Interactions and Implications of Renewable and Climate Change Policy on UK Energy Scenarios

Gabrial Anandarajah, Neil Strachan
School of Social Science and Public Policy
King's College London, Strand, London, WC2R 2LS
United Kingdom
gabrial.anandarajah@kcl.ac.uk, neil.strachan@kcl.ac.uk

Abstract

The government has set the ambitious target of reducing the UK's carbon emissions by 80% of the 1990 level by 2050. The UK also agreed with EU partners to a binding target that 20% of the EU's energy consumption must come from renewable sources by 2020. UK's contribution to this should be to increase the share of renewables to 15% by 2020. Renewable Obligation and Renewable Transport Fuel Obligation are the two of the UK's energy policies that positively contribute to climate change mitigation as well as to improve the energy security. This paper investigates the interacting and potentially conflicting roles of renewable and CO_2 reduction policies in long-run UK energy scenarios. In combining these two policy initiatives into an energy-economic model, this paper adds to the literature on long-term energy systems modelling as well as providing insights for evolving and iterative policy making. Analyses show that CO_2 reduction policies can increase the share of renewable on final energy but not enough to meet the EU renewable directive. The RO only policy neither meets the climate change targets nor EU Renewable directive. Increasing RTFO and RO together (without CO_2 constraint) reduce CO_2 emissions by 30% in 2020 and meet EU renewable directive (at 35% RO and 20% RTFO or at 40% RO and 15% RTFO) but will not meet the long term climate target of 80% CO_2 reduction in 2050. Both climate change target and EU directive can be met by combining renewable and long-term climate policies.

1. Introduction

Addressing climate change and ensuring UK's energy supply security are the two key goals of UK energy policy. The UK strongly supports international action to address climate change at EU, G8 and UN level and has set the ambitious target of reducing the UK's carbon emissions by up to 34% of the 1990 level in 2020 and by 80% by 2050, and these targets have been incorporated in the Climate Change Act (CCC, 2008). The UK government has also a challenging target of 15% renewable in final energy by 2020, in order to contribute to meet the EU's binding target that 20% of the EU's energy consumption must come from renewable sources by 2020 (CEC 2008).

There are two renewable fuel obligations currently in effect in UK: one is the Renewable Obligations (RO) for electricity generation and the other is the Renewable Transport Fuel Obligations (RTFO) for road transport fuel sales. The UK's Renewable Obligation, which in effect requires certain percentage of the total electricity sold in UK should be generated from renewable resources, is to increase the proportion of renewable in the electricity generation. The RO order came into effect in April 2002, essentially requiring 10% of all electricity generation should be from renewable resources by 2010. Since then, the RO has increased the level of RO-eligible renewable generation in the UK from less than 2% in 2001 to around 4.4% in 2006 (BERR, 2008). Figure 1 shows the renewable energy (RO basis) by wind, bio-fuels and others as well as the share of renewable on total electricity generation. In 2006, wind turbine generated 4225 GWh of electricity of which 15% is from offshore wind with the installed capacity of 304MW (DUKES 2007). In June-September 2008, the UK government also conducted a consultation (BERR 2008) in which raising the electricity RO was one of the measures to meet the 15% renewable share in final energy by 2020. The current level of RO is 9.1% for 2008/09 and it is raised to 15.4% in 2015/16 (BERR 2006).[1]

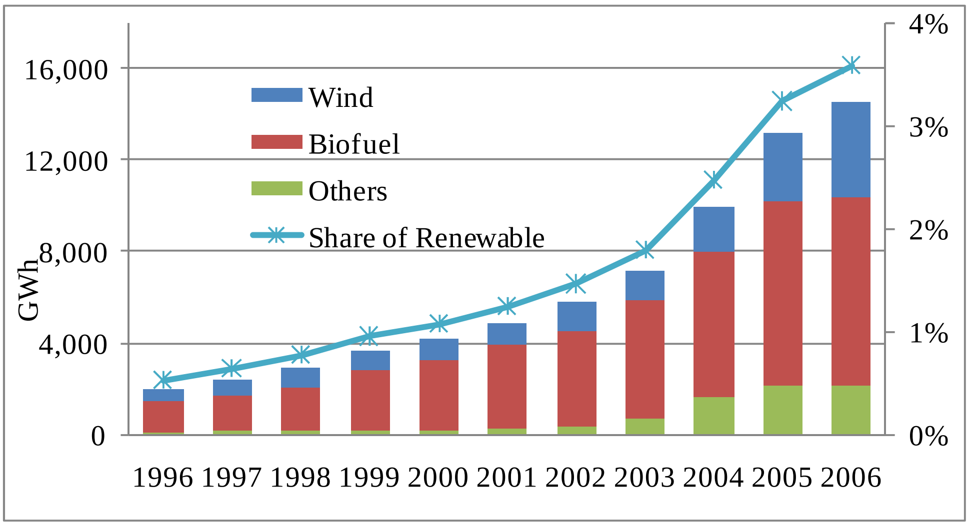

Figure 1: Renewable energy generation in UK (Renewable obligation basis)
Source: DUKES 2007

The Renewable Transport Fuel Obligation (RTFO) program is one of the Government's main policies for reducing greenhouse gas emissions from road transport, is in place from April 2008. It places an obligation on fuel suppliers to ensure that a certain percentage of their aggregate sales are made up of bio-fuels. The effect of this is to require 5% of all UK fuel sold on UK forecourts to come from a renewable source by 2010 (DFT 2006). It is intended to deliver reductions in carbon dioxide emissions from the road transport sector of 2.6 - 3.0 million tonnes per annum (DFT 2008).

