Determinants of Renewable Energy in EU

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1. Introduction and motivation

Climate change imposes real challenges to societies' environmental and economic wellbeing. This state of affairs urges us to think on ways to cope with the effects of climate change as well as finding potential alternatives to the roots of this human-caused phenomenon. Climate change has put a question mark on the traditional energy sources like coal, oil and natural gas, which have contributed to high levels of pollution and greenhouse gas emissions worldwide. Two thirds of total carbon dioxide emissions in the world come from the energy sector and their effect on human livelihood is increasingly negative. There are two potential ways of offsetting the impact of such emissions - adaptation and mitigation. Adaptation refers to the efforts to limit human exposure to climate change. Mitigation is related to human activities intended to reduce the magnitude of climate change and its impact on human life. Mitigation in the energy sector involves a two-fold strategy: reduction of carbon dioxide emissions through efficiency gains in energy consumption and production, and the shift to other, cleaner forms of energy production through the adoption of alternative sources. Renewable energy adoption is an important mitigation strategy for several countries like Germany, India and China. Renewable energy targets featured prominently in the Paris Agrement of 2015 where countries adopted legally binding targets to keep the average global temperatures from rising more than 2 degree celsius. Recent studies by Eyraud et al. (2011) and Del Río, Tarancón, and Peñasco (2014) identified that renewable energy sources will be the key drivers of the energy sector in coming years.

The main objective of this research project is to identify what are the determinants of renewable energy, more specifically wind and solar energy, across European countries and to what extend factors, such as income, changes in fuel prices, and interest rates have an impact on prospects of green energy. We do so using techniques learnt in data management and analysis in the course 'MPP-E1180: Collaborative Social Data Analysis'.

2. Literature review

The literature on around factors that influence renewable energy is recent and evolving. The first question is how best to operationalize renewable energy development. A good measure would of course be investments in renewable energy. However, data on investment in renewable energy projects tends to be classified and not widely available. Romano and Scandurra (2011) show that there are different ways of assessing the development of renewable energy sources. One method is to measure the replacement of traditional energy sources in the total energy supply. Another method, which is also mentioned by Bird et al. (2005), is to measure the total amount of renewable energy produced. Each of those approaches were used by Marques, Fuinhas, and Manso (2010) and Carley (2009). Marques, Fuinhas, and Manso (2010) use the contribution of renewable to energy supply as a percentage of total primary energy supply while Carley (2009) focuses on the yearly electricity generation from renewable energy sources.

By adopting this approach, Romano and Scandurra (2011) conducted a dynamic panel analysis of the investments in renewable sources from 1980 to 2008 in a sample of 29 countries with distinct economic and social structures as well as different levels of economic development. The results of this study show that there is a continuity of investment behavior in those countries that have shown sensitivity towards renewable energy sources. Moreover, it shows that countries with traditionally stable high income tend to show more attention to technologies with lower environmental impact and improved energy efficiency in comparison with fast-growing countries. Authors also concluded that the presence of nuclear power plants may affect investments in renewable energy sources.

Another important study on green investments was conducted by Luc Eyraud and Clements (2011), which analyzes the factors affecting green investments between 2000 and 2010 in 35 advanced and emerging countries. The authors conclude that green investment is boosted by economic growth, a sound financial system conducive to low interest rates, and high fuel prices. They also find that some policy interventions, such as the introduction of carbon pricing schemes, or "feed-in-tariffs," which require use of "green" energy, have a positive and significant impact on green investment.

The Luc Eyraud and Clements (2011) study was replicated by Ilas (2014) on an updated dataset. The paper reaffrimed that GDP per capita has a positive impact over investments in green technologies, while GDP growth and variables related to human development capacity as well as technological progress were not found to be statistically significant.

This papers seeks to carry out an in depth analysis of the determinants of renewable energy across countries of the European Union. We follow in the footsteps of Ilas (2014), but include a wider set of EU countries. The analysis is carried on data from 28 EU countries from 2005 to 2013. The countries of the EU are similar in stage of economic development, human capital development and renewable energy policies as compared to a world wide set. Factors such cost of conventional energy, level of innovation and technological expertise might be expected to play a stronger role in explaining the differences in RE development across EU countries.

