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Abstract

The aim of this study is to determine the nature of any relationship between renewable energy investment, oil prices, GDP and the interest rate, using a time series approach. We concentrate on three countries with different relationships to the renewable energy industry, with Norway and the UK being oil-exporters for most of the sample and the USA an importer. Following estimation using a VAR model, the results provide evidence of considerable heterogeneity across the countries, with the USA having a strong relationship between oil prices and renewable energy, Norway having a less pronounced relationship and the UK no relationship. These results reflect the fact that the USA is predominantly an oil-importer during most of this sample and supports renewable energy relatively less than the other countries, so changes to renewable energy investment reflect other factors in the market such as the price of substitutes to a greater extent than countries where renewable energy receives more government support. The main policy implications from this study are that in countries where there is little support for the renewable energy sector, investment will be more dependent on macroeconomic aspects as well as substitutes such as oil, therefore the authorities will need to potentially increase support when oil prices are low or when the economy is in a downturn.

JEL Code: E43, J11, Q28, Q42, Q43, Q48

Key Words: Renewable energy, VAR, Oil price, government policy

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1. Introduction

As concerns for the international environment grow, the international community needs to increase investment into the renewable energy sector by approximately $130bn over the next fifteen years. This is to ensure that carbon dioxide emissions peak in 2020 and global warming remains below 2°C (IEA, 2015), the generally accepted figure that, if broken, would push global warming to beyond acceptable limits. This means that investment into renewable energy needs to increase rapidly, but it is less clear what will facilitate this increase in renewable investment. The main factor considered here relates to whether the oil prices significantly affect investment and production of renewable energy. The price of oil has fallen by over 60% over the last 17 months, from highs of $107 in June 2014 to $40 in November 2015. This has created much debate on the potential effects it will have on investment into renewable energy. Clearly, there is no consensus on the effects that oil prices have on renewable investment, as it depends on the extent to which oil price changes encourage investment into renewable energy and so if the oil price increases from its current lows, as many analysts are predicting, what, if any, will be the impact of this rise be on renewables investment.

Following recent international agreements over the need to reduce greenhouse gases, such as the G8 statement that it aims to cut emissions by 50% before 2050, the means of achieving these cuts is becoming ever more important. One of the most commonly used policies has involved the use of renewable energy production as a substitute for fossil fuels. As international and European Union (EU) targets for reducing carbon dioxide emissions have become more important, so governments across the world have sought to expand the production of energy from renewable sources through the use mainly of subsidies and indirectly through additional taxation on fossil fuels. As a result, government intervention in the renewable energy market has been the dominant factor in determining renewable energy investment over the majority of the analysis period. Because government intervention in this market is declining, due to the increasing competitiveness of renewable technologies, and the substitution levels between renewable energy and oil is increasing, the conclusions from this study suggest that the relationship between renewable energy and its substitutes will become more significant and robust in some countries.

Most of the literature relating renewable energy to oil prices and the macroeconomy, have focused on how government policy can be used to encourage renewable investment, since historically renewable energy investment has not been able to compete openly with traditional fossil fuels in terms of cost, except in Norway. Sims *et al*., (2003) examined this relationship and the effect that reducing renewable costs may have. However, the authors noted how hard it is to generalise the costs of renewable energy, since it varies from location to location, and will include either costs or savings not usually experienced by traditional energy production, such as the increased costs from storing electricity, to the fact that solar energy is often installed at the point of the electricity use, so offsetting transportation and infrastructure costs. A common theme across this area of literature is that a major factor preventing investment into renewable energy is the uncertainty over the future returns it will provide.

Whilst there is a shortage of studies linking investment into renewable energy to oil prices, Sadorsky (2009) estimated a panel model of renewable energy consumption and included GDP as well as oil prices. They found that real per capita GDP and per capita CO_2 emissions were the main long-term drivers of consumption of renewable energy, whilst changes in oil prices had a weak negative relationship. Using G7 data, they found heterogeneity across the countries studied, with movements back towards equilibrium following a shock taking between a year and seven years. Apergis and Payne (2010) and (2011) also use a panel data model with cointegration and Granger causality tests to analyse the relationship between renewable energy consumption, GDP, investment and the labour force, finding evidence of a long-run equilibrium and bi-directional Granger causality between renewable energy consumption and GDP growth in OECD Countries and Central America. In addition, Henriques and Sadorsky (2008) showed that there existed a relationship between the stock prices of clean-energy stocks and oil prices, with movements in oil prices Granger causing the stock prices of the clean energy companies, which were also affected by movements in technology stocks and the interest rate in general. Apergis and Payne (2012) estimated a multivariable panel model for 80 countries finding bidirectional causality between renewable and non-renewable energy consumption and economic growth in both the short- and long-run. They further reveal that short-run bidirectional causality between renewable and non-renewable energy consumption is suggestive of substitutability between the two energy sources. Kumar *et al*. (2012) applied a VAR model to investigate the relationship between renewable energy prices, oil prices, technology stocks, interest rates and carbon prices. They find that oil prices and the interest rate movements affect renewable energy investment.

The aim of this paper is to contribute to the debate over the effects of oil prices and the wider economy on the use of renewable energy. In this context, we use annual time-series data for Norway, the UK and the USA from 1960 to 2015 and a vector autoregressive (VAR) approach to examine the relationships between oil prices, GDP and the interest rate with respect to renewable energy investment. We employ the generalized impulse response function (GIRF) and variance decomposition approaches to assess the response path of the renewable energy to a shock to itself and other variables in the model.