Bio-fuels play key role in decarburization of transport sector to meet the 80% reduction target in 2050. As transport sector needs to shift to bio-fuels to certain extent to meet the

[1] Renewable energy (RO basis) does not include all electricity generated from renewable, it include the only the electricity generated on the Renewable Obligation basis set out in BERR 2006. For example, 2496 GWhr of electricity generation from large hydro is excluded in the electricity generated in the RO basis in 2006.

long term carbon target, it would be relatively easy to increase the penetration of bio-fuels in transport by 2020 through increased level of RTFO to meet 15% renewable target in 2020.

This paper analyses the influence of renewable policies (renewable fuel obligations) and climate change policies (mitigation target) to meet the UK challenges (climate change, energy security and EU directive) using the UK MARKAL elastic demand model (MED). This paper is divided into six sections: following the introduction, Section 2 provides briefly discussion on the UK MARKAL model; Section 3 describes the scenarios, section 4 discusses results; and Section five concludes the findings.

2. UK MARKAL (MED) Model

The UK MARKAL model is a technology-rich energy systems model which has been substantially enhanced through a multi-year project within the UK Energy Research Centre (UKERC) (as discussed in Strachan et al., 2008 and Anandarajah et al., 2009), and has provided a major analytical underpinning to UK energy policy developments (including the Energy White Paper (DTI, 2007) and the Climate Change Bill (DEFRA, 2007). A range of modelling variants to address specific issues has been developed including MARKAL elastic demand (MED) which includes the response of consumers' demands for energy services to changes in energy prices. UK MARKAL is calibrated in its base year (2000) to data within 1% of actual resource supplies, energy consumption, electricity output, installed technology capacity and CO_2 emissions (all from DUKES, 2006). A comprehensive description of the UK model in given in the model documentation (Kannan et al., 2007), with peer reviewed publications including Strachan et al. (2008), Strachan and Kannan (2008) and Strachan et al. (2009); Anandarajah et al. (2009).

3. Scenario Description

This paper undertakes exploratory analysis of the interactions of intermediate renewables policy on long-term carbon reduction targets; specifically the four different scenarios are discussed:

1. Reference Scenario (RS): No CO_2 constraint and RO and RTFO are kept at level of 15% and 5% respectively from 2015
2. Low Carbon Scenario (LCS): CO_2 emission is constrained to 26% in 2020 and 80% in 2050
3. Renewable Policy Scenario (RPS), in which the RO has been increased by 5% in each successive runs to 50% starting from the Reference Case values of 15% from 2020. The RTFO has been increased from 5% to 20% with steps of 5% in each successive run. All other conditions are same as in RS
    a. RO only cases are included
    b. RO and RTFO cases are included
4. Low Carbon Renewable Scenario (LCRS): combinations of LCS and RPS

4. Results and Discussion

CO_2 emissions

The MED model shows that, if no new policies/measures are enacted, energy related CO_2 emissions in the Reference Scenario (RS) in 2050 is 584 MtCO_2, which is only 1% lower than the 1990 emission level. Existing policies and technologies would bring down the emissions in 2020 to about 500 MtCO_2 achieving over 15% reductions, which falls well short of the minimum target of a 26% reduction. The power sector has a relatively high share of total CO_2 emissions in the RS followed by transport, residential and industrial sectors (Figure 2). The contribution of the power sector to total CO_2 emissions increases from 35% in 2020 to 45% in 2050 while the transport and residential sectors show slight reductions. From 2020-2050, economic and energy service demand growth overwhelms near term efficiency and fuel switching measures (which are partially driven by the effects of the EU-ETS price, and the electricity and transport renewable obligations), and CO_2 emissions rise.

Under the LCS, decarbonisation is foremost in the power sector till the middle or end of the projection period (Figure 2). Then major efforts switch to the residential/transport sector/service sectors. Coal-CCS, Nuclear and wind are the major decarbonisation technology in the power sector replacing conventional coal power plants.

