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An analysis of the impact of bioenergy and geosequestration in the UK future energy system

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Abstract

Three different energy scenarios have been considered to analyse the impact of bioenergy and geosequestration to GHG emissions in the UK for 2050. The analysis was accomplished with the use of the DECC 2050 Pathways Calculator. The outcomes focused on energy demand and supply and GHG emissions. The results showed that bioenergy and geosequestration are key factors for a low carbon energy system as they are capable of reducing significanlty carbon emissions, in parallel with the deployment of other clean energy techlogies.

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Keywords: bioenergy, energy scenarios, electricity, geosequestration

1. Background

From 1990 to 2001 energy consumption was continuously growing in the United Kingdom, by reason of the economic prosperity that the country was experiencing at that time. However, from 2004 and afterwards, energy consumption slightly decrease. In particular, in 2011, a year set in the middle of the European economic crisis, the total UK primary energy consumption fell to 209.6 Mtoe, the lowest of energy consumption since 1984. This reduction is attributed to low factors such as the Growth Domestic Product (GDP) [1] in combination with new stronger environmental regulations launched in the UK energy market following 2000. Regarding energy

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consumption by fuel, in the past twenty years no substantial alterations in the energy resources were recorded except from a progressive integration of renewable power in the system, essentially noticed after 2008, when the UK Government committed to reduce its GHG emissions by 80% until 2050 (compared to 1990 levels), based on the Climate Change Act [2]. The use of coal has eliminated over the years as a highly polluting power source. On the other hand, oil continues to be the principal source mainly for transportation while the electricity system depends primarily on gas [3]

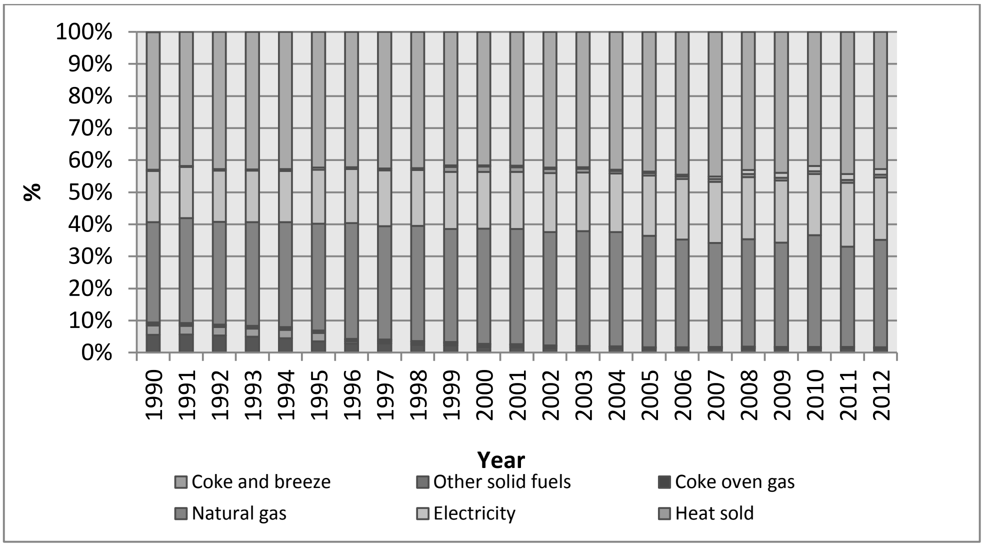

Fig. 1: Total Primary Energy Consumption by fuel, UK (1990-2012) [4]

One more common issue of concern is energy dependency. In the UK, the levels of energy production and consumption were almost equivalent at the beginning of 1990. During the period of 1990 to 2004, the UK production was larger than consumption allowing the UK to export energy to other European energy markets, while facilitating a safer energy sector. On the contrary, after that time, even though consumption remained at the same levels, the UK energy production declined, imposing the UK to rely on energy imports at a greater extent[5, 6].