The main contribution of this paper is to extend the existing empirical literature in two ways. Firstly, we examine the effects of oil price shocks on renewable energy investment in both predominantly oil-exporting and oil-importing countries within the context of a time series model. Secondly, it differs to other similar studies in that it analyses three different countries individually, so accounting for differences in the country's reliance on oil and policies towards renewable energy. Most of the empirical studies have confirmed that increasing oil prices should stimulate greater demand and supply of renewable energy however this paper investigates the sensitivity of renewable energy investment to changes in oil prices, GDP and the interest rate (Rifkin, 2002; Bleischwitz and Fuhrmann, 2006; McDowall and Eames, 2006; New Energy Finance, 2007). Finally, we would expect the three countries analysed to respond in different ways to an oil price shock, from the perspective of renewable energy investment and related policies. This will enable us to determine if the investment of renewable energy is market determined such that it moves in the opposite direction to oil prices, or is being stimulated by the use of policies which aim to encourage increased production of energy from renewable resources. Policy makers explicitly need to understand how oil prices and macroeconomic variables impact on the renewable energy investment.

Following the introduction, this study analyses the background into renewable energy in the three countries investigated, following this we assess the data and results and finally we conclude with a discussion of the policy implications of the study.

2. Country Background and Policies

The paper focuses on individual country analysis, as the relationship between renewable energy, oil prices and other macrocosmic variables is likely to vary substantially across countries, depending on whether the country is a net oil-exporter or importer, its policies towards encouraging renewable energy and its overall wealth. The countries analysed are Norway, the UK and USA as they include predominantly net-exporters and importers of oil and have differing policy approaches to the renewable energy sector.

2.1. The Norway

Norway is unique in the world in being a major oil-exporter and also an early champion of renewable energy. It is also one of the wealthiest countries in the world in terms of per capita GDP. Norway is simultaneously the fourteenth largest oil producer and seventh largest renewable-energy producer in the world (Central Intelligence Agency and Eurostat respectively), for instance over 100% of Norway's electricity requirements are met by renewable energy, so it is able to export electricity as well as oil. Norway may therefore already have a hedge against oil price fluctuations. If the oil price increases but renewable energy remains constant, then Norway can meet more of its energy obligations using renewable energy rather than oil, and vice versa if the oil price decreases.

Through decades of revenue from oil, Norway has the largest sovereign/pension fund in the world (GPFG), and so has a buffer against any short term oil fluctuations, this is of vital importance to Norway since oil and gas contributes more than 30% of Norway's GDP (Brander *et al.* , 2013). The pension fund means that in an economic downturn resulting from a loss of oil revenue there are alternative sources of wealth, rather than debt, although current regulation that the government cannot withdraw more than 4% value of the fund per year restricts how effective this method can be (Milner, 2015). Norway has considered using the GPFG as a hedge itself against oil price changes through divesting from fossil fuels, although it is not, for the time being however, pursuing this opportunity.

Although Norway is a major exporter of renewable energy, domestic renewable energy supply as a percentage of total primary energy supply is consistently between 40% and 50%, and the overwhelming majority of this comes from hydropower (IEA, 2011). Norway has the largest share of renewable energy of any IEA member country and most renewable energy supply has been without subsidies, which is in contrast to many other countries - this is almost entirely because of its cost-competitive hydroelectric operations (IEA, 2011). In

2012 Norway and Sweden jointly introduced a green energy certificate scheme, which was a market based incentive scheme to encourage more investment in renewable energy, however in 2016 Norway left this scheme as it was felt to be undermining the hydroelectric producers of electricity.

Overall therefore, whilst at first glance it may look like the question of 'How will the price of oil affect investment into renewable energy' is obvious for Norway, with its reliance on oil, it actually may be better suited to deal with oil price changes than other countries, so the relationship between oil prices and the renewable energy sector may not be as apparent as in other countries.

2.2. The UK

Whilst, historically a large net-exporter of oil, since 2005 the UK has been a net-importer of oil. With the fall in the oil price from highs of $107 in June 2014 to $40 in November 2015 this has hit North Sea oil production hard – the UK has the highest oil production costs of any major oil producing country in the world at about $40 a barrel, compared to the Middle East, where oil can be produced for as little as $5 (Chan, 2015). This change in oil price has had contrasting effects on the UK, North Sea oil production has been hit, but the UK has also had an economic upturn from the lower oil import prices.

The UK has been an advocate of renewable energy production both in the UK and in the wider world, between 2010 and 2014 renewable sources more than doubled the proportion of electricity they provided in the UK, to almost 20%. This renewable energy comes from a variety of sources including wind, hydro and bioenergy. Investment into renewable energy has unsurprisingly mimicked this increase in production, also more than doubling between 2010 and 2014 (IEA, 2012). The UK has also used various incentives schemes to encourage the production and use of renewable energy, including subsidies and the taxing of non-renewable energy sources, although recently the levels of subsidy have been reduced. For instance, subsidies for domestic solar power under the Green Deal have been more than halved. The renewable energy policies in the UK have proven to be controversial in some ways, for instance Ward and Inderwildi (2013) have suggested that to meet the UK's renewable energy targets, they will require a large amount of biomass, requiring substantial imports to meet these demands. They suggest this could have negative environmental externalities in the form of deforestation and food supply.

2.3. The USA

The United States' experience with oil is the reverse of the UK, having been a net-importer of oil since the 1940s, then in 2013 the USA became a net-exporter of oil again and now is the world's largest producer (note not the largest exporter however, due to large domestic demand for oil and restrictions on the legality of exporting oil)[4]. The reason for this huge increase in oil production is in a large part due to fracking, a method of firing a high-pressure water mixture at shale rock in order to release gas and oil from the rock, which is a cost effective way to produce oil and gas.

Alongside this increase in oil production, renewable energy investment and production has also increased in recent years, contributing 13.4% of domestically produced electricity in 2015 (according to EIA data).[5] Investment has increased proportionally with this increase in renewable production and has largely been supported to an extent by state and federal-level support as well as increased efficiency and potential returns from renewable investments.