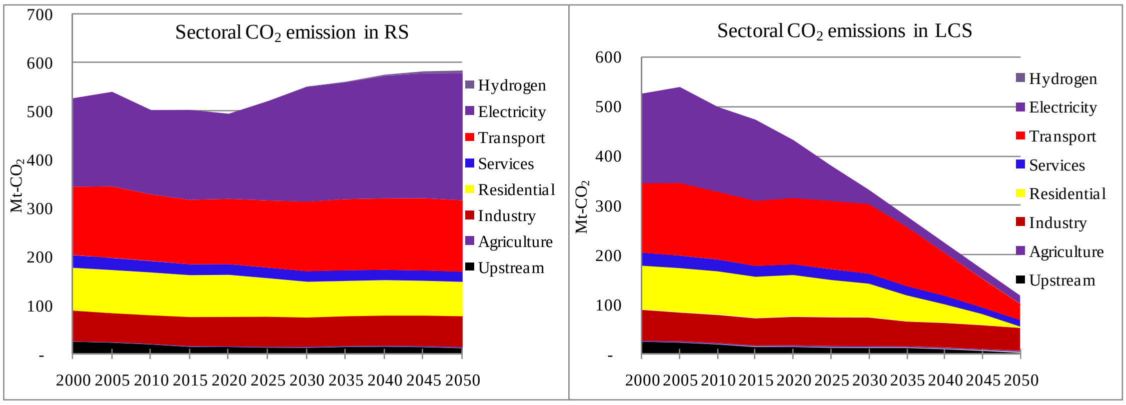

Figure 2: Sectoral CO_2 emissions in the Reference Case

Figure 3 presents sectoral CO_2 emissions in the RPS (no CO_2 emission constraint) in 2020 and 2050 at different levels of RO at a fixed RTFO of 5%. Increasing RO will reduce power sector CO_2 emissions and consequently total CO_2 emissions throughout the planning period. The renewable obligation is met mainly by offshore wind. It is possible to reduce the CO_2 emissions by 26% in 2020 by forcing the power sector to generate 35% of its generation from renewable resources. But in 2050, only 20% CO_2 reduction can be achieved at the RO level of 50%. Further CO_2 emission reduction is possible by increasing RTFO along with the RO (Figure 4). But, still the reduction in 2050 is far below the government target of 80%. The analyses clearly show that renewable policies (RO and RTFO only) can meet the short term carbon target of 26% (will not meet 34%) but not the long-term target.

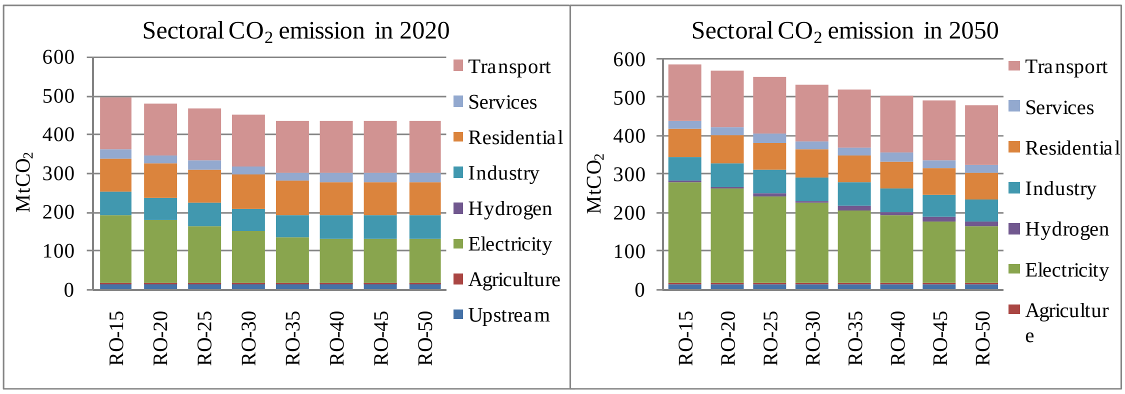

Figure 3: Sectoral CO_2 emissions under different ROs in RPS at 5% RTFO

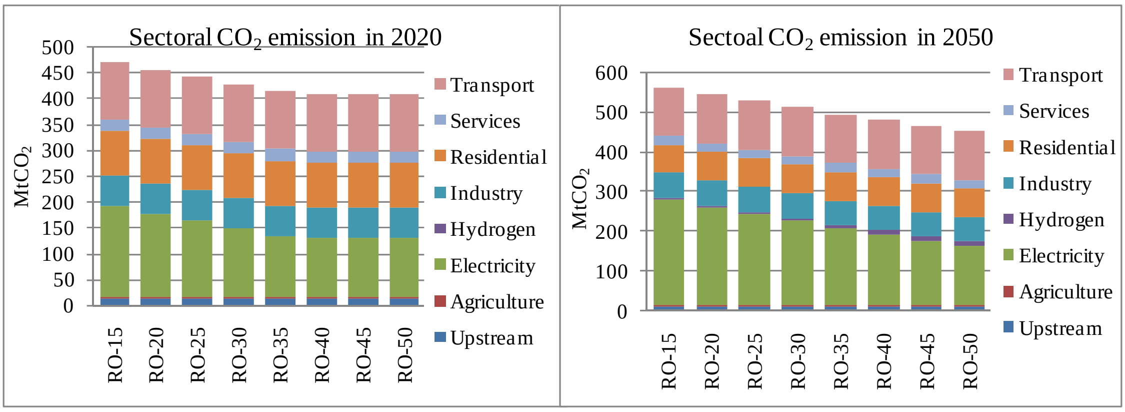

Figure 4: Sectoral CO_2 emissions under different ROs in RPS at 20% RTFO

When RO is increased in the LCRS, despite the selection of large amounts of wind at the higher RO levels (Figure 11), the CO_2 emissions from the power sector did not change much in 2020 (Figure 5). This is because of the replacement of coal-CCS by wind and conventional coal plants. Coal-CCS has 10% residual CO_2 emissions as its CO_2 capture efficiency is limited to 90%. When the coal-CCS is replaced by zero carbon wind, a small amount of conventional coal plants are selected to offset the avoided CO_2 emissions (10% from coal-CCS). When the RO level is increased the power sector is further decarbonised in 2050 while CO_2 emissions from services and residential sectors were increased (Figure 4).

When both RO and RTFO are increased in the LCRS, as presented in Figure 6, further CO_2 emission reduction is achieved in 2020 at the highest RO and RTFO levels. Over 30% CO_2 emission reduction is achieved at the RO and RTFO levels of 35% and 20% respectively. Transport sector emission did not change along with RO (Figure 6) but did change along with RTFO. Transport sector emitted 134 $MtCO_2$ at 5% RTFO and 112 $MtCO_2$ at 20% RTFO in 2020. Overall, RTFO reduce more carbon from transport as compared to the LCS and allow the power sector to emit more CO_2 emissions in 2020 (Figure 5 and Figure 6). In 2050, change in transport sector emissions at different RTFO level is marginal in LCRS as the transport sector needs more than 20% of its total energy demand from bio-energy to meet the 80% CO_2 reduction target in the LCS.