3. Data sources and description

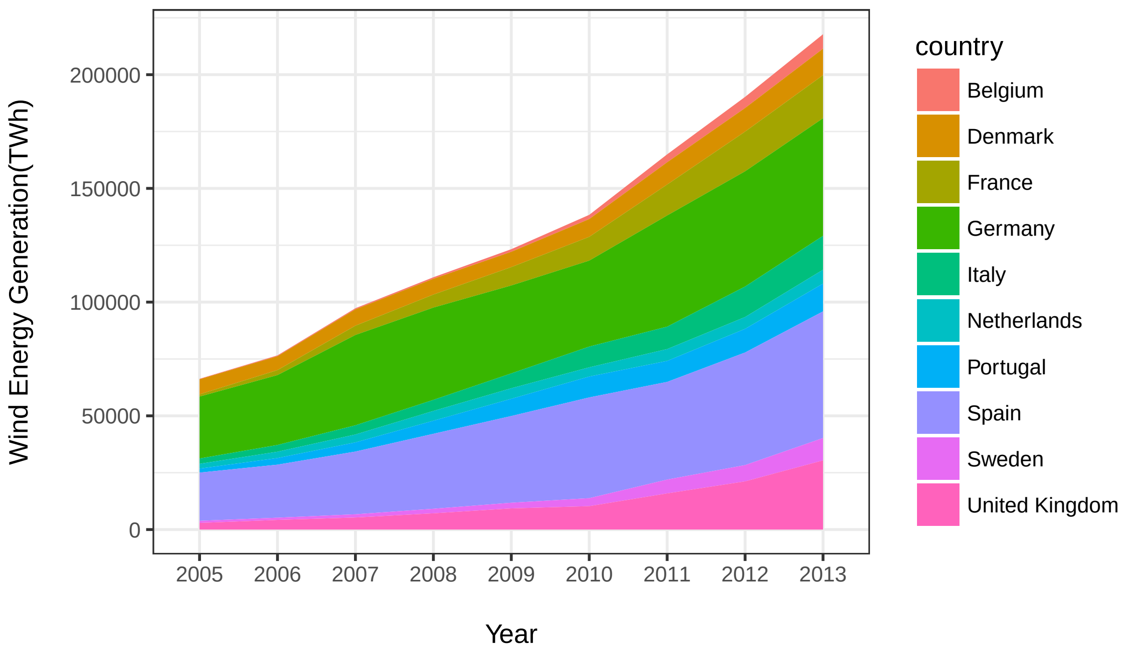
Dependent variable

We use **electricity generation** from Renewable Energy Sources (RES), namely wind and solar (photovoltaic), to operationalise the variable of our interest - renewable energy investments in the economy. Increase in renewable energy generation is expected to be correlated strongly with the underlying generation capacity and investments in renewable energy and is in line with the approach followed by Bird et al. (2005) and Carley (2009). The data on electricity generated from wind and solar energy (measured in Gigawatt-hour) is taken from the Eurostat database.[1][2]

Electricity generation from wind has been increasing every year in the last decade or so in EU countries. The graph below shows wind energy generation in the leading ten wind energy generating markets in EU from 2005 to 2013. Germany has been a leader in wind energy development, clearly seen in its large share of overall wind generation. Apart from Germany, Spain and increasingly UK and France are also important players in this market.

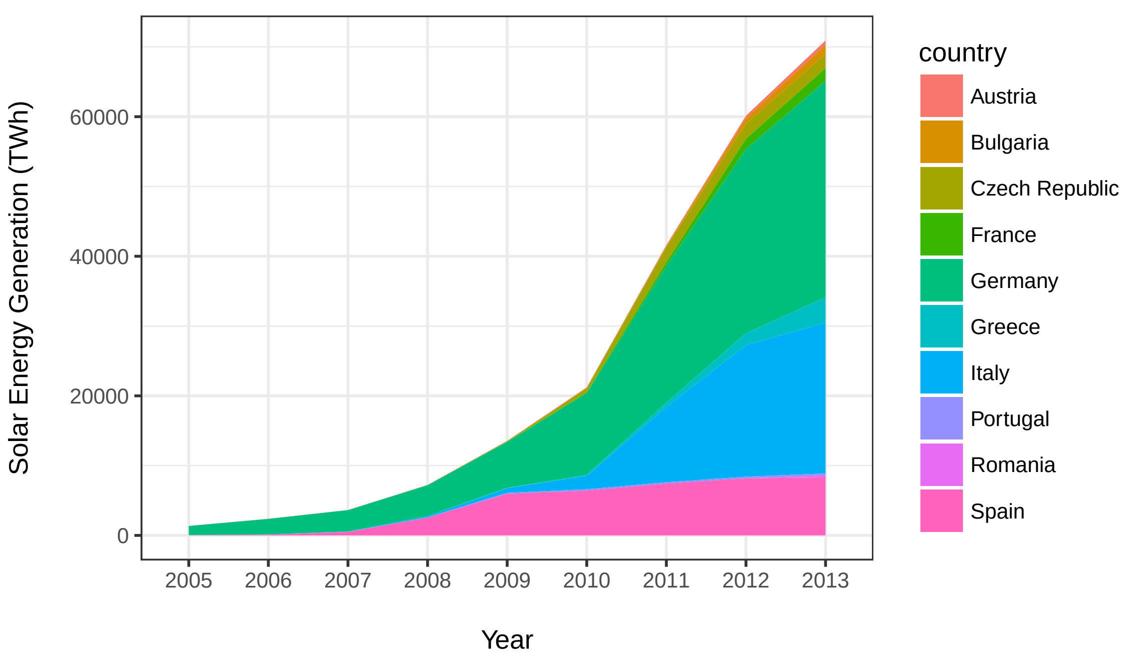
[1]Data available at http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do. Select wind and solar photovoltaic.
[2]The raw data downloaded from Eurostat is stored in the repository on Github and is accessible.

