price of Brent Crude, in constant 2001 Euro/bl	32.33	8.36	120
5	Ln (oil price)	Natural log of spot price of Brent Crude, in constant 2001 Euro/bl	3.45	0.24	120
6	Dln (oil price)	Log-difference of spot price of Brent Crude, in constant 2001 Euro/bl	0.11	0.15	100
7	Coal price	Spot price of steam coal, in constant 2001 Euro/ton	43.27	7.07	120
8	Ln (coal price)	Natural log of spot price of steam coal, in constant 2001 Euro/ton	3.75	0.17	120
9	Dln (coal price)	Log-difference of spot price of steam coal, in constant 2001 Euro/bl	0.01	0.24	100
10	Gas price	Spot price of natural gas (UN NBP), in constant 2001 Euro/MWh	12.84	4	100
11	Ln (gas price)	Natural log of spot price of natural gas (UK NBP), in constant 2001 Euro/MWh	2.51	0.32	100
12	Dln (gas price)	Log-difference of spot price of natural gas, in constant 2001 Euro/bl	0.20	0.15	80

13	Gas price for industries	Natural gas price for industrial consumers, without tax, in constant 2001 Euro/GJ	5.59	1.36	105
14	Ln (gas price for industries)	Natural log of natural gas price for industries, without tax, in constant 2001 Euro/GJ	1.69	0.25	105
15	Dln (gas price for industries)	Log-difference of natural gas price for industries, without tax, in constant 2001 Euro/GJ	0.04	0.17	85
16	Electricity price for industries	Electricity price for industries, without tax, in constant 2001 Euro/kWh	0.06	0.01	111
17	Ln (electricity price for industries)	Natural log of electricity price for industries, without tax, in constant 2001 Euro/kWh	-2.84	0.21	111
18	Dln (electricity price for industries)	Log-difference of electricity price for industries, without tax, in constant 2001 Euro/kWh	0.03	0.13	90
19	Generation from wind	Gross electricity generation from wind, 2001-2006, GWh	2744.67	5897.2	116
20	Ln (generation from wind)	Natural log of gross electricity generation from wind, 2001-2006, GWh	5.84	2.55	116
21	Dln (generation from wind)	Log-difference of gross electricity generation from wind, 2001-2006, GWh	0.39	0.41	96
22	GDP/capita	GDP per capita, in constant 2001 Euro	22177.93	12547.83	120
23	Ln (GDP/capita)	Natural log of GDP per capita, in constant 2001 Euro	9.81	0.69	120
24	Dln (GDP/capita)	Log-difference of GDP per capita, in constant 2001 Euro	0.03	0.04	100

3.3. Empirical results

Methodology used to estimate the model in this paper is the Ordinary Least Squares: Pooled OLS, Fixed Effects and Log-Differenced estimator. First, Pooled OLS and Fixed Effects are estimated for the spot prices of the crude oil, natural gas and coal (fixed to base year 2001), then Log-Differenced estimator is applied to the same data, to check the robustness of the results. In addition, same pattern is applied to second set of prices – end user prices for natural gas and electricity (for industrial consumers). I start out by estimating the elasticity of investment in the wind industry, as measured by natural log of cumulative installations of wind power in the European Union countries, 2001-2006, with respect to the spot prices of crude oil, natural gas and steam coal, fixed to base year 2001. Data for 20 out of 27 European Union member states is used for the analysis, as other countries had either no wind power capacity or no new wind power capacity in 3 out of 6 years, or data for electricity and natural gas prices for end users was not available. White Period Standard Errors are consistently used in regressions to remedy possible serial correlation.

Regressions (1)-(6) were estimated as in the equation below, (1), (3) and (6) with Pooled OLS , (2), (4) and (6) with country fixed effects estimation. Year fixed effects can not be applied, as the spot prices of oil, gas and coal do not vary by country.

$$\ln(Capacity_{it}) = \alpha + \beta * \ln(Fuelprice_{it_{-1}}) + \gamma * \ln(GDPc)_{it} + \mu_i + \varepsilon_{it}$$

where μ_i is country fixed effects, $\ln(GDPc)_{it}$ is a variable which controls for natural log of GDP per capita, as measured in €2001, $\ln(Fuelprice_{it_{-1}})$ stands for crude oil, steam coal and natural gas lagged prices, taken one by one.