A feature of the USA that affects how the price of oil impacts the economy is that the benefit resulting from oil price increases can vary substantially from state to state depending

[4] See IEA (2014).

[5] There is little reliable data on levels of subsides for renewable energy across these countries, as what constitutes a subsidy can be controversial. The Financial Times used IEA data and found that the USA has about \$15.4 billion of subsidy, whereas the UK, has about \$4.1 billion. In terms of subsidy relative to country GDP, the UK has approaching twice the level of subsidies to the USA in 2013 overall.

on whether they are oil-importing or exporting states. Whilst overall for the USA the decrease in the price of oil from 2014 has been seen as broadly positive in economic terms, there are substantial regional differences in the effects it has, and therefore the effect the oil price will have on renewable investment also (Schoen, 2016).

3. Renewable Energy Model

The model incorporates oil prices and the main macroeconomic variables that could affect investment in renewable energy production (REW). This produces the following empirical relationship:

$$REW = f(OIL, RGDP, INTR) \tag{1}$$

To account for changes in wealth we have included real GDP (RGDP), in general wealthier countries are more likely to invest in cleaner energy production, so we would expect a positive relationship between GDP and renewable energy production. Although investment in renewable energy and GDP haven't been directly analysed as yet, Anwer and Sampath (1999) showed that the long run relationship between economic growth and general renewable energy investment produces mixed results regarding causality between economic growth and investment, with some evidence of bi-causality. Economic growth can cause investment through rising wealth increasing the ability of government's to spend on infrastructure, raising the marginal productivity of labour, which encourages investment. The interest rate (INTR) is also included as it accounts for the monetary side of the economy, in particular the cost of borrowing, a key determinant of investment in the private sector. Sadorsky (1999) and (2001) identifies a relationship between renewable energy stock prices (which in turn influence investment) and interest rates. Finally, oil prices (oil) have been introduced into the model, reflecting a substitute for renewable energy, such that as oil prices rise, it becomes more cost effective to invest in and produce renewable energy. However as mentioned this relationship will depend on whether the country is an oil-exporter or oil-importer among other factors. We would expect oil-importers to have a closer relationship between renewable energy and oil prices, as due to energy security factors they are more likely to feel the need to increase production of non-oil based energy, when oil is scarce and prices rise. Many studies indicated that an oil price increase has a positive impact on the renewable energy investment in oil-importing countries (Sadorsky, 2012b; Kumar *et al.*, 2012; Wen *et al.*, 2014, Reboredo, 2015). Over most of the sample analysed, Norway and the UK are net oil producers whilst the US is a net oil importer, so we would expect a closer relationship between oil prices and renewable energy investment in the USA.

3.1. Methodology

To assess the response of renewable energy investment to the oil price, GDP and interest rate shocks, the study employs an unrestricted VAR model (proposed by Sims, 1980). The VAR Model gives a multivariate approach where changes in a particular variable are dependent on its own lags and the lags of other variables (see, Lutkepohl *et al.*, 2009). The VAR considers all variables as jointly endogenous and does not impose any *a priori* restrictions on the structural equations.

The VAR model is specified as; $z_t = \alpha + \sum_{j=1}^{2} \beta_j z_{t-j} + u_t$ (2)

where $z_t = [\Delta REW_t \quad \Delta OIL_t \quad \Delta GDP_t \quad \Delta INTR_t]'$ is a vector of endogenous variables at time t, $\alpha = (\alpha_1, \ldots, \alpha_4)'$ is the (4x1) is a vector of constants, β_j is the j^{th} (4x4) matrix of AR coefficients for j=1,2 and $u_t = (u_{1t}, \ldots, u_{4t})'$ is the (4x1) vector of error terms. The DREW, DOIL, DGDP and INTR are the first differences of renewable energy (REW), oil price (OIL), GDP and interest rate (INTR) respectively. The form of the unrestricted VAR model can be specified as;

$$\begin{bmatrix} \Delta \mathrm{REW}_t \\ \Delta \mathrm{OIP}_t \\ \Delta \mathrm{GDP}_t \\ \Delta \mathrm{INTR}_t \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \end{bmatrix} + \beta(\mathrm{L}) \begin{bmatrix} \Delta \mathrm{REW}_{t-j} \\ \Delta \mathrm{OIP}_{t-j} \\ \Delta \mathrm{GDP}_{t-j} \\ \Delta \mathrm{INTR}_{t-j} \end{bmatrix} + \begin{bmatrix} u_{1t} \\ u_{2t} \\ u_{3t} \\ u_{4t} \end{bmatrix} \tag{3}$$

where $\beta(\mathrm{L})$ is the lag polynomial operator, the error term vectors are expected to be zero mean and uncorrelated. The dynamic response of renewable energy to shocks in the macroeconomic variables or oil price can be traced using the generalized impulse response functions (GIRFs). The GIRF, introduced by Koop et al. (1996) and Pesaran and Shin (1998), takes the traditional distribution of the residuals into account and computes the dynamic response to the reduced form shocks in the VAR. This approach entails no identification restrictions and is unaffected by the ordering of variables when computing the impulse responses. Forecast error variance decomposition has also been estimated to explain the relative contribution of a variable to the variance of renewable energy.