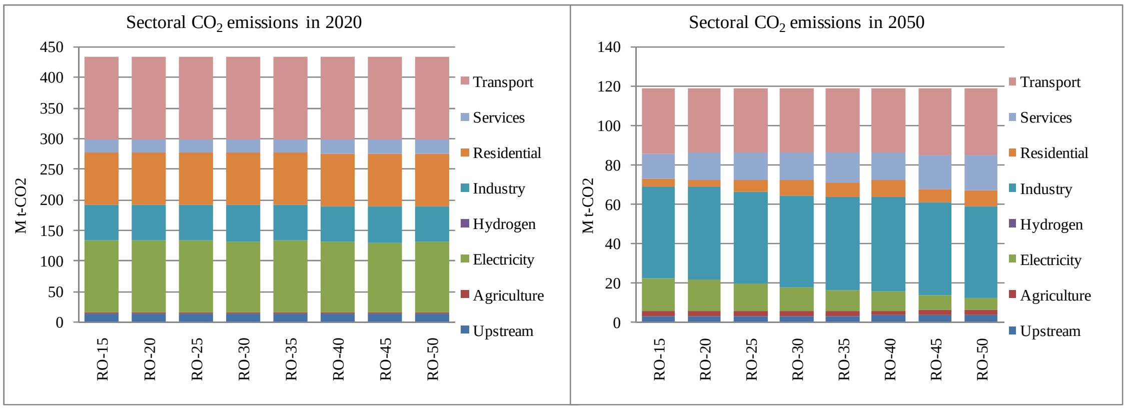

Figure 5: Sectoral CO_2 emissions under different ROs in LCS at 5% RTFO

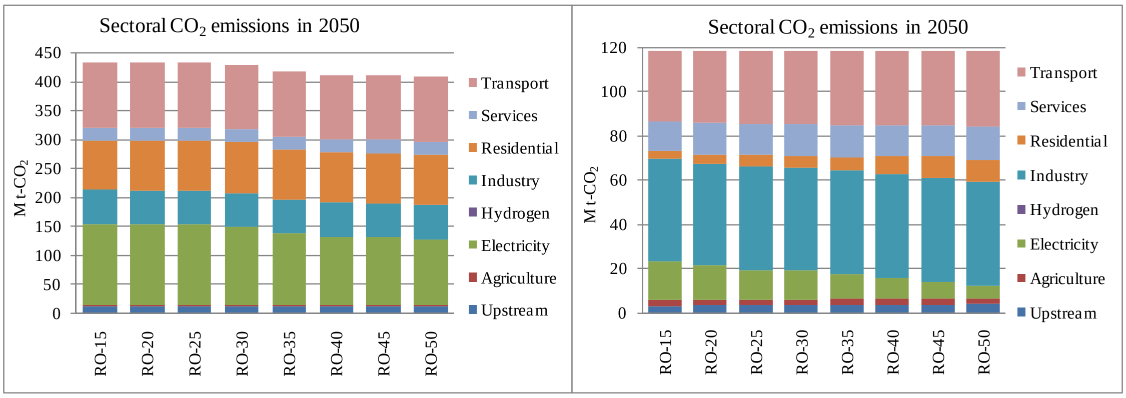

Figure 6: Sectoral CO_2 emissions under different ROs in LCRS at 20% RTFO

Generation Mix

In the RS, total install capacity in UK is 89 GW and 98GW in 2020 and 2050 respectively. Over two thirds of total electricity generation is from fossil fuels (coal and gas) in 2020 (Figure 7). In the absence of significant CO_2 pricing, high carbon content coal becomes the dominant fuel for electricity generation gradually replacing gas and nuclear over the years, generating more than 80% of the total electricity supplied in 2050. Contribution of wind to electricity generation seems to be decreased from 11% in 2020 to 7% in 2050. In the model, onshore wind resources are limited to 8.36 GW (annual average wind speed of > 6.0 m/s), which is fully selected in the reference scenario in 2050. Model also invests 3GW of offshore and 5GW of marine (tidal) in 2050. Selection of offshore wind and marine is not due to cost effectiveness of the technologies, but it is just to meet the RO requirement. A small amount of biomass and waste is also selected for electricity generation. As peak load contribution of wind is limited the electricity system requires considerable amount of open cycle gas turbine plants (as reserved capacity) when large amount of wind generation is selected.