With the intention of achieving both the long-term emissions declines along with energy security, the UK energy system has to be fundamentally transformed from its present form. The principal sources of energy, fossil fuels, have to be substituted by renewables along with innovative and efficient technologies so as to move towards a zero carbon future. As such, this paper aims to emphasise on bioenergy as an eco-friendly energy resource and on geosequestration as a novel technology which can significantly contribute in the reduction of CO_2 emissions.

The use of bioenergy can contribute significantly to the reduction of GHG emissions as it is a clean form of energy that has the ability to replace fossil fuels and concurrently become a factor towards the improvement of the rural sector in the UK. New modern technologies can participate in commercializing biomass from feedstocks in order to provide high quality energy services according to Slade et al. [7]. Nonetheless, several uncertainties and challenges exist which stem from the use of bioenergy. These are associated with the cost, the quality and the quantity of the raw material. That is directly related with the land that will be cultivated in order to provide the sufficient amounts of biomass, as there is a constant competition with other land uses such as farming, cultivation of other plants for human consumption etc. Another question that may arise for bioenergy is if it can indisputably reduce emissions and other environmental impacts that may be associated with water and air pollution and biodiversity [8].

On the same direction towards sustainability, geological sequestration has a large potential to decrease CO_2 emissions[9]. The concept is to separate carbon from coal straight from the atmosphere, either through gasification previous to the combustion or with its extraction from the flue gas after the combustion process, [10]. The technologies used to accomplish this task are engineered air capture technologies or enhanced weathering processes. The second step is to store carbon in soils, building materials, rocks or other elements of the geochemical system. The differentiation between Carbon Capture and Storage technology (CCS) is that it does seize CO_2 from the atmosphere and not in power stations [10, 11].

With the scope to explore these future solutions towards decarbonisation, three different scenarios were developed. The scenarios were assessed using the 'DECC 2050 Pathways Calculator' [12], a public available tool. The reason for assessing these two different technologies is that the 'DECC 2050 Pathways Calculator' segments the generation of negative emissions into two sectors: bio-energy plus carbon capture and storage; and geo-sequestration. The exploration of these technologies is still at an early stage, however both seem to have a wider impact on the UK energy sector and can contribute to make a more sustainable energy in the UK. Their analysis needs to reflect not only their potential to deliver real decarbonisation, but also the impacts in terms of wider sustainability and policy practicality and the systems which might be needed to deploy them. In that sense, in the following chapters a brief description of the scenarios will be presented while a sensitivity analysis on these two factors will be applied based on the default assumption provided by the calculator.

2. Energy Scenarios for 2050

2.1. Description of the Scenarios

The three scenarios analysed are presented in the following table[†].

Table 1: 2050 UK Scenarios

Scenario Name	**Description**
Scenario A	Predominant Fossil Fuels
Scenario B	Predominant Renewables and Nuclear
Scenario C	100% Renewables

Scenario A makes the assumption that the future UK energy sector will not make any consistent efforts to implement renewable energy projects as they require particularly high capital costs for research, development and construction, but also their operation and maintenance is expensive. This is attributed to low sensitization towards sustainability whilst efforts to decarbonise the energy system initialise only when the impacts of climate change becomes globally irrevocable. As such, the predominant energy source will be fossil fuels coal, oil and gas, with nuclear power as a supplementary resource. Scenario B is a scenario promoting sustainability with large deployment of different form of renewables (solar, wind, biomass, wave, geothermal) alongside the construction of new, more advanced nuclear power plants and the use of technological developments such as CCS, energy storage and fuel cells. Scenario C assumes a pathway dedicated completely to renewables.

2.2. Scenario Results

In the following paragraphs a brief presentation of three different projection images for the UK 2050 energy sector are given based on the figures illustrated in the DECC calculator webpage.

Attributable to the choice of approximately the same demand side assumptions among the scenarios, energy demand remains stable in all the pathways, almost at 1537 (±4) TWh/yr in 2050. On the other hand, as regarding electricity demand, even though the demand side assumptions are not differentiated, we identified sensitivity in the geosequestration assumption. Although it belongs to the supply side assumptions, geosequestration has a large impact in the final electricity demand, this will be analysed in detail in the following sections. Hence, in Scenario A that doesn't involve any important deployment of new technologies and geosequestration, electricity demand stays in low levels in 2050 (602 TWh/yr). In Scenarios B and C geosequestration is more developed, therefore more electricity is required to generate the sequestration machines and the level of power demand grows to 701 and 663 TWh/yr respectively.