Wind Energy Generation in ten largest wind energy markets in Europe



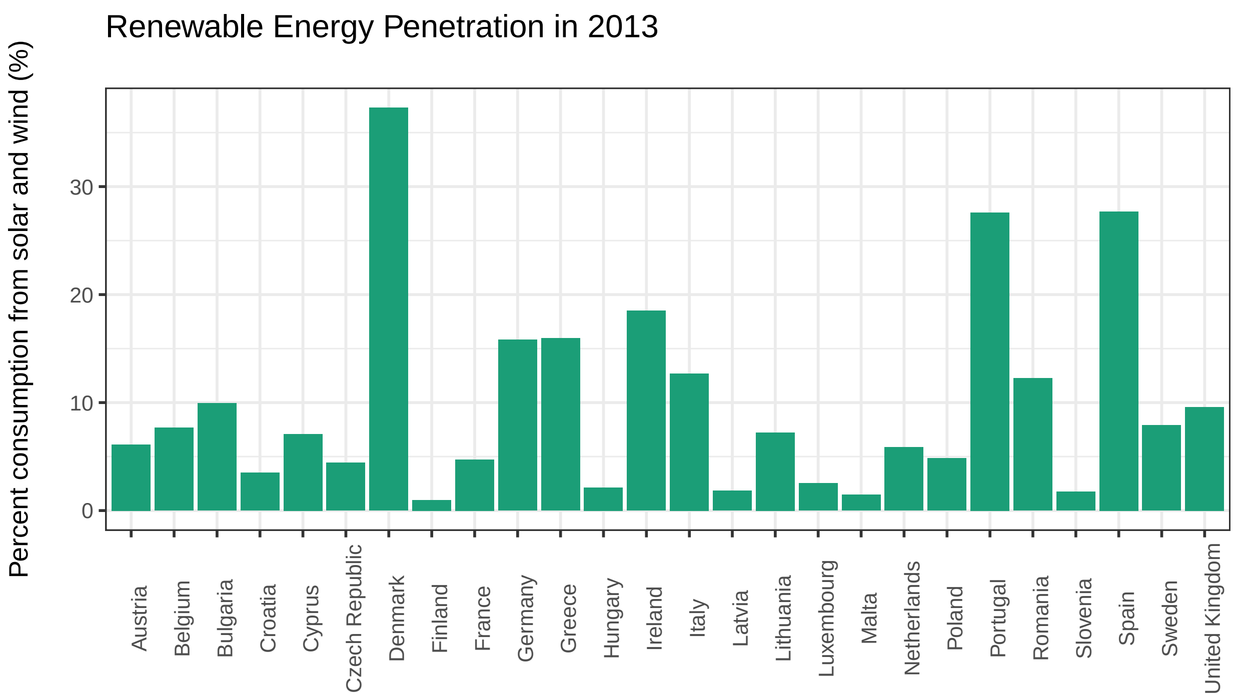
Solar electricity generation scenario is somewhat different. Electricity generation using solar photovoltaic technology was relatively small up to 2009. Since then it has grown rapidly. The graph below shows solar energy generation in the leading ten solar energy markets in the EU. Germany again is a consistent leader. Spain and Italy are also important solar energy markets and have seen an increase in their share of solar electricity generation since 2010.

Solar Energy Generation in ten largest solar energy markets in Europe



We also estimate an alternative model specification that uses **renewable energy penetration** as the dependent variable. This follows the approach adopted by marques2010motivations. In this paper renewable energy penetration is captured by calculating the share of total electricity consumption coming from wind and solar energy. Apart from helping us test the robustness of our model, the alternate specification has the added advantage that it allows us to meaningfully interpret country specific fixed effects. This variable is created using data from Eurostat database[3] on total electricity consumption in each country and electricity generated from wind and solar (photovoltaic) energy.