Regressions (7) and (8) were estimated with country fixed effects as below, first with Pooled OLS and then with fixed effects estimation:

$$\ln(Capacity_{it}) = \alpha + \beta * \ln(Oilprice_{it_{-1}}) + \beta * \ln(Gasprice_{it_{-1}}) + \beta * \ln(Coalprice_{it_{-1}}) + \gamma * \ln(GDPc)_{it} + \\ + \mu_i + \varepsilon_{it}$$

Column (1) was estimated with Pooled OLS regression to obtain causal effect of crude oil price on the investment in wind power capacity, using GDP per capita as a control variable. GDP per capita is an important factor, as there is a tendency for countries with high GDP per capita to invest more in wind energy. All of the variables are in logs; therefore, the coefficients can be interpreted as elasticities. In column (2) Fixed Effects estimation was applied. As can be seen from column (1) of Table 3 below, elasticity of investment in wind power with respect to the oil price is statistically significant both in Pooled OLS and in Fixed Effects estimation.

Columns (3) and (4) repeat the same exercise for steam coal price, and columns (5) and (6) for natural gas price. The point estimate on coal price suggests an increase in the capacity installed of 1.05 % for every 1% price increase in the price of coal, ceteris paribus; however, the coefficient becomes insignificant in the Fixed Effects estimation. The point estimates for gas price depicted in columns (5) and (6) show positive and statistically significant effect on the increase of gas price on the level of investment in wind power (1.15 and 0.84 percentage points increase in the investments for every 1 percent increase in gas price, holding GPD per capita fixed). At this point, oil and gas remain significant even with Fixed Effects estimation. To see whether one has a stronger effect than the other, both are included in the regression, along with the coal price and GDP per capita, regression are estimated first with Pooled OLS (7) and then with country fixed effects (8). These regressions give us the following results: the coefficient on oil price is not significant at any conventional significance level, neither in Pooled OLS, nor in fixed effects estimation; the coal price shows an elasticity of 0.49 in Pooled OLS, coefficient is marginally significant at 10% level, and is not significant in fixed effects regression; gas price has consistent elasticities of 0.78 and 0.77, both point estimates being significant at 1% level. Therefore, we can conclude that it is natural gas price which is the correct variable to explain variation in wind energy investment.

This is easily understood when one takes into account that wind electricity is used both in household and industrial sectors. Households use electricity for heating purposes, therefore from the grid or locally produced wind electricity. In industrial sector, large consumers can purchase electricity from the grid, and substitute it for the generation of electricity from gas. According to Blok (2007), industrial consumers in Europe often generate electricity in Combined Heat and Power plants, where gas boilers are used. As gas price is an important variable and it is correlated with oil price, therefore, regressions (1) and (2) suffer from the omitted variable problem, which is eliminated when we use both oil and gas prices in a regression. Therefore, we can conclude that even once the country specific, time invariant factors are accounted for by the fixed effects estimation, gas price in the previous period (as we are using first lagged values of fuel prices) has a positive effect on the investment in wind, with elasticity being equal to 0.77. Importantly, GDP per capita is statistically significant in all of the regressions, and its magnitude increases in each of the cases, when country fixed effects are applied.

The country fixed effects method was applied in order to separate the effect of unobserved, time-invariant factors which are specific to certain countries, which correlate with both GDP and the investment in wind power. In the case of wind energy, such country fixed effects are legislation to support wind power producers, attitude of the public to wind energy, social and political regime, environmental and climate change awareness, which is higher in some countries than in the others. Moreover, renewable energy policies in the countries of the study were consistent over the period 2001-2006, they are considered country fixed effects because in some countries there was strict regulation and enforcement of renewable energy deployment, in others, either wind was not the main renewable energy source, or renewable energy was not so widespread.

Table 3

	Dependent variable							
	Ln (cumulative wind power capacity, 2001-2006, in MW)							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Ln(oil price(-1))	1.78 (0.31)***	0.89 (0.41)**					0.26 (0.44)	-0.05 (0.42)
Ln(coal price(-1))			1.05 (0.29)***	0.31 (0.27)			0.49 (0.26)*	0.40 (0.26)
Ln(gas price(-1))					1.15 (0.22)***	0.84 (0.34)**	0.78 (0.25)***	0.77 (0.26)***
Ln (GDP per capita)	1.75 (0.72)**	6.03 (1.01)***	1.76 (0.72)**	7.20 (0.91)***	1.69 (0.72)**	4.15 (1.75)**	1.68 (0.73)**	3.77 (1.84)**
Country fixed effects	No	Yes	No	Yes	No	Yes	No	Yes
Observations	98	98	98	98	79	79	79	79
R-squared	0.28	0.96	0.27	0.96	0.28	0.97	0.28	0.98