4. Data and Results

The date used is annual and consists of renewable energy investment, oil prices, real GDP, and the interest rate covering the period 1960-2015.[6] The data was limited to annual data as higher frequency data for renewable energy is not available for an extended period of time for Norway and the UK. The paper uses the renewable energy generation as a proxy for renewable energy investment, as they are very similar series, in that as soon as installed the renewable energy is almost costless to produce. The reason for using renewable energy

[6] The data are taken from the International Energy Agency, International Financial Statistics (IFS), OECD database Edition: Feb 2017. The real Gross Domestic Product (GDP) series is GDP at constant prices (Units: National Currency; Scale: Billions). The nominal Oil Price series is the petroleum average crude price (Units: US Dollars per Barrel). The interest rate is defined as the government long-term bond yield. All data is downloaded from the UK data service available at: https://stats.ukdataservice.ac.uk/

generation data rather than using installed capacity is that the data availability for installed capacity is only available since 1990, whereas generation figures have been available since 1960. Whilst there is not a perfect correlation between the two, between 1990 and 1960 for the three countries selected correlation between generation and installed capacity is significant at the 1% level for all three countries. All the data is in logarithmic form (except the interest rate).

To begin with we test for a unit root in all the variables, as a preliminary analysis, we apply the standard linear Augmented Dickey Fuller (ADF) and Phillips-Perron (PP) tests. As a further test we have conducted the Ng and Perron (2001) unit root tests with a structural break. These tests are modified versions of the existing unit root tests, but with a better performance in terms of power and size distortions. Ng and Perron introduced a set of four unit root tests, namely MZa, MZt MBS and MPT. The number of lags to compute the tests has been chosen using the modified AIC (MAIC) proposed by Ng and Perron (2001). Table A1 in the appendix presents unit root test results together with the corresponding critical values. Being in line with the other pass-through studies, the unit root analysis does reject the null hypothesis of a unit root in each of the four series at the 5% significance level. The results are similar to both the conventional without structural breaks and with structural breaks unit root tests.

As all the variables are I(1), we next need to test for cointegration. We have used the Johansen Maximum Likelihood Procedure and Engle-Granger cointegration methods, with results in the Appendix Table A2. The study also finds that there was no threshold (asymmetric) cointegration[7]**.** As there is no evidence of cointegration, there is no long-run equilibrium relationship, so we have not formed the VECM, instead a VAR is used, with the variables all in first-difference form. A VAR model of growth in renewable energy, real GDP, oil prices and the interest rate are estimated. Furthermore, in order to control for the oil price shocks of 1973-74 in all countries and the UK financial crisis in 1990 Iraq war, we have

[7] Results are available on request.

employed dummy variables as exogenous variables in the VAR estimation. Table 1 reports VAR estimation and diagnostic tests, for all countries the optimal lag selected by the Akaike and Bayesian Information Criteria indicates a value of 2. No root lies outside the unit circle and the VAR satisfies the stability condition for all countries. Column 4 indicates the value of the LM test for autocorrelation along with the corresponding p-values, indicating that there is no autocorrelation in any of the models. Overall, there are no significant outliers left unmodelled and we consider the estimates satisfactory.

Table 1: Summary of the VAR estimations and diagnostic tests

Country	N	*VAR*-lag	Root	LM Test P-value	Jarque-Bera, p-values				
					Rew	Oil	GDP	Interest	Joint
Norway	55	2	0.977	0.134	0.674	0.003	0.820	0.001	0.000
UK	55	2	0.996	0.276	0.482	0.000	0.019	0.279	0.000
USA	55	2	0.983	0.532	0.011	0.784	0.090	0.144	0.200

Firstly, Granger causality is computed using LA-VAR Wald tests, proposed by Toda and Yamamoto (1995), indicating that renewable energy is explained by past movements in oil prices in the USA, but GDP and interest rates do not Granger-cause renewable energy (Appendix Table A3). For Norway, the renewable energy is influenced by the lagged GDP and lagged interest rates. Since interest rates are a lagging economic indicator, this result is consistent with the view that increased economic growth leads to higher interest rates. Neither GDP, nor oil prices have a Granger causal impact on renewable energy in the UK. However, oil prices, GDP and the interest rate jointly Granger-cause renewable energy in Norway and the USA.

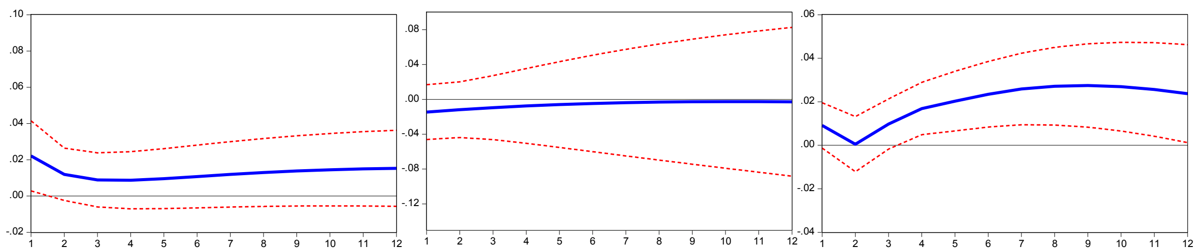
To analyse the effects of a shock to oil prices and its effect on renewable energy, the GIRFs[8] are used in Figure 1. For Norway (initially) and the USA, shocks to oil prices have a significantly positive effect on renewable energy, whereas in the UK the effect is not significant. The oil price shocks have, as expected, a positive and highly significant effect on the renewable energy in the oil-importing country; USA, where renewable energy investment increases by about 2% after the shock. This is consistent with the findings, reported by Kumar

[8] For robustness, we computed Cholesky one standard deviation impulse responses, where findings are parallel to generalized impulse responses.

et al. (2012), Sadorsky (2012a, and 2012b) and Managi and Okimoto (2013) and Inchauspe *et al*. (2015), finding that there is a significant impact of oil prices on renewable energy. However, the oil price shocks have a negative and negligible effect on the renewable energy in UK, the effect is very small and became zero after 3 lags. This may be because the UK was an oil-exporter most of the period under study and oil price shocks discouraged more investment in the renewable sector. We further computed a non-linear VAR for the UK to analyse the asymmetric effect of oil prices on renewable energy investment, because there was no linear relationship present, by using Mork's (1989) approach[9]. The findings of the non-linear model parallel the linear model regarding the negligibility and insignificant impact of oil price shocks on renewable energy. However, the magnitude of the response is higher in the non-linear model as compared to the linear model, the results are reported in Appendix Figure A1.