The UK energy supply increase ranges between 15 and 27% for the three scenarios according to Fig. 2. It is observed that Scenario B projects the highest (3.157 TWh/yr) energy supply based on a variety of resources such as renewables, nuclear and a low level of fossil fuels. Scenario A projects lower levels of energy supply with increased numbers of imports and dependency on fossil fuels. The factors that affect the energy supply are related with the various technologies used, the intermittency of renewables, energy imports and exports, energy losses and other assumptions that were considered in order to increase energy security and reduce emissions for the future UK energy system.

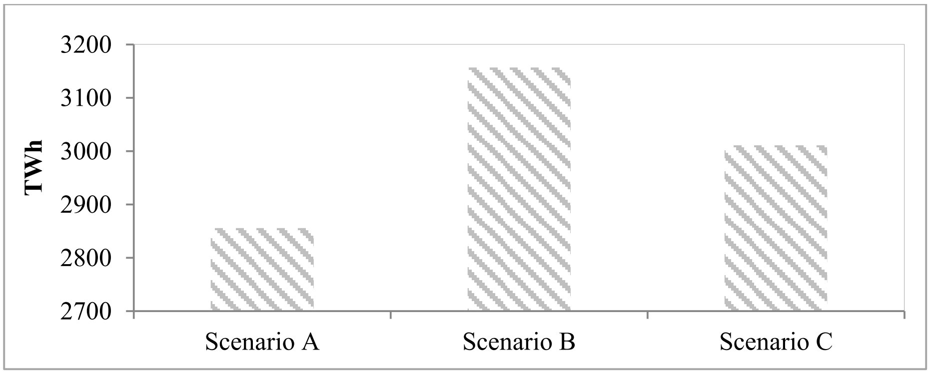

Fig. 2: Energy supply outputs for 2050 for Scenarios A, B and C

The following figure presents the electricity supply for the UK in 2050. Scenario A with predominant fossil fuels forecasts an increase of 143%. Scenario C, with high penetration of renewables, projects the largest increase in electricity supply. It is assumed that in 2050 power supply will be approximately 5 times greater compared to 2010 levels which is the base year for the DECC calculator. Scenario B, that supposes a midway case, combing renewables and nuclear, forecasts a 2 times increase. It is evident that increase in electricity supply is vast compared to energy supply growth. That leads to the assumption that the future energy system including industrial, domestic and commercial sectors but also transportation, will rely in a great extent on electricity.

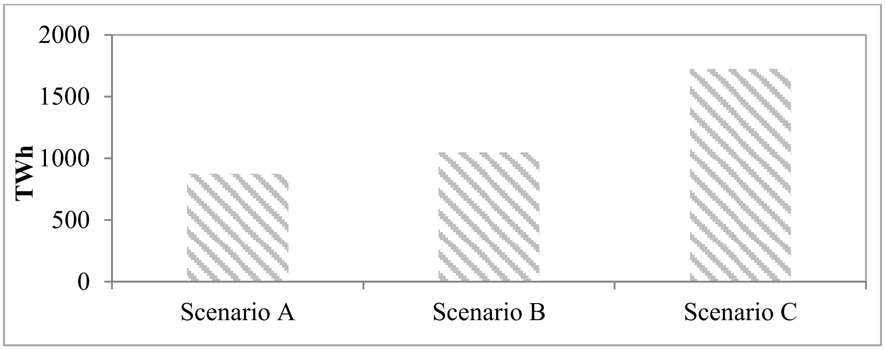

Fig. 3: Electricity supply outputs for 2050 for Scenarios A, B and C

Scenario C is the most green pathway as it succeeds 80% emissions reduction (compared to 1990 levels) close to 2042, eight years before the milestone of 2050. Scenario B is also a sustainable scenario attaining to reduce its GHG levels and achieve both CCA targets for 60% reduction in 2030 and 80% for 2050 compared to 1990 base year. On the other hand, Scenario A emphasised on conventional power resources fails to achieve both the 2030, 2050 targets. In spite of this, the extensive use of CCS attains to succeed 46.1% decline by 2030 and 68.9% by 2050.