Estimation method: Ordinary Least squares, pooled and fixed effects
White Period Standard Errors are given in parentheses.
*** significant at 1%, ** significant at 5%, * significant at 10%

In order to test the robustness of results obtained from first set of regressions I introduce a new dependent variable, and estimate the same regressions, only with the new regressand – gross electricity generation from wind in Gigawatt-hours. In order to remedy potential serial correlation, robust White Period Standard Errors were used throughout the analysis. Equations (1)-(6) were estimated as in the equation below, by regressing electricity generation from wind on different fuel prices, one by one and GDP per capita. Two panel data methods applied in the previous set of regressions are also applied here: Pooled OLS and country fixed effects.

$$\ln(Generation_{it}) = \alpha + \beta * \ln(Fuelprice_{it_{-1}}) + \gamma * \ln(GDPc)_{it} + \mu_i + \varepsilon_{it}$$

Where μ_i is country fixed effects, $\ln(GDPc)_{it}$ is a variable which controls for natural log of GDP per capita, as measured in €2001, $\ln(Fuelprice_{it_{-1}})$ stands for crude oil, steam coal and natural gas lagged prices, taken one by one.

Regressions (7) and (8) were estimated as in the equation below, with Pooled OLS and fixed effects.

$$\ln(Generation_{it}) = \alpha + \beta * \ln(Oilprice_{it_{-1}}) + \beta * \ln(Gasprice_{it_{-1}}) + \beta * \ln(Coalprice_{it_{-1}}) + \gamma * \ln(GDPc)_{it} + \\ + \mu_i + \varepsilon_{it}$$

where μ_i is country fixed effects, $\ln(GDPc)_{it}$ is a variable which controls for natural log of GDP per capita, as measured in €2001, $\ln(Oilprice_{it_{-1}})$ stands for the lagged price of crude oil, $\ln(Gasprice_{it_{-1}})$ stands for the lagged price of natural gas and $\ln(Coalprice_{it_{-1}})$ stands for the lagged price of coal.

Results of regressions are depicted in Table 5 below.

Table 5

	Dependent variable							
	Ln (gross electricity generation from wind, 2001-2006, in GWh)							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Ln(oil price(-1))	1.80 (0.30)***	0.72 (0.39)*					0.61 (0.75)	0.0004 (0.34)
Ln(coal price(-1))			0.95 (0.27)***	0.14 (0.23)			0.42 (0.25)*	0.38 (0.22)*
Ln(gas price(-1))					1.12 (0.22)***	0.91 (0.34)***	0.56 (0.53)	0.81 (0.39)**
Ln (GDP per capita)	2.07 (0.83)**	7.58 (1.60)***	2.09 (0.83)**	8.65 (1.33)***	1.98 (0.83)**	4.30 (2.13)**	1.98 (0.85)**	3.93 (2.24)*
Country fixed effects	No	Yes	No	Yes	No	Yes	No	Yes
Observations	98	98	98	98	79	79	79	79
R-squared	0.31	0.97	0.30	0.97	0.30	0.98	0.30	0.98

Estimation method: Ordinary Least squares, pooled and fixed effects
White Period Standard Errors are given in parentheses.
*** significant at 1%, ** significant at 5%, * significant at 10%

The results of this set of regressions are consistent with the previous results. Gas price is significant and positive in all regressions, which it enters, except one (column (7)). The oil price is significant by itself and shows that 1 percent increase in the oil price in the previous period causes 1.8 percent more investment in this period, holding all other factors fixed. However, once regressed together with other fuel prices, it does not have that effect anymore. The coal price is significant at 10% level in regression (8), once fixed effects have been controlled for; this result is new. However, we can trust the first set of results more, as generation of wind electricity not only depends on the capacity of power, but also on the availability of wind and actual performance of wind turbines. Certain disruptions in the performance of the wind turbines, if they appear in some years, and not in the others, can affect generation. However, only with the second set of variables it is possible to account for year fixed effects, which will be done in the remainder of the section.