The graph below shows the renewable energy penetration across the 26 EU countries in 2013. There is significant variation in the proportion of electricity attributable to wind and solar energy, from over 30 percent in Denmark to less than 5 percent in Latvia and Hungary. In general, the countries that are appear to have the highest quantities of wind and solar electricity generation - Germany, Spain, Italy and United Kingdom - also have high penetration of renewable electricity.



Explanatory variables

Long-term interest rates: Higher interest rates imply that business will have less incentives to invest in renewable sources whereas lower interest rates foster long-term investments. We thus expect interest rates to be negatively related to renewable energy development. As the realization of investments especially those related to infrastructure occurs in the long-run, a ten-year maturity interest rate is used in this analysis. The indicator chosen for this study is the Maastricht criterion bond yields which is used as a convergence criterion for EMU for long-term interest rates (central government bond yields on the secondary market, gross of tax, with around 10 years' residual maturity). This data is obtained from Eurostat.[4]

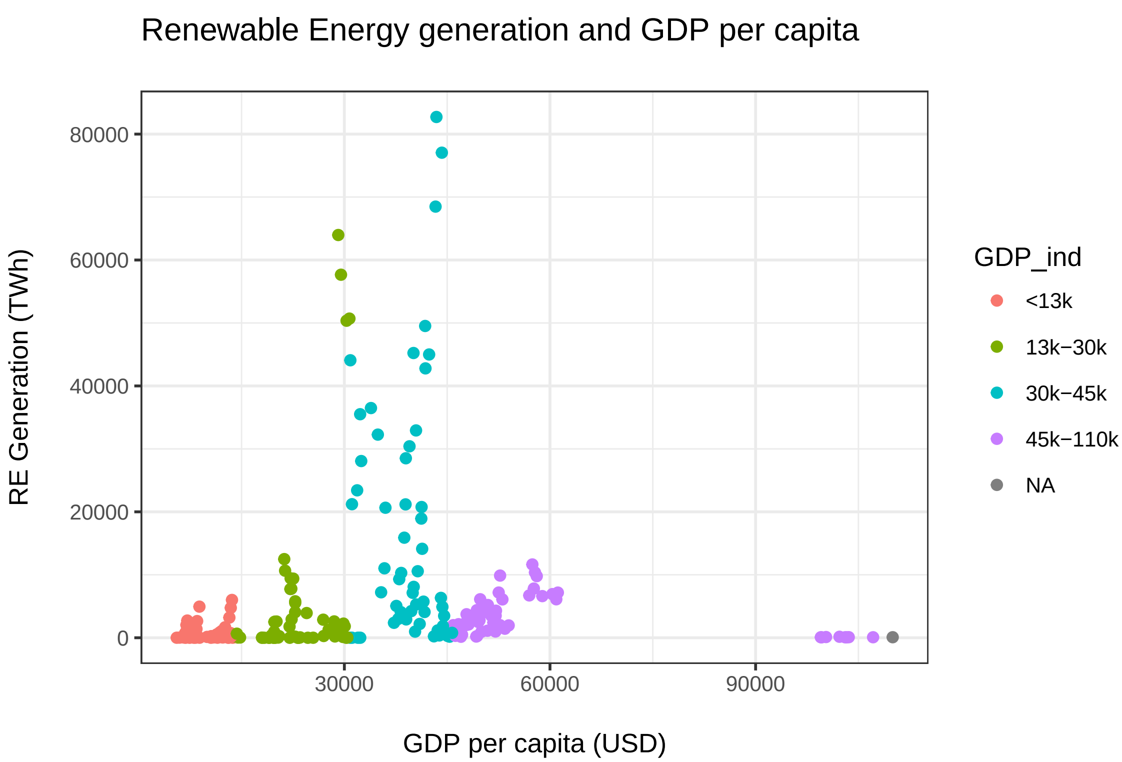
Crude oil prices: Crude oil prices can be used as proxy for the demand of energy from fossil fuels. We hypothesize that a higher price in crude oil means higher demand, or at least, scarcer availability of fossil fuels in general, and therefore, it may produce an incentive for countries to invest in renewable energy sources. The benchmark for crude oil price is the OPEC Reference Basket. This basket represents the average of

[3]Data available at http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do
[4]Data available at http://ec.europa.eu/eurostat/web/interest-rates.

prices of petroleum blends produced by OPEC members. The historical data for oil price is obatined from the OPEC website.[5]

GDP per capita: In the literature, Gross Domestic Product is often associated with higher levels of green investment. We use data available from the World Development Indicators on Gross Domestic Product per capita.[6][3a] This is calculated as Gross Domestic Product divided by midyear population, in constant 2010 USD to correct for domestic inflation and exchange rate fluctuations.