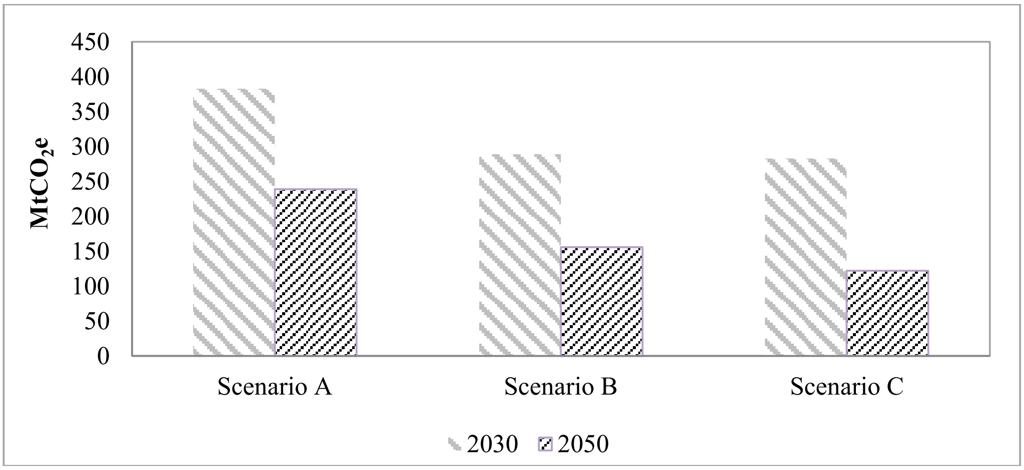

Fig. 4: Greenhouse Gus emissions outputs for 2030 and 2050 for Scenarios A, B and C

3. Analysis of the scenarios – The case of bioenergy and geosequestration in 2050

3.1. Bioenergy

The above outcomes vary significantly while differentiating their input-assumptions. As already mentioned, the 'DECC 2050 Pathways Calculator' exposes a key sensitivity, the 'Bioenergy Constraint' that has a considerable effect on GHG emissions. Bioenergy is an adaptable form of energy, which through various conversion processes can be applied to meet different types of energy demand, including transport, heat or power[10]. The raw material derives from biomass such as crops, algae or residues-wastes and in order to eliminate risks associated with bioenergy they have to be produced with sustainable ways using bio-cascading and bio-refining procedures[13].

The main types of biofuels produced by the transformation of biomass and extensively used the last two decades are bioethanol, biomethanol, biomethane, biohydrogen, biobutanol, biodiesel fatty acid methyl esters and fatty acid ethyl esters used mainly for transporation (aviation, shipping etc) but also for heat and power [14].The use of biofuels has a large potential in the UK. According to a recent study from the Manchester University, bioenergy could provide power for nearly 44% of its energy requirements in 2050 [15], although other reports suggest ratios close to 12% [8]. However, several uncertainties related with biomass have to be surpassed in order to achieve such a wide deployment in the UK. Policy enforcement can establish strong foundations upon which bioenergy use can be supported and promoted. An initial framework for this achievement is attempted by the UK government plans to follow a strategy consisted of four key points. These can be concisely presented as [8]:

- Policies which encourage bioenergy should actually contribute to carbon reductions that facilitate success in meeting UK carbon emissions targets for 2050.
- Bioenergy should become a cost effective clean form of energy
- The extensive use of biomass has an objective to improve the national economy while minimising the overall costs
- Other sectors of land use should be considered and in case of increased demand of biomass, its impact on these sectors should be examined, ensuring and protecting biodiversity and food security