Taking into consideration that panel datasets often suffer from serial correlation in the residuals, data has been transformed into Log-Differenced form in order to remedy potential serial correlation and further test the robustness of the results. Log differencing is identical to first differencing as far as both eliminate unobserved effects, however, coefficients of variables in the log-differenced equation can be interpreted as elasticities of the changes in investment in wind with respect to the changes in fuel prices. Analysis has been performed using the same set of fuel prices at the RHS and cumulative wind power capacity installed at the LHS: columns (1) through (3) were estimated by interchanging different fuel prices as in the following equation:

$$\Delta \ln(Capacity_{it}) = \alpha + \beta * \Delta \ln(Fuelprice_{it_{-1}}) + \gamma * \Delta \ln(GDPc)_{it} + \Delta \ln u_{it}$$

where $\Delta \ln(Capacity_{it})$ is wind power capacity, $\Delta \ln(Fuelprice_{it_{-1}})$ is price of crude oil, natural gas and steam coal, $\Delta \ln(GDPc)_{it}$ is GDP per capita, all variables are log-differenced across time. Column (4) was estimated by including natural gas and steam coal prices, and column (5) by including the oil price together with the gas price, as given in two equations below. Results of the regressions are presented in Table 6 below.

(4) $\Delta \ln(Capacity_{it}) = \alpha + \beta * \Delta \ln(Coalprice_{it_{-1}}) + \beta * \Delta \ln(Gasprice_{it_{-1}})\gamma * \Delta \ln(GDPc)_{it} + \Delta \ln u_{it}$

(5) $\Delta \ln(Capacity_{it}) = \alpha + \beta * \Delta \ln(Oilprice_{it_{-1}}) + \beta * \Delta \ln(Gasprice_{it_{-1}})\gamma * \Delta \ln(GDPc)_{it} + \Delta \ln u_{it}$

Table 6

	Dependent variable				
	First difference of ln (cumulative wind power capacity), 2001-2006, MW				
	1	**2**	**3**	**4**	**5**
Dln(oil price(-1))	0.09 (0.31)				0.15 (0.40)
Dln(coal price(-1))		-0.01 (0.20)		0.35 (0.90)	
Dln(gas price(-1))			0.02 (0.48)	0.65 (1.73)	-0.10 (0.55)
Dln (GDP per capita)	0.97 (1.34)	1.07 (1.34)	2.87 (1.36)**	2.82 (1.44)*	2.82 (1.44)*
Observations	78	78	59	59	59
R-squared	0.01	0.01	0.07	0.07	0.07

Estimation method: Log-differenced estimator
White Period Standard Errors are given in parentheses.
*** significant at 1%, ** significant at 5%, * significant at 10%

As a result of these regressions, I estimated that increase in oil, gas and coal prices increases investment in the next period, but the estimates are not statistically different from zero. GDP per capita is significant in columns (3), (4) and (5). For example, point estimate in column (3) suggests that holding gas price fixed, 1 percentage point higher GDP per capita means that the country invests 2.87 percentage points more in wind energy in a given year. Oil price, when taken by itself, was significant in regression (2) of Pooled OLS and fixed effects, with log-differencing we can not reject the null that the coefficient is equal to zero. Log-differencing fully eliminated the unobserved effects, and is a suitable model for estimation with data, which suffers from serial correlation. The coefficient on gas price in column (3) of the table above is not statistically significant at any conventional significance level. Neither it is significant when included together with coal and oil prices, respectively.

Due to the fact that Pooled OLS, Fixed Effects and Log-Differencing game me different results, I suspect that the sample suffers from serial correlation, which is eliminated in the differenced estimator. Therefore, I performed tests for serial correlation in the residuals following E-Views 5.1 User's Guide (2005). Tests for the presence of common unit root process in the data for cumulative installation of wind power provided me with the following results: Levin, Lin and Chu (LLC) test failed to reject the null of a unit root; Hadri test statistic, which tests the null hypothesis of no unit root, rejected the null in favor of unit root. Other test, which assume individual unit root process give contradictory results: IPS and Fisher PP fail to reject the null of a unit root, whereas ADF-Fisher rejects the null of a unit root. Moreover, looking at correlogram of the same variable, which displays autocorrelation, we can see that the first lag of the variable has an autocorrelation coefficient of 0.786, which also implies high degree of correlation between the residuals over time, second lag has coefficient of 0.559 which is still high. Durbin Watson statistic shows a value of 1.7 which is close to 2, meaning that differenced estimator eliminated serial correlation in the residuals.

As a result of performing all the tests for serial correlation, described in the paragraph above, most of which implied high degree of correlation and process which is close to unit root, following Wooldridge (2003), I conclude that estimation using Log-differenced variables is the most trustworthy in the presence of serial correlation. Fixed Effects estimation fails to estimate the relationships between the regressand and the regressors correctly in the presence of high serial correlation in the idiosyncratic errors. According to Wooldridge (2003), taking first difference of all variables, and similarly, first difference of their logs, transforms an integrated time series process into a weakly dependent process, eliminating autocorrelation in the errors.