A plot between log income and RE generation reveals that in EU the relationship between Gross Domestic Product per capita and renewable energy is not straight forward. Countries in the highest quartile of income are not the ones with highest level of RES generation; countries in the third income quartile display the highest level of RES generation. The data is also right skewed.

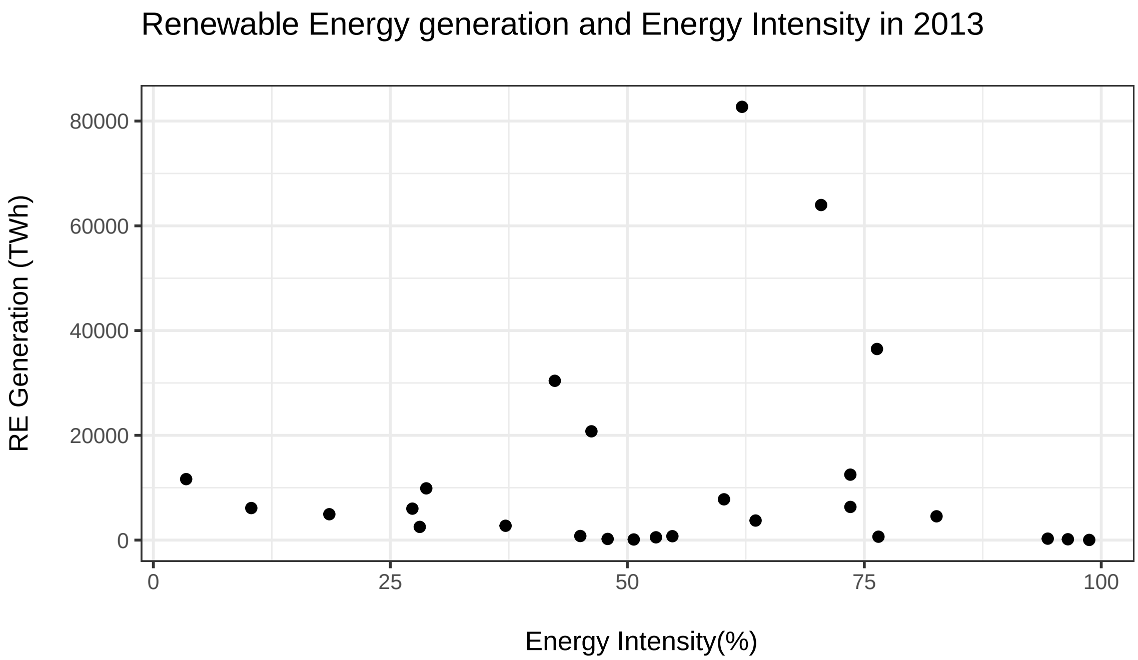


Political support for renewable energy: The percentage voteshare of the green parties in the most recent elections is taken as a measure to gauge the public support for renewable energy. We derive this data from the previous work done by Abou-Chadi (2016).[7] We expect that higher public support for renewables, as demonstrated by higher voteshares of green parties, would be positively related with the level of renewable energy penetration.

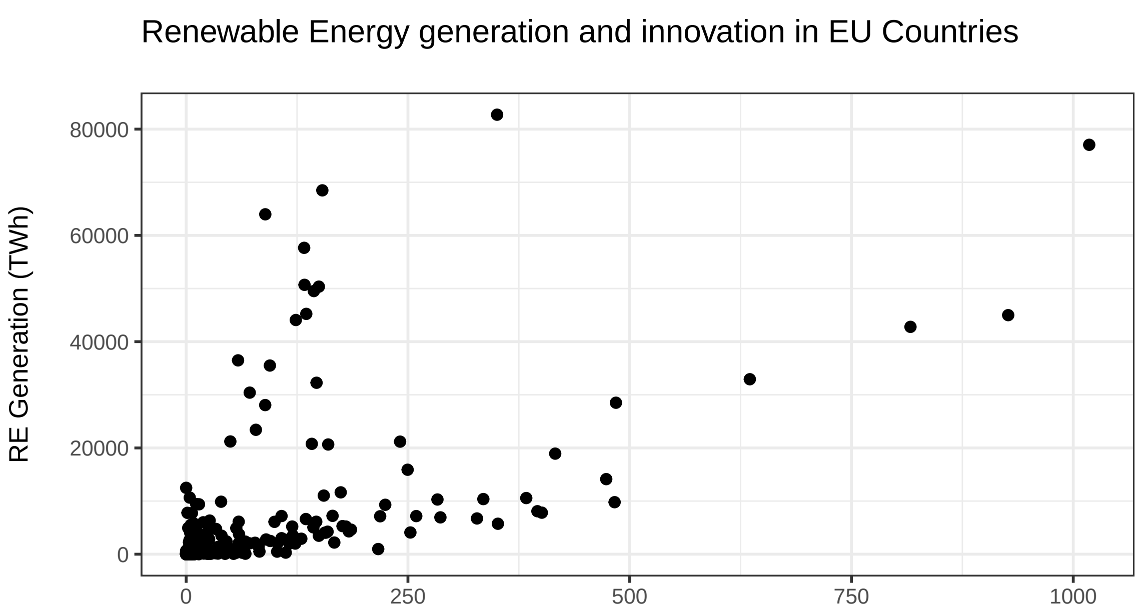
Energy imports, net (% of energy use): Energy imports indicate the country's dependence on energy from other countries. We expect that higher energy imports incentivize countries to use electricity generated locally via wind and solar energy sources. The data on net energy imports is obtained from World Development Indicators[8] and is estimated as energy use less production, both measured in oil equivalents. Energy use refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport.