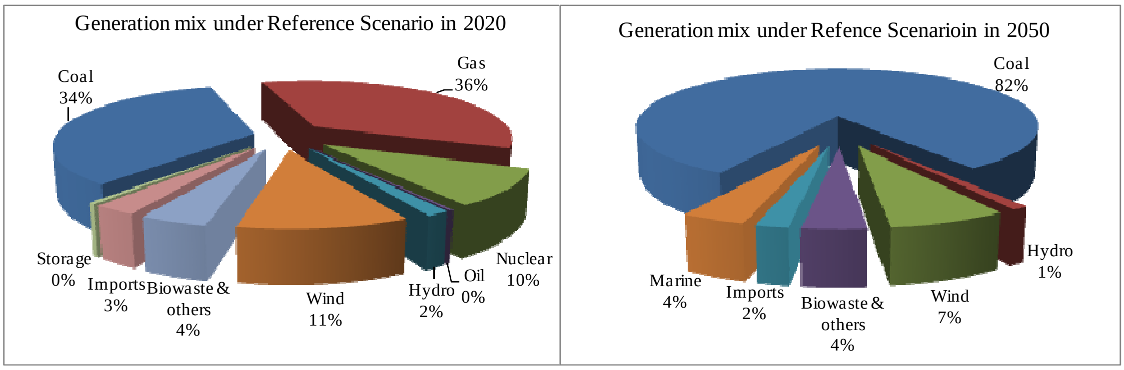

Figure 7: Electricity generation mix in RS in 2020 and 2050

When the RO is increased from RO-15 to RO-75 in the RPS at 5% RTFO, the renewable obligation is met through the penetration of large amount of wind especially offshore replacing gas and coal plants in 2020 and replacing coal plants in 2050 (Figure 8). Selection of expensive wind plants to meet RO reduces electricity demand by end-use sectors (especially transport) leading a reduction of 10% in total electricity generation between RO of 15% and RO of 50% scenarios in 2050. When the RO is increased from 15% to 50%, the transport sector electricity demand decreased from 120 PJ to 31 PJ in 2050. When the RTFO level is increased, electricity generation increases (Figure 8 and Figure 9) as the transport sector prefers to consume less fossil fuel (and demand more electricity) in order to reduce the consumptions of expensive bio-energy. For example, at 20% RTFO, transport sector should consume 0.2 unit of bio-energy for every unit of fossil fuel it consumed in order to fulfil the RTFO requirement.

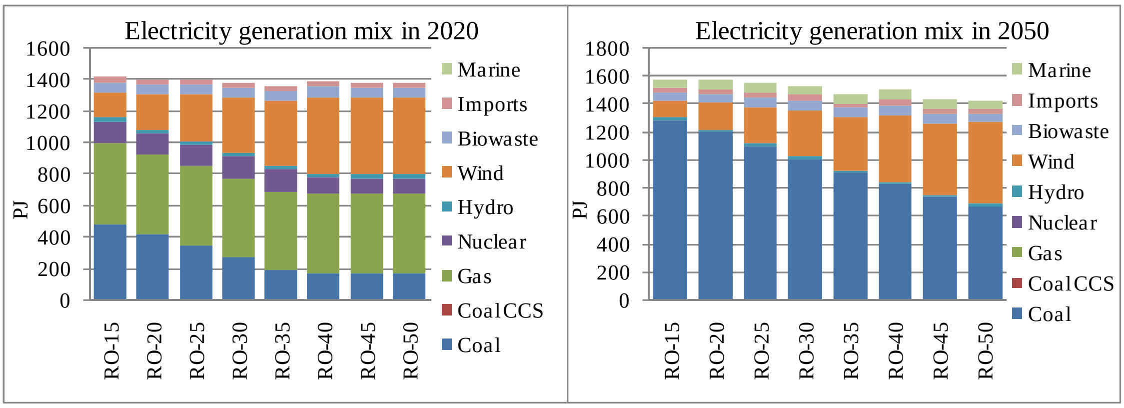

Figure 8: Generation mix under different Renewable Obligations in RPS at 5% RTFO

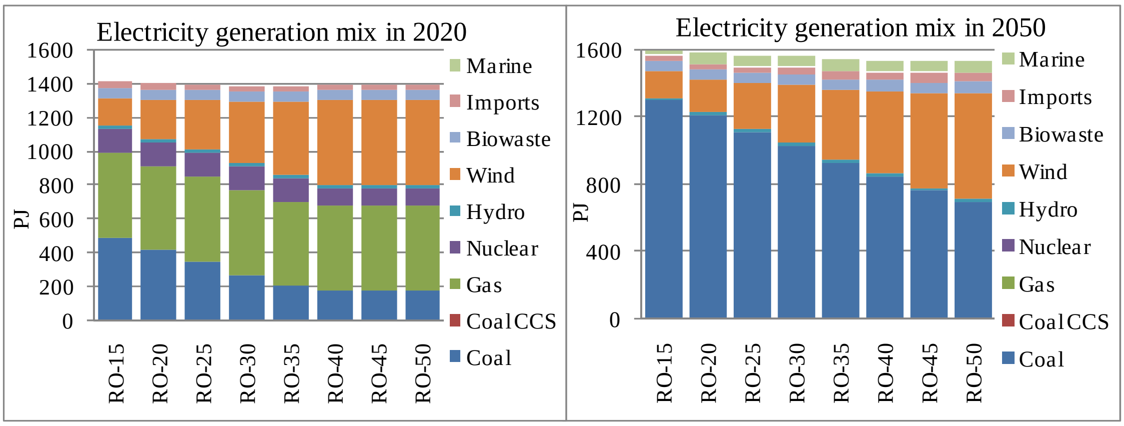

Figure 9: Generation mix under different Renewable Obligations in RPS at 20% RTFO

Since coal is responsible for almost all CO_2 emissions from the power sector in 2050, decarbonisation of the power sector in the long-term involves decarbonising coal generation by coal-CCS and/or replacing coal generation with nuclear and renewable generation such as wind, biomass, marine and solar. In the In 2020, the early decarbonisation requirements of the electricity sector are achieved by replacing coal plants with coal-CCS plants in the LCS (Figure 10). The coal plants are replaced by coal-CCS and nuclear in 2050. As the end-use sector decarbonisation is achieved by shifting to electricity, demand for electricity is higher in the LCS (2071 PJ) than that in the RS (1583 PJ).