Figure 1: Renewable Energy Response to Oil Price

a. Norway b.8UK8 c.8USA8



Output (productivity) shocks have positive effects on renewable energy, which causes an increase in renewable energy investment in all countries as reported in Figure 2. This parallels the findings of Chien and Hu (2008), Apergis and Payne (2010) and Sebria and Ben-Salhab (2014) that renewable energy increases economic growth. However, the response of renewable energy to output shocks is insignificant in the UK and USA. For Norway, the response of renewable energy to a productivity shock is significantly positive and permanent.

Figure 2: Renewable Energy Response to GDP Shocks

a. Norway b.8UK8 c.8USA8

[9] Mork defines positive and negative annual OP (ΔOIL_t^+ and ΔOIL_t^- respectively) innovations in the following ways; $\Delta OIL_t^+ = \max[0, (OIL_t - OIL_{t-1})]$ $\Delta OIL_t^- = \min[0, (OIL_t - OIL_{t-1})]$ (4)

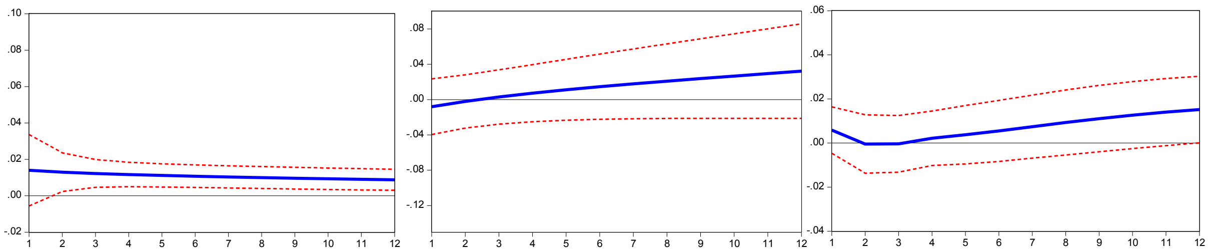
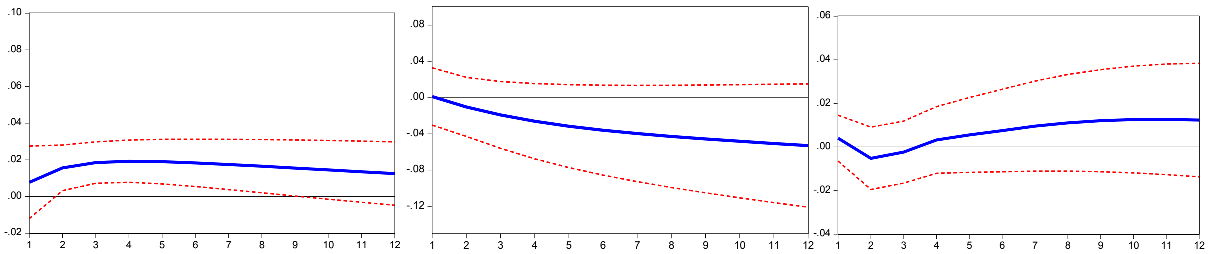


Figure 3 shows that the monetary shocks have a positive effect on renewable energy in Norway and the USA, this could be because a positive shock to interest rates increases demand and therefore the price of oil, making renewable energy more competitive, but the impact is insignificant in the USA. In contrast, the response of renewable energy is negative but insignificant in the UK.

Figure 3: Renewable Energy Response to Interest Rate Shocks

a. Norway b.8UK8 c.8USA8



The forecast error variance decomposition is used to measure the proportion of variations in renewable energy investment caused by oil prices, output and interest rate shocks respectively. The results are slightly different to the IRFs, as oil prices tend to only explain a small amount of the renewable energy variance, with the exception of the USA. In this case after 12 time periods, 40% of the variance is explained by oil prices, as reported in Table 4. In Norway it is approximately 7% and for the UK only about 1%, see Table 2 and 3. For the latter countries, it is the interest rate that explains most of the renewable energy variance, where the forecast error variance of renewable energy to the interest rate shocks are about 20% in Norway and 10% in the UK. Output shocks contribute about 5%, 2% and 4% of the changes in renewable energy in Norway, UK and USA respectively. This suggests that only in the USA is there a substantial relationship between renewable energy and oil prices, reflecting the different nature of the US renewable energy market, which is far more market orientated than in other countries, with fewer policies encouraging renewable energy through the tax and subsidy systems. In the UK during the time period investigated, the renewable energy market is subject to more interference by government, with higher levels of subsidy and use of environmental taxes. Norway appears to lie between these two extremes, reflecting the lesser need for the authorities to intervene in the market, as Norway's hydro-electric industry operates in a market environment and doesn't require high levels of subsidies.