[5] Data available at http://www.opec.org/opec_web/en/data_graphs/40.htm.
[6] Data available at http://data.worldbank.org/indicator/NY.GDP.PCAP.KD?locations=BY.
[7] Data available at: https://www.cambridge.org/core/journals/british-journal-of-political-science/article/div-classtitleniche-party-success-and-mainstream-party-policy-shifts-how-green-and-radical-right-parties-differ-in-their-impactdiv/AEF265EED2CAA81C35A3808F47F5908A#fndtn-supplementary-materials.
[8] Data available at http://data.worldbank.org/indicator/EG.IMP.CONS.ZS?locations=BY.

Looking at aggregate data there does not seem to be any clear relationship between energy imports and renewable energy generation. Except for a few countries which have moderate level of energy imports and are also doing well in terms of RES generation, there does not seem to be a distinct relationship.



Innovation in Renewable Energy: The number of patent applications in renewable energy is used as a proxy for innovation in clean energy. It is expected to be positively related to investments in renewable resources. Number of patents applications submitted to the European Patent Office for renewable energy/climate mitigation by the country is obtained from the Eurostat database.[9]



[9]Data available at http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=pat_ep_nrg&lang=en.

4. Research Design

To estimate the determinants of renewable energy, a pooled OLS regression is estimated. We take the log of the variable GDP per capita to reduce the skewness in the data.The estimates obtained using pooled OLS are likely to be biased as a number of unobserved factors - geographic and institutional features of the country - may also affect development of renewable energy. To control for these unobserved factors, a **fixed effects (FE)** regression for panel data is employed.[10]

The equation that we estimate is thus equivalent to:

$$y = \beta 1 * oilprice + \beta 2 * log(GDPpercapita) + \beta 3 * greenpartyvote + \beta 4 * interestrate + \beta 5 * patents + \beta 6 * netenergyimports$$

5. Key Results

The results of the pooled OLS regression, shown in the table below, indicate that GDP per capita, oil price, political support and innovation are important factors in determining renewable energy growth. But the sign of the coefficient of GDP and political support is counter intuitive.

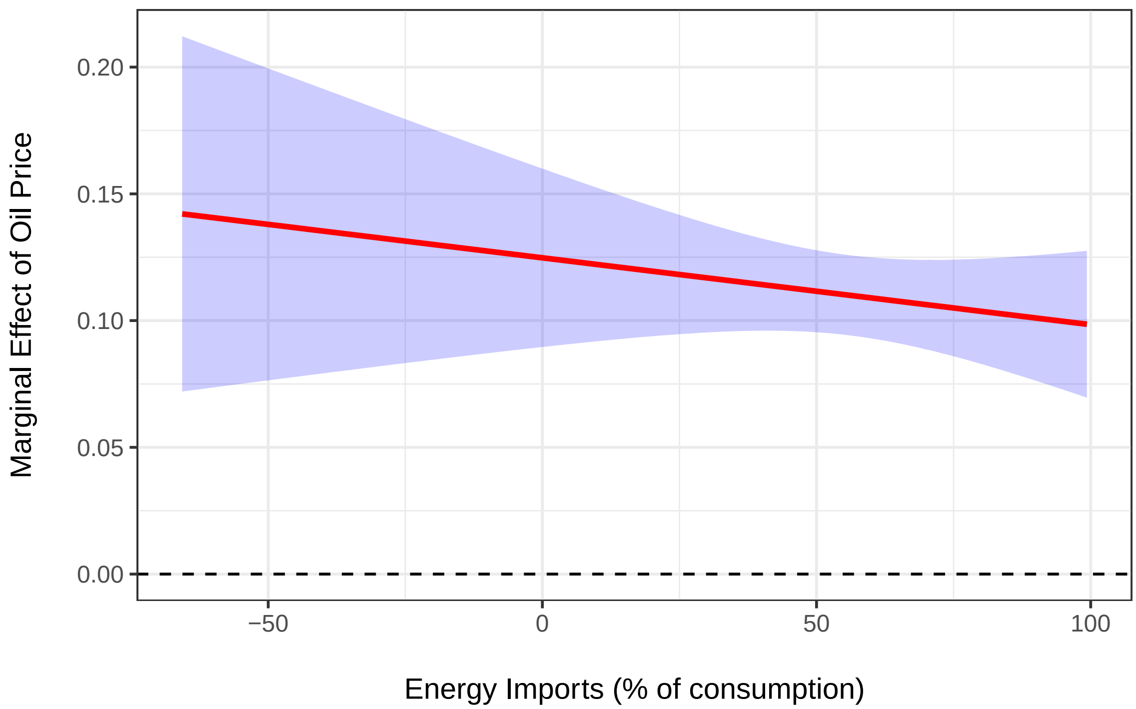
We prefer the estimates of the fixed effects model for both choices of our dependent variable - (1) actual electricity generation from wind and solar **(re_gen)** (2) percent of electricity consumption coming from wind and solar **(sw_pc_elec)** or . The results of the fixed effects estimations are also shown in the table below.