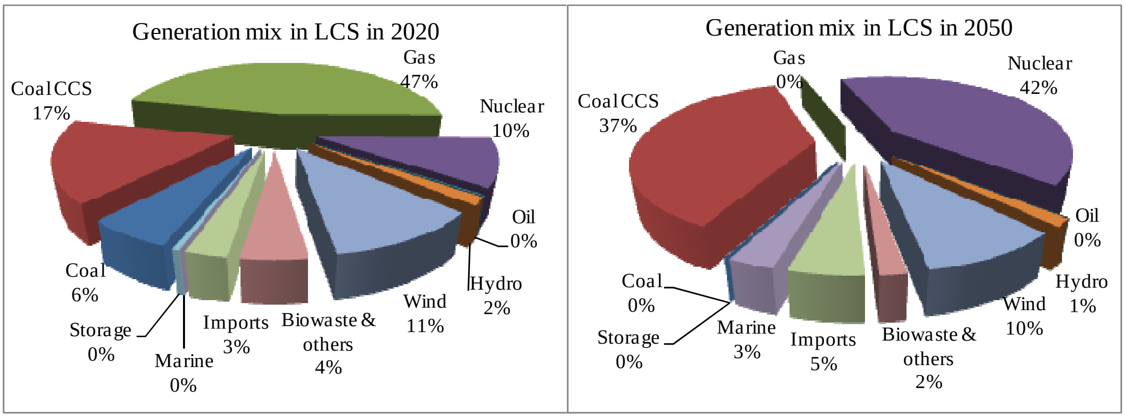

Figure 10: Electricity generation mix in LCS in 2020 and 2050

When only RO is increased in the LCRS, at higher RO levels as expected the wind generation increased replacing coal-CCS in 2020 and coal-CCS and nuclear in 2050 (Figure 11). Electricity generation from coal plants also increases when the RO is increased in 2020 as the low carbon coal-CCS plants is replaced by zero carbon wind plants. Due to the high cost of electricity as the expensive wind is selected at higher ROs end use sectors demand less electricity especially residential, hydrogen production and upstream especially at high RO levels. Since the power sector is completely decarbonised at higher ROs in 2050, the end-use sectors are now allowed to emit more CO_2 emissions by shifting to fossil fuels from electricity, hydrogen and/or biomass.

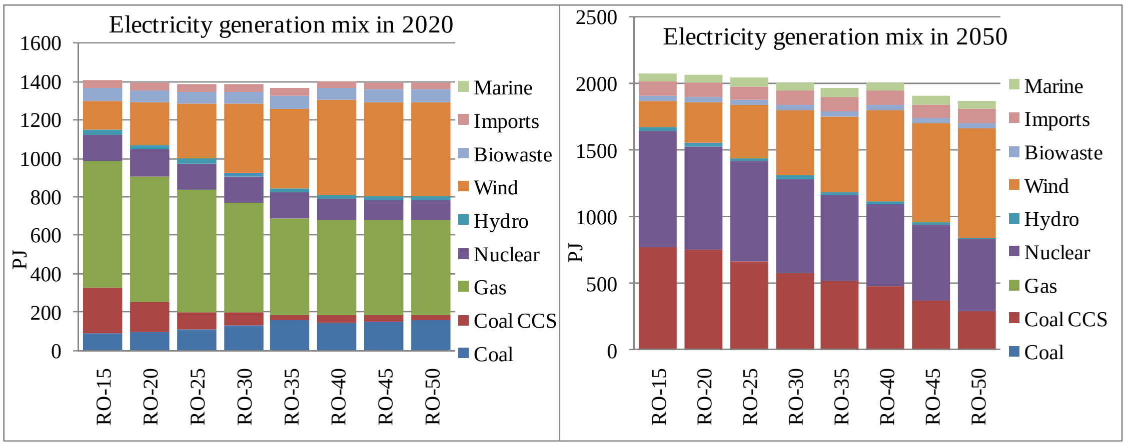

Figure 11: Generation mix under different Renewable Obligations in LCRS at 5% RTFO

When the RTFO is increased along with the RO in LCRS there is a gradual shift from coal-CCS to coal in 2020. At higher RTFO, transport sector emission is reduced in two ways: one is by consuming more bio-energy and the other is due to the increased demand for electricity (fossil fuel consumption is minimised in order to limit the consumption of expensive bio-energy in order to meet the RTFO requirements). Reduction in transport sector emissions leads to increased level of emissions from the power sector (Figure 5 and Figure 6) by shifting to coal from coal-CCS (Figure 11 and Figure 12) in 2020