In the DECC model, the 'Bioenergy Constraint' stands for: 'Land Dedicated to Bioenergy' which is a principal assumption impacting the availability of biomass and particularly biocrops according to Slade et al. [7]. It is evident through the use of the calculator, that bionergy has a twofold contribution to the UK energy and economy sectors as it can be either used as an energy source for domestic use or it can be exported (as it is a limited source with great demand in the whole Europe) offering both revenues and 'Bioenergy Credits'. These credits are counted as negative emissions. While biocrops produced in the UK decrease emissions in other European countries, they make it possible for the UK to offset any unreduced emissions. The calculator divides it in 4 Levels with diverse stages of availability:

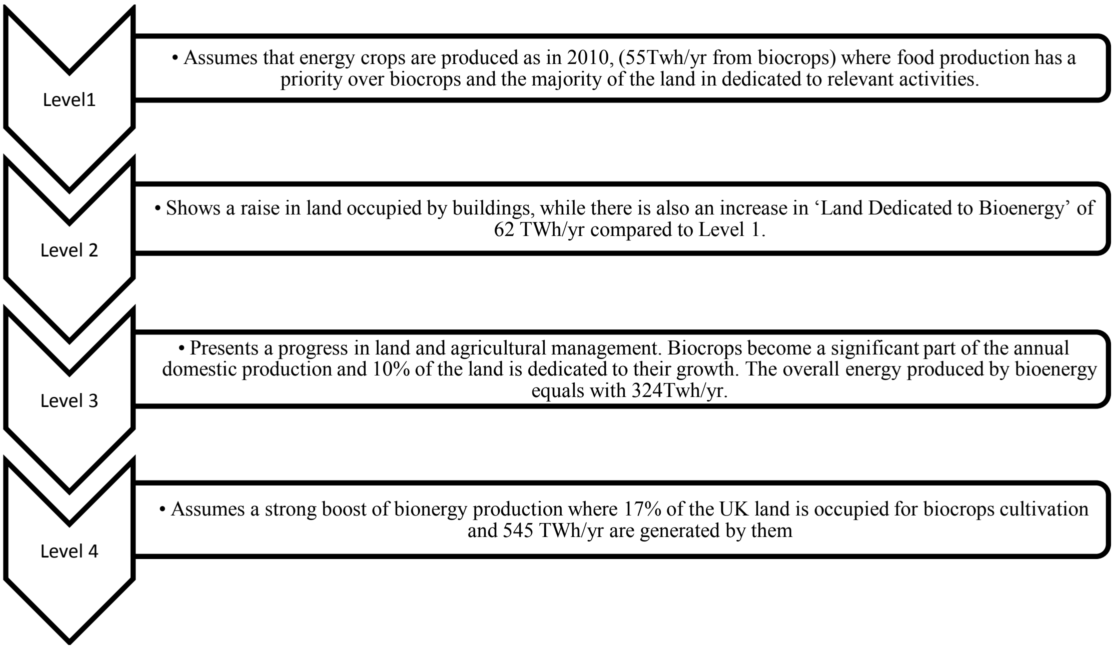

Fig.5: The 4 Levels in 'Land dedicated to Bioenergy' assumption [10]

The assumptions along with the actual calculator results present an important gradual increase in bioenergy use (land dedicated to biomass production) through the four levels. The most significant increase is between levels 2 and

3 with 5.3 times difference. This leads to a decrease in carbon emissions, ranging between 11% and 13% for 2030. The most significant reductions are observed in 2050 results as those reflect the development of the agricultural management and the improvements in biocrops promotion. Hence, Scenarios B & C including high levels of biomass and improved sustainable use of land present a decline in GHG emissions close to 25% in 2050 while this responds to a 5% increase in the amount of land. Regarding Scenario A, even though it does not rely on bioenergy, has the prospective to export large amounts of biocrops produced in the UK and therefore raise its 'Bioenergy Credits' through the system of negative emissions. This leads to a remarkable reduction of 30% (from level 2 to 3 for 2050). It is also significant the result of the sensitivity analysis for level 4 in Scenario A.
Fig.6 illustrates that case A projects the lowest GHG emissions while it experiences a significant increase in biocrops production although its predominant source remains to be conservative forms of energy.