	Dependent variable:		
	re_gen		sw_pc_elec
	(1)	(2)	(3)
log(GDP per capita)	−369.468	−23,487.600***	−18.210***
	(1,274.417)	(7,399.235)	(3.543)
Energy Imports (	(26.714)	(61.979)	(0.030)
Interest Rate	−643.332*	−446.263**	0.006
	(353.938)	(214.134)	(0.103)
Oil Price	99.044***	143.109***	0.110***
	(32.201)	(16.908)	(0.008)
sumgreen	−903.361***	−1,627.951**	−0.224
	(248.725)	(639.136)	(0.306)
patents	61.005***	−3.418	−0.002
	(5.550)	(4.653)	(0.002)
Constant	−3,049.173		
	(13,365.710)		
Observations	234	234	234
R^2	0.420	0.274	0.498
Adjusted R^2	0.407	0.236	0.430
F Statistic	27.352***	12.702***	33.346***
Note:			*p<0.1; **p<0.05; ***p<0.01
			(1) Pooled OLS (2) Fixed Effects (3) Fixed Effects

[10] LM test and Hausman test confirms that fixed effects model is a better model than pooled OLS or random effects model. Refer to Diagnostics.

The coefficient of **oil price** is statistically significant at 1% level of significance in both the fixed effects models. The sign on the coefficient of oil price is positive, as expected. It also has substantive significance - an increase in price of oil by $1 is associated with 0.11 percent increase in the share of solar and wind in total electricity consumption. Thus in line with the findings in the literature we find that increase in cost of conventional energy is an impetus for renewable energy development.