Table 2: Forecast-Error Variance Decompositions of Renewable Energy Norway

Horizon	Renewable	Oil Price	Output	Interest Rate
1	100.00	0.00	0.00	0.00
2	97.54	0.00	0.48	1.98
3	93.58	0.06	1.23	5.13
4	89.41	0.24	1.97	8.38
5	85.54	0.59	2.62	11.25
6	82.11	1.14	3.14	13.61
7	79.09	1.88	3.56	15.47
8	76.44	2.77	3.89	16.90
9	74.10	3.78	4.16	17.96
10	72.02	4.88	4.37	18.73
11	70.17	6.03	4.54	19.26
12	68.51	7.20	4.68	19.61

Table 3: Forecast-Error Variance Decompositions of Renewable Energy UK

Horizon	Renewable	Oil Price	Output	Interest Rate
1	100.00	0.00	0.00	0.00
2	98.78	0.69	0.49	0.04
3	98.49	0.59	0.52	0.40
4	97.80	0.60	0.44	1.16
5	96.73	0.67	0.38	2.22
6	95.44	0.76	0.39	3.41
7	94.05	0.87	0.48	4.60
8	92.64	0.98	0.65	5.73
9	91.22	1.09	0.90	6.79
10	89.81	1.21	1.22	7.76
11	88.40	1.34	1.62	8.64
12	86.99	1.49	2.08	9.45

Table 4: Forecast-Error Variance Decompositions of Renewable Energy

USA

Horizon	Renewable	Oil Price	Output	Interest Rate
1	100.00	0.00	0.00	0.00
2	95.75	1.90	0.71	1.64
3	94.04	1.98	1.29	2.69
4	91.65	4.59	1.32	2.44
5	88.29	8.39	1.19	2.13
6	83.68	13.44	1.02	1.86
7	78.34	19.13	0.92	1.61
8	72.81	24.76	0.99	1.44
9	67.45	29.92	1.28	1.35
10	62.49	34.35	1.83	1.33
11	58.09	37.91	2.65	1.35
12	54.31	40.57	3.72	1.40

Conclusions and Policy Implications

This paper has analysed the interrelationship between renewable energy investment and oil prices along with the main macroeconomic factors, providing a quantitative analysis of a topic hitherto mainly qualitatively discussed. Granger causality tests indicate that movements in oil prices, GDP, and interest rates each have some power in explaining the movements of the renewable energy, except in the UK. The results show the oil prices have a highly significant impact on the renewable energy sector in USA, but the impact of oil prices on renewable energy is less significant in Norway. These findings add to a small but growing literature (see Henriques and Sadorsky, 2008) showing that oil price movements are not as important as once thought because investors may view renewable energy investments as similar to other high technology companies, which tend not to be highly correlated to commodity prices. The results also suggest that GDP and interest rate shocks have positive significant effects on renewable energy investment in Norway. However, the empirical evidence also shows that there is no significant response of renewable energy investment to oil price and different macroeconomic shocks. The variance decomposition shows the oil price explained a significant part of about 40% of the variance of renewable energy investment in the USA. Furthermore, interest rates explained a substantial part of the forecast error variance of renewable energy in both Norway and UK, showing is sensitivity to the costs of borrowing.

These results from the VAR show just how important government policy has been in mapping the course of renewable investment, especially for the UK, although of less importance in the USA. This was a common theme in the literature but was often assumed rather than quantitatively suggested. It also seems that traditional determinants of investment in general, such as GDP growth, can only go part of the way towards explaining renewable investment, there must be other determinants that can better explain changes in renewable investment, i.e. government intervention. Recently government spending in renewables has fallen, and with costs of renewables now a fraction of what they were in the past, in future the VAR model should be able to better show the determining factors of renewable energy.

There are a number of important policy implications resulting from this study, with regard to energy policies which aim to reduce carbon emissions whilst encouraging the renewable energy sector to become more market orientated. In addition, the evidence suggests the renewable energy markets are fundamentally different across countries, depending on whether the country is a net-exporter or importer of oil, the approach of the authorities to supporting renewable energy, the extent to which the geography of a country supports renewable energy as in Norway and the wealth of a country. Where a country has a more market orientated energy sector as well as being a net-importer of oil, as in the USA, the renewable energy industry has a strong relationship with the oil market. However, in countries such as the UK, where until recently there was a comprehensive policy framework of support for the renewable sector, investment and therefore production of energy from renewables will be less sensitive to movements in the oil market. Given recent volatility in the oil market and recent falls in support for renewable energy, it could be worthwhile designing policies that take into account the need to smooth investment and production in the renewable sector throughout the oil cycle, in the future.

Future research needs to take into account that the world of renewable energy has changed over the past years, with less financial support and will continue to do so in future, so the economic analysis surrounding it will need to reflect these changes, including the impact of increased demands for cleaner fuels and a less polluted environment. In addition, future research will need to take into account some of the negative externalities associated with renewable energy, such as the impact on the environment of increased use of biomass.

References:

Anwer, M., and Sampath, R. (1999). Investment and Economic Growth. *Colorado State University, Department of Agricultural and Resource Economics.*

Apergis, N. and Payne, J.E. (2010). Renewable Energy Consumption and Economic Growth: Evidence from a Panel of OECD Countries, *Energy Policy*, 38, 656-660.

Apergis, N. and Payne, J.E. (2011). The Renewable Energy Consumption – Growth Nexus in Central America, *Applied Energy*, 88, 343-347.

Apergis, N. and Payne, J.E. (2012). Renewable and Non-Renewable Energy Consumption – Growth Nexus: Evidence from a Panel Error Correction Model, *Energy Economics*, 34, 733-738.

Bleischwitz, R. and Fuhramann, K. (2006). Introduction to the Special Issue on 'Hydrogen' in 'Energy Policy'. *Energy Policy*, 34, 1223-1226.

Brander, A. S., Brekke, H., & Naug, B. E. (2013). The Effect of a Fall in Oil Prices on the Turnover of Norwegian Enterprises. *Norges Bank. Oslo: Norges Bank*.

Brief, C. (2014). Two Degrees: The History of Climate Changes Speed Limit. Retrieved 11 18, 2015: http://www.carbonbrief.org/two-degrees-the-history-of-climate-changes-speed-limit

Brief, C. (2015). Expert Views: How Low Oil Prices Affect the UK's Climate and Energy policy. Retrieved 11 18, 2015: http://www.carbonbrief.org/expert-views-how-low-oil-prices-affect-the-uks-climate-and-energy-policy

Chien, T. and Hu, J. (2008). Renewable Energy: An Efficient Mechamism to Improve GDP. *Energy Policy*, 36, 3045-52.