This outcome designates the fact that there is not only one direction towards sustainability and emissions reduction and there is an assortment of assumptions to be considered in order to accomplish a low carbon viable energy future for the UK. A strategic factor that should be taken into account in the inputs selection regarding the bioenergy constraint is the land use dedicated to food productions. Requirements for nutrition are projected to increase while population increases in the UK, which is forecasted to reach 21% boost in 2050 compared to 2012 levels [16, 17]. Consequently, this might lead in amplification of food production that will demand additional land. A possible 10% or even worse 17% of land dedicated to biomass will result in expansion of food imports which embeds high uncertainties related to global prices and policies. In that sense, a balance between the different uses of land has to be considered in order to prevent shortages of food produced in the UK and at the same time support the sustainable production of biomass.

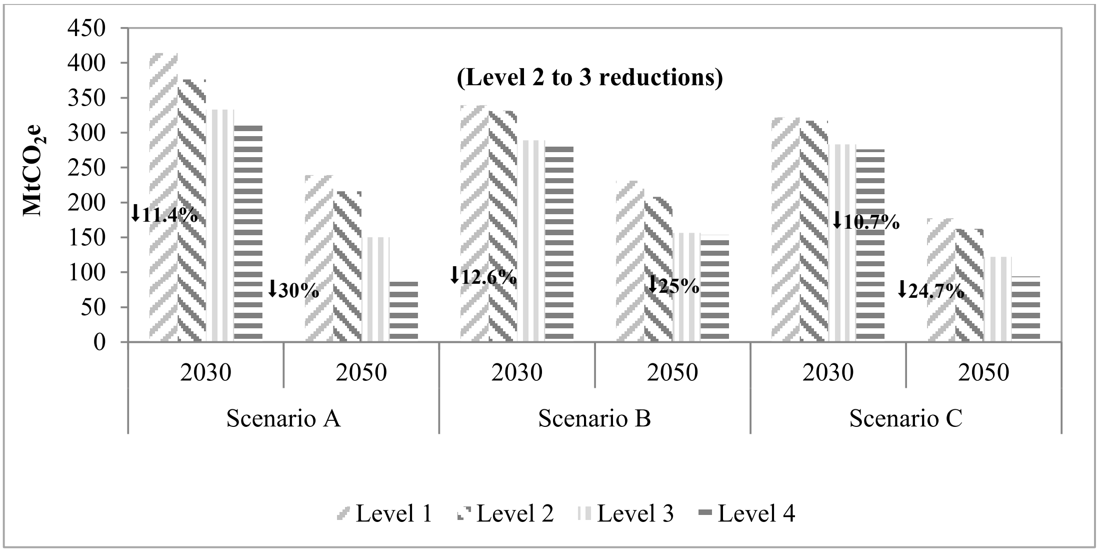

Fig.6: Sensitivity Analysis in the Bioenergy constraint applied to Scenarios A, B & C for GHG emissions results

3.2. Geosequestration

One more assumption in the DECC calculator affecting considerably the GHG emissions projections for 2050 is geosequestration. Deep geological sequestration along with CCS have a key role in the direct diminution of carbon emissions and contribute to the society and the environment by prohibiting carbon from the atmosphere[9, 18]. In particular, although carbon sequestration cannot replace the genuine emissions reduction, it is suggested as one of the most effective and sustainable choices for achieving future targets not only in the UK but also from a global perspective[19, 20]. Geosequestration projects could also have some indirect benefits such as development in research, employment and improvements in the soil quality[20]. Nonetheless, the current legislation framework is not sufficient for a full-scale commercialisation and a more inclusive policy development is required to be established in order to provide rules for the sites of geosequestration projects and other details related with the deployment of this technology[9]. According to HM Government [10] the four levels of geosequestration deployment may be presented in the following figure.