Results of log-differenced estimation imply that, when the fixed effects have been accounted for, the fuel prices do not directly feed into the investment in wind energy. Therefore, if it is not fuel prices which determine level of investment in wind power capacity in Europe, then the other factors deserve more attention: EU and its member countries' wind energy policies, aimed at increasing deployment of wind power and other renewable energy sources. These policies are influenced by the increasing trend in the fuel prices, uncertainty about the future prices of oil and natural gas and concerns about their depletion. According to Martino and Fiorello (2008), issues of security of energy supply and energy availability are occupying an important place in the agenda of European governments (Martino and Fiorello 2008). Moreover, the authors state that oil price hike of 2008 proved that oil and other fossil fuels are limited resources, therefore, it is inevitable that their prices will increase over time, as demand will expand once the world economies have recovered from the current financial crisis.

Therefore, the results of all the estimation methods bring us to a conclusion that country fixed effects play an important role for the investment in wind power. High energy prices have an overall impact on the policies of European countries. This way, energy prices have an indirect impact on the investment decisions, which is through the policies.

Another important issue at the European agenda is meeting the targets for decreasing overall emissions of greenhouse gases (GHG's) by world developed countries by 5% (compared against the base year levels – 1990) by 2012. In the framework of reducing emissions of 6 greenhouse gases and combating climate change, each country has a domestic target to meet. For example, target for Germany are Denmark is 21% reduction of GHG emissions, whereas for European Community as a whole it is 8% and for France and Finland the reduction has not been stipulated, it is 0% (The Kyoto Protocol and climate change – background information 2002).

These targets, along with the concerns over the uncertainty of the future of energy prices and its availability, stimulate adoption of legislation aimed at improving energy efficiency and promoting renewable energy in the EU member countries.

In order to see whether using country specific end user natural gas and electricity prices gives different results that using spot prices of fuels, I have used these as second set of regressors. Cumulative capacity of wind power has been regressed on natural gas and electricity prices for industries using Pooled OLS, fixed effects and log-differenced estimator. in accordance with the equations below:

(1),(2): $\ln(Capacity_{it}) = \alpha + \beta * \ln(Gasprice_{it_{-1})} + \gamma * \ln(GDPc)_{it} + \mu_i + \eta_t + \varepsilon_{it}$

(3), (4): $\ln(Capacity_{it}) = \alpha + \beta * \ln(Electricityprice_{it_{-1})} + \gamma * \ln(GDPc)_{it} + \mu_i + \eta_t + \varepsilon_{it}$

(5): $\Delta \ln(Capacity_{it}) = \delta \ + \beta * \Delta \ln(Gasprice_{it_{-1}}) + \gamma * \Delta \ln(GDPc)_{it} + \Delta u_{it}$

(6): $\Delta \ln(Capacity_{it}) = \delta \ + \beta * \Delta \ln(Electricityprice_{it_{-1}}) + \gamma * \Delta \ln(GDPc)_{it} + \Delta u_{it}$

Results of the regressions are presented in Table 7 below, for Pooled OLS and fixed effects estimation logarithmic form of the variables is used, for log-differenced estimation – log difference of the variables is used. μ_i and η_t are not present in the regressions, as fixed effects cancel out in the differencing.

As can be seen from Table 7 below, point estimate for gas price is positive, but not statistically significant in regressions (1)-(3). As a result of regressions in columns (4)-(6), we can not reject the null that coefficient for electricity price is different from zero. Coefficient on GDP is significant at 5 and 10 percent levels in Pooled and fixed effects regressions, however, it is not statistically significant in log-differenced regression. This means that in Pooled OLS, unobserved factors, which are represented by policies, are affecting the regressand and correlated with the right-hand side variable GDP per capita, therefore the regression suffers from omitted variable problem. Fixed effects regression does not estimate the coefficients correctly in the presence of serial correlation. Log-differenced estimator eliminates the unobserved factors and takes account of serial correlation. With log-differenced estimation, all coefficients are not statistically significant, which means that, once unobserved country heterogeneity has been controlled for, prices and GDP per capita do not have a statistically significant impact on wind power investment.

It is important to note, that a possible explanation of such a result is the fact that end user prices are quite often regulated to some extent, therefore, we would not see a substitution effect with the end user prices.