Chan, S. P. (2015). IMF: Oil Price Collapse will Cripple North Sea Producers. Retrieved March 21, 2016, from The Telegraph: http://www.telegraph.co.uk/finance/oilprices/11535265/IMF-oil-price-collapse-will-cripple-North-Sea-producers.html

Henriques, I. and Sadorsky, P. (2008). Oil prices and the stock prices of alternative energy companies. *Energy Economics*, 30, 998-1010.

Huang, A. Y., Cheng, C. M., Chen, C.-C., & Hu, W.-C. (2012). Oil Prices and Stock Prices of Alternative Energy Companies: Time Varying Relationship with Recent Evidence. J*ournal of economics and Management*, 8, 221-258.

IEA. (2011). Energy Policies of IEA Countries - *Norway 2011 review*. IEA. Paris: IEA.

IEA. (2012). Energy Policies of IEA Countries - The United Kingdom. IEA. Paris: IEA.

IEA. (2014). Energy Policies of IEA Countries - The United States. IEA. Paris: IEA.

IEA. (2015). Energy and Climate Change. Paris: IEA.

Inchauspe, J., Ripple, R.D. and Trück, S. 2015). The Dynamics of Returns on Renewable Energy Companies: A State-Space Approach. *Energy Economics*, 48, 325-335.

Koop, G., Pesaran, M.H., Potter, S.M. (1996). Impulse Response Analysis in Nonlinear Multivariate Models. Journal of Econometrics, 74, 119–147.

Kumar, S., Managi, S., Matsuda, A., 2012. Stock Prices of Clean Energy firms, oil and Carbon Markets: A Vector Autoregressive Analysis. *Energy Economics*. 34, 215–226.

Managi, S., Okimoto, T., (2013). Does the Price of Oil Interact with Clean Energy Prices in the Stock Market? Japan and the World Econom*y*, 27, 1–9.

McDowall, W. and M. Eames (2006). Forecasts, Scenarios, Visions, Backcasts and Roadmaps to the Hydrogen Economy: A Review of the Hydrogen Futures Literature. *Energy Policy*, 34, 1236-1250.

Milner, B. (2015). Alberta and Norway: Two Oil Powers, worlds apart. Retrieved March 26, 2016, from The Globe and Mail: http://www.theglobeandmail.com/

Mork, K., (1989). Oil and the Macroeconomy when Prices Go Up and Down: An Extension of Hamilton's Results. *Journal of Political Economy,* 97, 740-744.

Ng, S. and Perron, P. (2001). Lag Length Selection and the Construction of Unit Root Test with Good Size and Power, Econometrica, 69, 1519–1554.

Pesaran, M.H., Shin, Y. (1997). Long-Run Structural Modelling. Unpublished Manuscript. *University of Cambrid*ge. (Internet: http\\www.econ.cam.ac.uk\faculty\pesaran\).

Reboredo, J.C. (2015). Is there Dependence and Systmic Risk Between Oil and Renewable Energy Stock Prices, *Energy Economics*, 48, 32-45.Rifkin, J. (2002). The Hydrogen Economy: The Creation of the Worldwide Energy Web and the Redistribution of Power on Earth: Penguin Putnam. *New York*, 294.

Sadorsky, P. (1999). Oil Price Shocks and Stock Market Activity. *Energy Economics*, 21, 449-469.

Sadorsky, P. (1999). Risk Factors in Stock Returns of Canadian Oil and Gas Companies. *Energy Economics*, 23, 17-28.

Sadorsky, P. (2009). Renewable Energy Consumption, CO_2 Emissions and Oil Prices in the G7 Countries, *Energy Economics*, 31, 456-62.
Sadorsky, P. (2012a). Information Communication Technology and Electricity Consumption in Emerging Economies. *Energy Policy,* 48, 130–136.

Sadorsky, P. (2012b). Modeling Renewable Energy Company Risk, *Energy Policy*, 40, 39-48.

Sims, C. (1980, January). Macroeconomics and Reality. *Econometrica,* 48, 1-48.

Sims, R., Rogner, H. and Gregory, K. (2003). Carbon Emission and Mitigation Cost Comparisons between Fossil Fuel, Nuclear and Renewable Energy Resources for Electricity Generation. *Energy Policy,* 21, 1315-1326.

Schoen, J. (2016, January 25). Oil Price Plunge isn't All Good News for the Economy. Retrieved March 21, 2016, from CNBC: http://www.cnbc.com/2016/01/25/oil-price-plunge-isnt-all-good-news-for-the-economy.html

Sebria, M. and Ben-Salh, O. (2014). On the Causal Dynamics Between Economic Growth, Renewable Energy Consumption, CO2 Emissions and Trade Openness: Fresh Evidence from BRICS Countries. *Renewable and Sustainable Energy Reviews*, 39, 14-23.

Ward, D. and O. Inderwildi, (2013), Global and local impacts of UK renewable energy policy, *Energy and Environmental Science*, 6, 18-24.

Toda, H.Y., Yamamoto, T. (1995). Statistical Inference in Vector Autoregressions with Possibly Integrated Process. *Journal of Econometrics*, 66, 225–250.