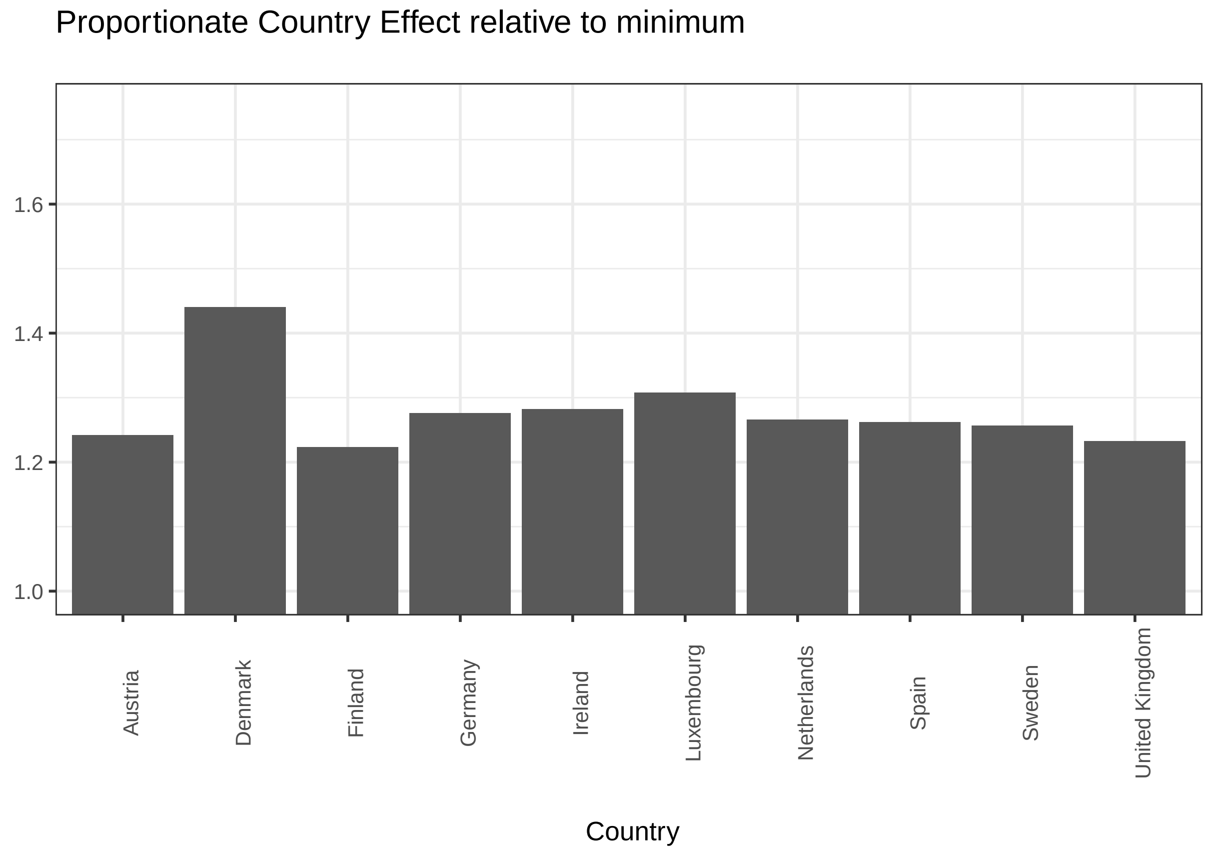
We also tested if the price of oil has a greater role to play in the countries of the EU that are more dependent on energy imports. Specifically we look at whether the effect of oil price on RE penetration increases with the import intensity of the country. Intuitively we would expect such an effect; a country that imports a lot of fossil fuels can be expected to react more when oil price increases. To test this we estimate a model specification with the interaction of variables 'oil price' and 'net energy imports'. The partial effect of oil price on renewable energy penetration across various levels of energy imports can be seen in the graph below. It seems that the effect of oil price does vary across energy imports but the difference is not statistically significant.



The coefficient of **GDP per capita** is statistically significant at 1% level of significance in both the fixed effects models. The sign of the coefficient of GDP per capita is negative contrary to expectation. One reason for this might be that the dependent and independent variables seem to be trending over time, which could lead to spurious regression results. In order to de-trend the series, another FE model specification with a time trend and year dummies was also estimated. The negative sign persists in all model specifications and even on inclusion of the time trend. More work is needed to understand this counter-intuitive relationship.

The coefficients on **interest rate** and **net energy imports** are statistically significant with the correct sign in one of the fixed effects models but insignificant at the usual levels of significance in others. The variable capturing political support has a negative sign, which is again counter intuitive. The coefficient of patents is statistically insignifiant in both fixed effects models.

We also extract **country specific fixed effects** from the fixed effects model, which are comparable to country specific dummies in an OLS regression. This is done for the model specification which has share of consumption coming from wind and solar as the dependent variable. The fixed effects captures the effect of country specific policies, regulatory environment, geographic location on RE development which are consistent over time and are not captured by the variables in the fixed effects model. We find that country specific fixed effects are statistically significant in explaining the level of RE penetration. The top ten countries with the highest fixed effects are shown in the graph below and include Denmark, Germany, Ireland and Spain. The next step would be to disentangle the effect of policy from fixed effects by creating a variable that captures the efficacy of renewable energy policies.



6. Diagnostics

- **Testing for Panel effects**: A Lagrange-Multiplier with the null hypothesis that there is no significant difference across units (i.e. no panel effect) was employed. The test returns a p value < 0.001, suggesting presence of panel effects.
- **Testing for Random vs. Fixed effects**: A Hausman Test with the null hypothesis that the preferred model is random effects vs. the alternative the fixed effects was used. The test returns p value <0.001. Therefore, fixed effects is preferred over random effects as the latter would provide inconsistent coeffeicient estimates.
- **Multicollinearity**: A VIF test confirms that there is no significant collinearity between the explanatory variables.
- **Heteroskedasticity**: A Breusch-Pagan test is carried out with the null hypothesis being homoskedasticity. A p-value < 0.01 indicated presence of heteroskedasticity. In order to correct for serial correlation in errors and heteroskedasticity we estimate robust standard errors (using the vcovHC "arellano" estimator which corrects for both heteroskedasticity and serial correlation and is recommended for fixed effects). There is however no significant variation in regression results and levels of significance of the variables GDP per capita and oil price. But the coefficient for net energy imports is no longer significant.

7. Conclusion

8. References

Wickham and Francois (2016) and R Core Team (2015) works on R Programming were used as reference for this research proposal.

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