Table 7

	Dependent variable: Ln (cumulative wind power capacity, 2001-2006, MW)					
	Pooled	Fixed Effects	Log-differencing	Pooled	Fixed Effects	Log-differencing
Gas price$_{t-1}$ for industries	1.31 (1.70)	0.68 (0.54)	0.19 (0.18)			
Electricity price$_{t-1}$ for industries				29.98 (25.96)	-0.30 (0.43)	0.12 (0.22)
GDP per capita	1.39 (0.77)*	3.13 (1.56)**	1.11 (1.36)	1.48 (0.75)*	3.41 (1.77)*	1.41 (1.42)
Country and Year fixed effects	No	Yes	N/A	No	Yes	N/A
Observations	87	87	67	91	91	70
R-squared	0.23	0.98	0.02	0.25	0.97	0.02

Estimation method: Pooled OLS, Fixed Effects and Log-difference
White Period Standard Errors are given in parentheses.
*** significant at 1%, ** significant at 5%, * significant at 10%

Conclusion

The purpose of this paper is to analyze the determinants of growth in wind energy investment, and to identify to what extent the EU wind energy policy and fuel prices have had an impact on the installations of wind power capacity. In this paper, I have tested an empirical relationship between fuel prices and investment in wind energy. Methodology used to estimate the relationship is Pooled OLS, Fixed Effects and Log-difference. Unobserved factors, policy schemes are present in the model.

Pooled regressions suggest that fuel prices matter for the investment in wind, as coefficients for natural gas price are statistically significant at 1% level (Table 3, column (7)). However, due to unobserved factors affecting the investments in wind power, which are energy policies in the EU countries, OLS suffers from omitted variable bias. Using fixed effects, we obtain positive and statistically significant relationship between natural gas price and investment in wind power capacity (Table 3, column (8)). We can not fully trust the result of fixed effects estimation due to the presence of serial correlation. Therefore, log-differenced estimator has been used, which has eliminated both the unobserved effects and auto-correlation in the residuals. From log-differenced equation we can conclude that once the unobserved effects have been controlled for, energy prices in the previous period do not determine the level of investment in the following time period. Therefore, I concluded that unobserved effects are important for the investment in wind power. These unobserved effects being wind power support schemes in the European Union member countries, we have come to a conclusion, that the support schemes play a major role in the development of wind industry in these countries.

Moreover, GDP per capita is important variable as it appears positive and significant not only in Pooled OLS and fixed effects, but also in some of the log-differenced regressions. High GDP per capita leads to higher level of investment in wind power, ceteris paribus.

Results obtained from regressions with end user gas and electricity prices as RHS variables gave the following results: end user prices do not seem to matter for the development of wind industry, as they are significant in none of the regressions. This is partly due to the government regulation of the end user prices for natural gas and electricity. Therefore, the overall conclusion of the paper is that national wind energy policies in the EU countries have contributed to the investment in wind energy and drive the growth of wind industry, along with decreasing production costs of wind power. Long term planning horizons and stable framework, security for investors and elimination of various administrative and grid access barriers for wind power producers are main factors which make an effective support scheme.

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Appendix

Figure 6. Gross electricity generation from renewables in EU27 in 1995, by renewable energy source, in GWh

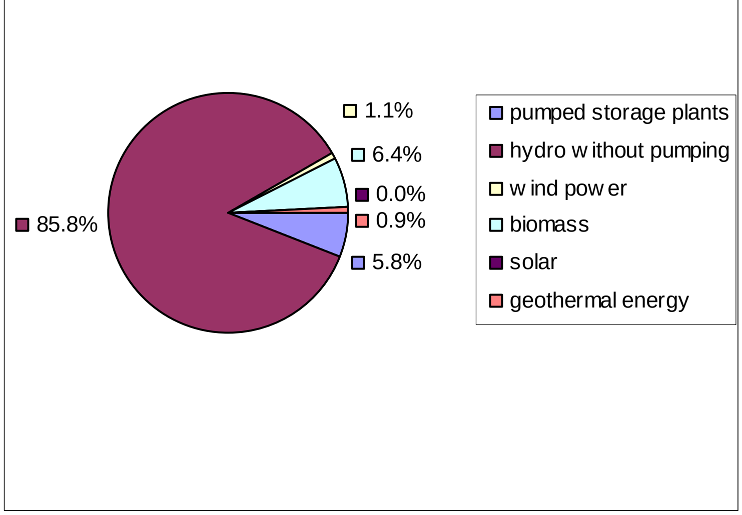

Figure 7. Gross electricity generation from renewables in EU27 in 2006, by renewable energy source, in GWh