Appendix

Figure A: Asymmetric Response of Renewable Energy to Oil Price Shock for UK

a. Positive change in OP b. Negative change in OP

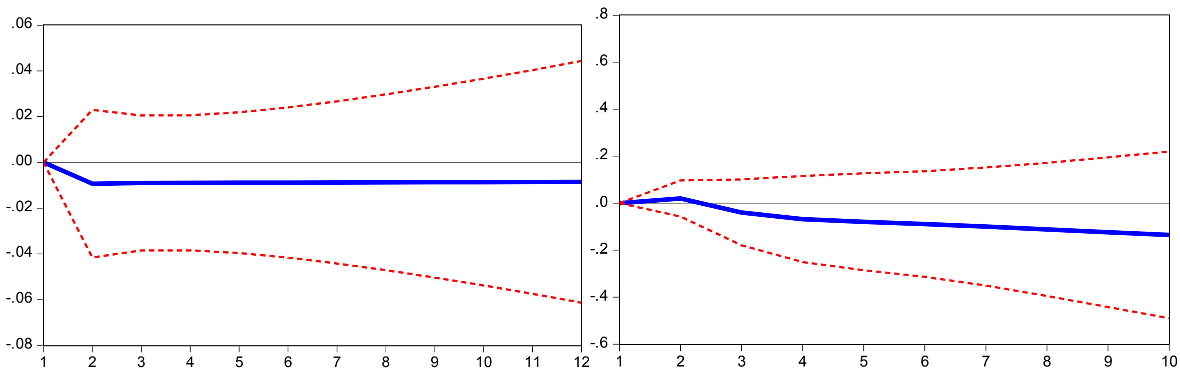


Table A1: Unit Root Test Results

Variables		ADF	PP	MZ_{α}^{GLS}	MZ_{t}^{GLS}	MSB^{GLS}	MP_{T}^{GLS}
	Norway						
Renewable	Level	-2.94	-2.62	-1.76	-0.77	0.44	39.43
	1st difference	-6.38*	-14.52*	-20.13*	-3.16*	0.16*	4.56*
Oil Price	Level	-1.68	-1.82	-5.96	-1.65	0.27	15.20
	1st difference	-6.86*	-6.85*	-26.93*	-3.55*	0.13	4.05*
Real GDP	Level	-0.27	-0.22	-2.07	-0.71	0.34	28.48
	1st difference	-4.53*	-4.87*	-26.98*	-3.67*	0.14*	3.39*
Interest Rate	Level	-0.89	-0.97	-1.10	-0.56	0.51	54.23
	1st difference	-5.62*	-5.60*	-26.15*	-3.61*	0.14*	3.51*
	UK						
Renewable	Level	-1.38	-1.20	-2.37	-0.90	0.38	30.86
	1st difference	-8.44*	-8.68*	-26.74*	-3.65*	0.14*	3.41*
Oil Price	Level	-1.68	-1.82	-5.96	-1.65	0.28	15.20
	1st difference	-6.86*	-6.86*	-26.93*	-3.55*	0.13*	4.05*
Real GDP	Level	-0.46	-0.50	-0.46	-0.18	0.39	39.73

	1st difference	-5.24*	-4.94*	-24.54*	-3.50*	0.14*	3.72*
Interest Rate	Level	-1.71	-1.60	-2.01	-0.89	0.54	38.75
	1st difference	-5.92*	-7.52*	-26.06*	-3.61*	014*	3.49*
	USA						
Renewable	Level	-152	-1.61	-3.59	-1.34	0.37	25.38
	1st difference	-7.33*	-7.37*	-26.92*	-3.65*	0.14*	3.51*
Oil Price	Level	-1.68	-1.82	-5.96	-1.64	0.27	15.20
	1st difference	-6.86*	-6.86*	-26.92*	-3.55*	0.13*	4.05*
Real GDP	Level	-2.30	-1.52	-6.35	-1.54	0.24	14.32
	1st difference	-5.66	-5.48	-24.83	-3.52	0.14	3.68*
Interest Rate	Level	1.49	-1.55	-2.47	-1.00	0.41	32.63
	1st difference	-6.43*	-6.43*	-26.50*	-3.64*	0.14*	3.44*

Model with Constant and Linear Trend: Critical Values

	ADF	PP	MZ_{α}^{GLS}	MZ_{t}^{GLS}	MSB^{GLS}	MP_{T}^{GLS}
1%	-4.13	-4.13	-23.80	-3.42	0.14	4.03
5%	-3.49	-3.49	-17.30	-2.91	0.16	5.48
10%	-3.18	-3.18	-14.20	-2.62	0.18	6.67

Note: * indicate the level of significance at the 5%.

Table A2: Cointegration Tests Results

Hypothesised No. of CE(s)	Trace Test		Maximum Eigenvalues		Engle-Granger Test	
	Statistics	Critical Values 5%	Statistics	Critical Values 5%	Statistics	Critical Values 5%
Norway						
None	44.80	47.86	21.09	27.58	-4.84	4.22
At most 1	23.70	29.80	12.37	21.13	NA	
UK						
None	41.25	47.86	19.83	27.58	-2.80	4.22
At most 1	21.46	29.80	13.68	21.13	NA	
USA						
None	42.31	47.86	18.03	27.58	-1.49	4.22
At most 1	24.27	29.80	12.79	21.13	NA	

Table A3: Granger Causality Tests Based on a VAR Model

1: Norway

Null Hypothesis	Chi-square	lag	Prob.

Oil price does not Granger cause Renewable energy	0.01	2	0.91
GDP does not Granger cause Renewable energy	12.75	2	0.00
Interest rate does not Granger cause Renewable energy	8.56	2	0.00
All oil price, GDP and interest rate does not Granger cause renewable energy	14.32	2	0.00

2: UK

Oil price does not Granger cause Renewable energy	0.42	2	0.81
GDP does not Granger cause Renewable energy	1.91	2	0.39
Interest rate does not Granger cause Renewable energy	1.39	2	0.49
All oil price, GDP and interest rate does not Granger cause renewable energy	3.49	2	0.75

3: USA

Oil price does not Granger cause Renewable energy	13.19	2	0.00
GDP does not Granger cause Renewable energy	0.73	2	0.69
Interest rate does not Granger cause Renewable energy	1.46	2	0.48
All oil price, GDP and interest rate does not Granger cause renewable energy	19.86	2	0.00