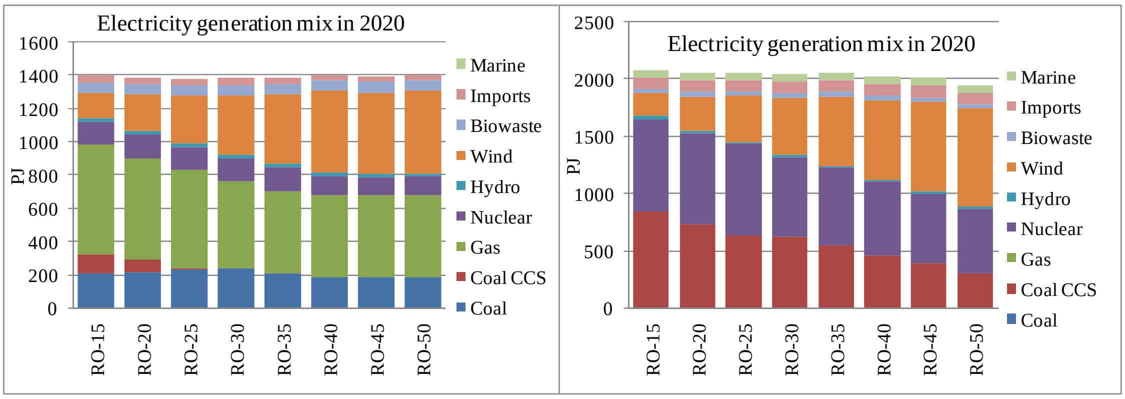

Figure 12: Generation mix under different Renewable Obligations in LCRS at 20% RTFO

__End Use Technology Trade Off__

Among the end-use sectors, decarbonisation occurs mainly in the transport, residential and services sectors. Major decarbonisation technologies in residential sector are electric boilers and heat pumps replacing gas boilers for space and water heating and in services sector are biomass and electric boilers replacing gas boilers in the LCS. The transport sector is decarbonised by shifting to car plug-in (petrol), car ethanol (E85), HGV-hydrogen, and LGV plug-in (diesel/biodiesel) from traditional gasoline and diesel vehicles in the LCS.

In the LCRS, heat pumps are replaced by electric boilers for heating in the residential sector and at high RO electric boilers are replaced by gas boiler leading to increased level of CO_2 emission from it. Biomass is replaced by gas (boilers) for space heating and hot water in the services sector leading to high level of CO_2 emissions. The major end-use sector carbonisation technology at high RO and RTFO levels is the gas boilers in residential and services sectors. In the LCRS, main technology trade off is shift from petrol car to ethanol car (E-85) in 2020. The RTFO is mainly met by shifting to ethanol car (E-85) from petrol IC engines in 2020. When the RTFO is increased to 10%, 15% and 20%, the share of ethanol car (E-85) in total car transport increases to 3% to 12% and 19% respectively in 2020. Even more interestingly, when the RO levels are increased in conjunction with CO_2 constraints (the LCRS scenario), use of low carbon electricity is further complicated by the competition for limited sustainable biomass resources and the reduction in use of hydrogen for transport modes. For example in the transport sector, hydrogen HGV is replaced by hybrid diesel/biodiesel based HGV, LGV diesel plug-in is replaced by diesel/biodiesel hybrid leading to higher demand for diesel and biodiesel and lower demand for electricity and hydrogen.

When the RO levels are increased under the RPS scenarios, there is a major trade-off in the use of more expensive electricity (for example in the replacement of residential electric boilers for natural gas heating). This limits any CO_2 emission reduction advantages of the RPS.

Biomass demand for end-use sectors

In the Reference Scenario, 11 PJ and 14 PJ of biomass is selected for residential and services sector heating while transport sector consumes 70 PJ of biomass in 2020 to meet the RTFO of 5%. It is not cost effective for residential heating in 2050. When the CO_2 emission is constrained in LCRS, there is no significant contribution of biomass in residential and services sector heating in 2020. Transport sector biomass consumption is to meet the RTFO levels in 2020. But in 2050, bio-fuel is critical in transport sector contributions to meet the climate change target as two third of the road transport fuel is bio-fuel at all RO levels. A small amount of biomass is also consumed by services sector for heating in the LCRS but its contribution is not significant at high RO and RTFO levels while biomass is not cost effective at all for residential heating.

EU renewable directive

The Renewable Obligation increases the share of renewable in power sector and reduces the use of biomass in the end-use sector when RO is increased in all respective scenarios. For example, when the RO is increased from 15% to 35%, services sector demand for biomass is reduced respectively from 168 PJ to 84 PJ in LCRS at 5% RTFO. Calculations show that none of the RO levels (Ro-15 – RO-40 in 2020) in the LCS meet the EU's renewable directive of at least 15% of UK final energy from renewable by 2020 if the

RTFO level is kept at the current requirement of 5%. Share of renewable in the final energy demand would go to 10% at the RO-30 and 12% at the RO-40 in 2020 in the LCRS. In 2050, the share of renewable in the final energy consumption is in the range of 28%-47% in the LCS.

Analyses at increased RTFO levels in the LCRS show that RO and RTFO together will increase the share of the renewable on final energy. The EU directive can be met at the RO level of 40% if the RTFO is increased to 20% or at the RO level of 35% if the RTFO is increased to 15% in 2020 (Table 1). As a bonus, despite the model is constrained to meet 26% target in 2020, in addition to meeting the EU renewable directive at the said RO and RTFO levels, it will also reduce the CO_2 emissions in 2020 by over 30%. Since the share of bio-fuels in transport energy demand was two third in 2050 the LCS, though the RTFO is applied till 2050, the impact of higher RTFO level in 2050 is minimal.

Table 1: Share of renewable in final energy in the LCRS in 2020

	RO-15	RO-20	RO-25	RO-30	RO-35	RO-40
RTFO -5	7%	8%	9%	9%	10%	11%
RTFO -10	8%	9%	10%	11%	12%	13%
RTFO -15	10%	11%	12%	13%	14%	15%
RTFO -20	11%	12%	13%	14%	15%	16%

Economic Implications

Marginal carbon price varies from £165/t-CO_2 to £183/t-CO_2 across the scenarios in 2050. Demand reduction levels are in the range of 0-5% in 2020 and 5%-30% in 2050 across the scenarios. Societal welfare losses (change in consumer + producer surplus) are up to £7 billion in 2020 and £40 billion in 2050 in 2000 prices to meet the climate change targets.