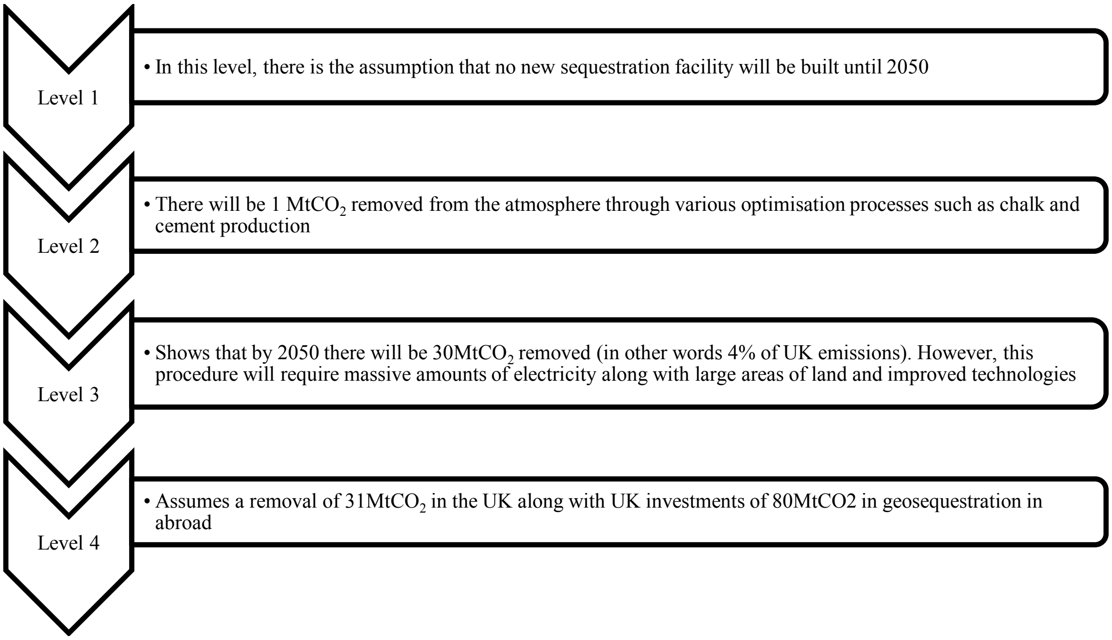

Fig.7: The 4 Levels in 'Geosequestration' Assumption [10]

The 2050 calculator shows that the greater impact in GHG emissions reduction is recorded between level 3 and level 4. This big divergence is obtained from the fact that level 4 includes very optimistic assumptions that project a large scale international deployment of geosequestration with emphasis on the less pricey areas of the world due to global pressures. As these projects will be developed with the participation of the UK, the country will acquire shares of negative emissions which will enhance the efforts to accomplish its national emissions targets. Furthermore, power generation required for geosequestration machines is not included in the UK domestic electricity consumption. As a result, while negative emissions are growing fast, emissions from power remain in the same levels as in level 3 leading to a remarkable overall emissions reduction. Between levels 2 and 3 (30$MtCO_2$ capture difference) the calculator user would expect also larger differences in carbon emissions, however as geosequestration machines require large amounts of electricity for their operation, its decarbonisation impact is by some means offset by the extensive power supply which generates high levels of emissions.

According to

Fig.8, it is observed an increase between levels 2 and 3 before 2030 for the reason that geosequestration projects have not been widely implemented yet. Scenario B appears to have the largest deviation among levels 3 and 4 due to the fact that it records the lowest emissions in level 3, therefore although the same amount of carbon is captured (80$MtCO_2$) the overall reduction percentage is higher for case B. This sensitivity analysis demonstrates that Scenario B and not Scenario C can become the most beneficial and sustainable future case. While employing all the available assumptions and keeping the rest of the inputs same in the three different pathways, case B remains always the one with the lowest emissions projections. Additionally, this scenario has reduced electricity imports and contains relatively low costs compared to the rest of the cases regarding the development of new projects and the electricity prices. It has to be mentioned that 2030 results do not present any important declines as geosequestration is an immature technology which entails years of research in order to become commercially deployed to a full extend. In that sense, only after 2025 we observe a slight effect of geosequestration on the results.