In 2020, the UK MARKAL MED model shows zero/very low marginal carbon price at higher RO and RTFO levels. It means that the transport and electricity renewable obligations will alone enough to bring down the CO_2 emissions below the 2020 target of 26%, at which the economy can emit 432 Mt-CO_2. Total CO_2 emissions in 2020 in the LCRS when the EU renewable directive is met are below 427 Mt-CO_2. Incremental cost that is the change in total discounted system cost when the RTFO of 15% and 20% is implemented in order to meet the EU renewable directive as compared to the LCS is not significant, about a couple of billion pounds in 2000 prices. But cost of implementing the RTFO policy will relatively be high and challenging. The transport sector demands 175 PJ, 262 PJ and 349 PJ of bio-fuels at the RTFO levels of 10%, 15% and 20%, respectively. Great challenge in implementing RTFO is ensuring production of bio-fuel in a sustainable way with minimum environmental impacts. Engineering challenge is electricity grid with increased share of intermittent sources at high RO.

5. Conclusion

This paper investigated the interacting roles of renewable and CO_2 reduction policies in long-run UK energy scenarios. The analysis shows that increasing RO will increase the total system cost and electricity prices leading less electricity demand from end-use sectors. In LCS, complete decarbonisation of power sector at higher RO will allow the end-use sectors such as residential and commercial sectors to emit significant amount of CO_2 emissions at a higher RO levels. It will not be possible to meet the EU directive on final energy if only electricity RO is implemented. Increasing RTFO is crucial in order to meet the EU renewable energy directive. There trade-off in sectoral emissions between power and transport when the RTFO is included in the UK MARKAL model. Research find out that increasing the electricity RO together with RTFO not only meet the RU directive of 15% renewable in UK final energy consumptions but also reduce the total CO_2 emissions at least 30% of the 1990 level in 2020. Interesting trade off is observed in the between transport and power sector at High RTFO levels where the transport sector demand more electricity as it tries to minimise the consumption petrol and diesel in order to avoid the consumption of expensive bio-fuels. This paper acknowledges that there are great challenges in implementing the higher RTFO levels and in ensuring sustainable bio-fuels production.

References:

Anandarajah, G. N. Strachan, P. Ekins, R. Kannan, N. Hughes. 2009. Pathways to a Low Carbon Economy: Energy Systems Modelling. *UKERC Energy 2050 Research Report 1*, UKERC, http://www.ukerc.ac.uk/

BERR 2006. The Renewable Obligation Order 2006. Statutory instruments, 2006No. 1004. http://www.opsi.gov.uk/si/si2006/uksi_20061004_en.pdf

BERR 2008. UK Renewable Energy Strategy: Consultation Documents. Department for Business, Enterprises and Regulatory Reform (BERR), UK, June 2008. http://www.berr.gov.uk/files/file46799.pdf

CCC (Committee on Climate Change) (2008) Building a low-carbon economy – the UK's contribution to tackling climate change. TSO, London. http://hmccc.s3.amazonaws.com/pdf/TSO-ClimateChange.pdf

CEC (Commission of the European Communities). 2008. Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources. Commission of the European Communities, Brussels.

DEFRA, 2007, *MARKAL Macro analysis of long run costs of climate change mitigation targets*, Analysis by AEA Energy and Environment, http://www.defra.gov.uk/environment/climatechange/research/index.htm

DFT 2006. About the RTFO Programme, Department for Transport, 2006. http://www.dft.gov.uk/pgr/roads/environment/rtfo/aboutrtfo

DFT 2008. Carbon and sustainability reporting within the Renewable transport Fuel Obligation: requirements and guidance. Department for Transport, 2006. http://www.dft.gov.uk/pgr/roads/environment/rtfo/govrecrfa.pdf

DTI, 2007, *Energy White Paper: Meeting the Energy Challenge*. Department of Trade and Industry, London, http://www.berr.gov.uk/energy/whitepaper/page39534.html

DUKES (2006), *Digest of UK Energy Statistics*, Department of Business Enterprise and Regulatory Reform, London

DUKES 2007. Electricity generated from renewable sources on Renewables Obligation and Renewables Directive basis, Digest of UK Energy Statistics (DUKES 7.5) (Excel, 31Kb).
http://www.berr.gov.uk/energy/statistics/source/renewables/page18513.html

Kannan R., and Strachan N, 2008, Modelling the UK residential energy sector under long-term decarbonisation scenarios: Comparison between energy systems and sectoral modelling approaches, *Applied Energy*, In Press

Kannan R., Strachan N., Pye S., and Balta-Ozkan N., 2007, UK MARKAL model documentation. http://www.ukerc.ac.uk/

Strachan N. and R. Kannan 2008, *Hybrid Modelling of Long-Term Carbon Reduction Scenarios for the UK*, Energy Economics, Vol. 30, No. 6 pp. 2947-2963

Strachan N., Pye S., and Kannan R., 2008b, The iterative contribution and relevance of modelling to UK energy policy, *Energy Policy*, In Press

Strachan N., S. Pye and R. Kannan 2009, *The Iterative Contribution and Relevance of Modelling to UK Energy Policy*, Energy Policy, Vol. 37, No. 3, pp. 850-860