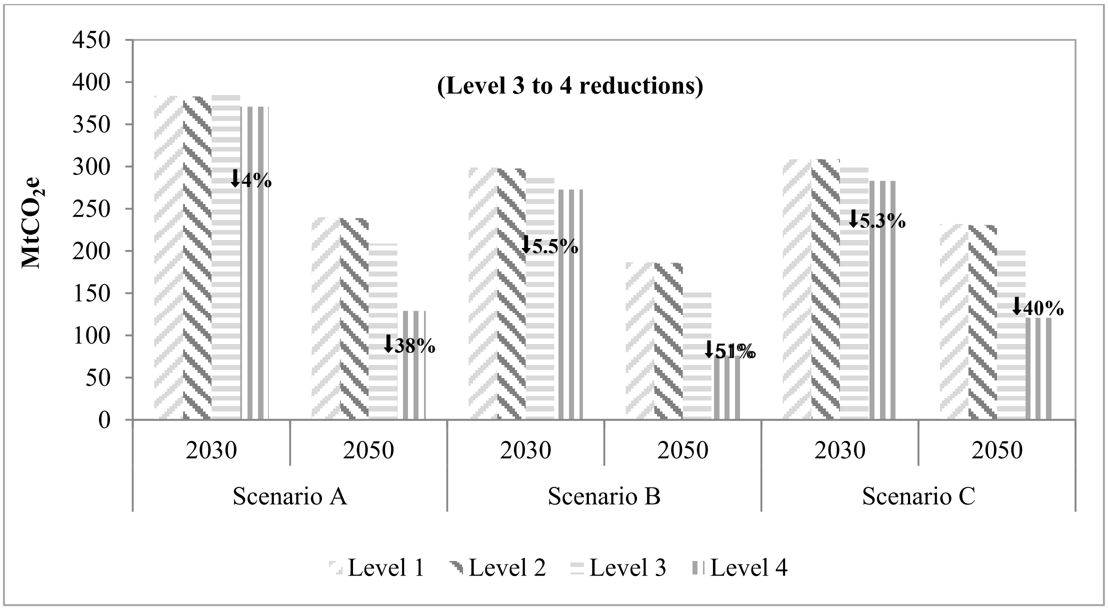

Fig.8: Sensitivity Analysis of the Geosequestration applied to Scenarios A, B, C for GHG emissions output

4. Conclusions

The energy sector in the UK in the past 20 years has been through a number of changes such as the rapid growth of natural gas close to the year of 2000 and the recent growth of renewables. However, in order to achieve the 2030 and 2050 emissions targets, the UK has to imply several transformations and modify its current form of the energy sector. Bioenergy and geosequestration were identified among other technological developments as two measures to combat climate change. Although, still not sufficiently developed and both surrounded by restraints, for example, bionenergy and food imports, sequestration and electricity supply, both have great potential to achieve emissions reduction.

A sensitivity analysis was applied to three scenarios, using the DECC 2050 Pathways Calculator in order to analyse the different projection images for the UK energy system by 2050, with a purpose to quantify the effect of these two technologies. By covering the entire range of all the available different options separated in four levels, we find the optimum pathway in terms of low emissions. In that sense, keeping all the assumptions as were initially selected [13]and varying the bioenergy constraint from level 1 to 4 it became evident that Scenario A with the main energy source deriving from fossil fuels, records the lowest emissions for 2050 (91 $MtCO_2$). This projection is for level 4 assuming a wide expansion of bioenergy arriving principally form biocrops, while geosequestration is on level 2. Regarding geosequestration the greenest case is B with emissions equal to76 $MtCO_2$ in 2050. As such, it is proved that geosequestration among levels 1 to 4 has a greater impact in decreasing carbon emissions and presents the largest decrease. On the other hand, without underestimating biomass, it records comparatively smaller percentages of deviations among the various outcomes. In conclusion, through this analysis it is shown that there in not only a single solution which may form a sustainable future energy system in the UK. A combination of different assumptions such as technologies, energy resources, policies, political and social decisions, human behaviour may have a huge impact in the energy sector.

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