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Un-burnable oil: An examination of oil resource utilisation in a decarbonised energy system[☆]

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HIGHLIGHTS

- We examine volumes of oil that cannot be used up to 2035 in a low CO_2 energy system.
- 500–600 billion barrels of current 2P reserves remain unused.
- At least 40–55% of yet to be found deepwater resources must not be developed.
- Arctic oil and most light tight oil resources remain undeveloped.
- Unconventional oil production is generally incompatible with a low CO_2 energy system.

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ABSTRACT

This paper examines the volumes of oil that can and cannot be used up to 2035 during the transition to a low-carbon global energy system using the global energy systems model, TIAM-UCL and the 'Bottom up Economic and Geological Oil field production model' (BUEGO). Globally in a scenario allowing the widespread adoption of carbon capture and storage (CCS) nearly 500 billion barrels of existing 2P oil reserves must remain unused by 2035. In a scenario where CCS is unavailable this increases to around 600 billion barrels. Besides reserves, arctic oil and light tight oil play only minor roles in a scenario with CCS and essentially no role when CCS is not available. On a global scale, 40% of those resources yet to be found in deepwater regions must remain undeveloped, rising to 55% if CCS cannot be deployed. The widespread development of unconventional oil resources is also shown to be incompatible with a decarbonised energy system even with a total and rapid decarbonisation of energetic inputs. The work thus demonstrates the extent to which current energy policies encouraging the unabated exploration for, and exploitation of, all oil resources are incommensurate with the achievement of a low-carbon energy system.

1. Introduction

There is widespread agreement in the scientific community that increasing atmospheric concentrations of CO_2 will lead to an increase in average global temperatures (see e.g. Solomon et al., 2007). Various methods have been described in the literature that relate levels and impacts of climate change, and their associated probabilities of occurrence, to levels of emissions of greenhouse gases (GHG) or CO_2. Authors have for example related the probability of different levels of temperature rise to: stabilisation at various atmospheric concentrations of CO_2 or GHG (Solomon et al., 2007), cutting emissions from current levels by certain factors (Stern, 2006), or the date of a global peak and subsequent decline in emissions (Smith et al., 2009; UNFCC, 2009). One of the most lucid metrics for estimating the likelihood of staying within certain levels of average temperature rise however is the cumulative emissions of CO_2 that are possible within a given timeframe.

Two of the most prominent examples of these 'carbon budgets' are provided by Allen et al., 2009; Meinshausen et al., 2009. Meinshausen et al. indicate that if global CO_2 emissions between 2000 and 2050 are limited to 1440 billion tonnes (Gt) CO_2 then there is a 50:50 chance of restricting the average global temperature rise to 2 °C. Allen et al. examine a longer time horizon and argue that cumulative emissions of one trillion tonnes of carbon, or 3660 Gt CO_2, over all time would similarly give an evens chance of a 2 °C average temperature rise. Of this trillion tonnes they indicate that around half has been emitted already.

Consequent to the concept of carbon budgets, many authors and organisations (e.g. IEA, 2012, Leaton, 2011, Meinshausen et al., 2009) have sought to relate estimates of the recoverable resources of fossil

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fuels, or some portion thereof,[1] to these budgets. Meinshausen et al. themselves for example suggested that the combustion CO_2 emissions of global reported 'proved reserves' of oil, gas and coal reserves in 2009, estimated to total around 2800 Gt CO_2, was almost double the carbon budget for the first half of the 21st century. The International Energy Agency (IEA) also frequently publishes a commentary on the volumes and distribution of reserves that can be utilised in a low-carbon scenario (see e.g. IEA, 2012). Similarly others have predicted a 'carbon bubble' arising from the fact that large quantities of proved reserves of listed fossil fuel producers cannot be burned because their embodied CO_2 emissions surpass the limits suggested by these climate models (Leaton, 2011); it is hence argued that their market values are significantly inflated.

These simple arithmetic sum or accounting approaches provide useful context when discussing the large potential resource base of fossil fuels. However they fail to account for many of the true dynamics involved when considering which resources should or should not be consumed. Examples of the factors that are not captured include: the role of CCS and/or biomass to create zero or potentially negative emissions, process emissions for example the natural gas required to produce certain categories[2] of oil and gas, the role of resources that are not currently considered reserves such as those that are not currently economic to produce or those resources estimated to be undiscovered, and substitution between the different types of fossil fuel. A further key factor overlooked is the consideration that some volumes of each of the fossil fuels need be produced in order to satisfy energy demand during the transition towards a low-carbon energy system.[3] It therefore remains an open question what volume of fossil fuels can be used and where these are located while attempting to keep average temperature rises below 2 °C.

There are a wide range of models available that can incorporate such effects that can help inform this discussion however. For example, energy systems or integrated assessment models used for the Special Report on Emissions Scenarios (SRES) and Representative Concentration Pathways (RCP) by the IPCC, 2000; van Vuuren et al., 2011, or shorter-term whole system simulation models such as by Shell, 2013 and the IEA, 2012, or oil-sector specific models such as by Statoil, 2012. These are employed by a variety of organisations including upstream oil and gas companies, international organisations, consultancies, and academic institutions. While these models have a number of uses they tend to be used to generate outlooks for energy production and consumption rather than using modelling results to examine the fossil fuel resources that are available but that remain unused over their specific modelling horizons (e.g. IEA, 2012).

The outlooks from other organisations also disregard modelling a pathway to 2 °C, preferring to examine uncertainty in factors other than limiting CO_2 emissions or only producing only a 'most likely' pathway or forecast (BP, 2013; EIA, 2011; ExxonMobil, 2013; Shell, 2011,2013). A separate subset of studies on the other hand focus on one sector in isolation and so can fail to capture the full range of possible substitution between different energy types (e.g. Campbell and Heapes, 2009; Schindler and Zitell, 2008 look solely at the oil market).

CO_2 constraints also play an important, although rarely discussed, role in another active and ongoing debate surrounding the availability of oil. Estimates of oil resources and reserves can vary for a range of technical, socio-economics, and definitional factors (McGlade, 2012) and so differences in assumptions can lead to a wide range of estimates in volumes of oil considered to be recoverable. Possible reductions to oil availability arising from constraints placed on CO_2 emissions are a further uncertainty that should be considered when estimating recoverable resources, especially when estimating volumes of oil reserves.

This paper seeks to quantify what oil resources can and cannot be used during the transition to a low-carbon energy system, the nature of these resources, and where they are located. To take account of the dynamics of the energy system more robustly than simple accounting methods we use an innovative approach linking the outputs of a technology-rich whole energy systems model (TIAM-UCL) with a data-rich bottom up oil field level model (called the 'Bottom Up Economic and Geological Oil field production model' or BUEGO). TIAM-UCL is first used to generate an estimate of the most cost-effective energy system that limits the global average temperature rise to 2 °C. Two different scenarios are examined and hence TIAM-UCL generates two overall oil demand levels that are commensurate with a low-carbon energy system. These are then used as an input to BUEGO which provides a detailed characterisation of the oil resources that are and are not used under these scenarios.

The remainder of this paper is set out as follows: Section 2 provides an overview of the two models employed, TIAM-UCL and BUEGO, the assumptions on which they rely, and the scenarios that are generated in this work. Section 3 next examines the outputs of these models and the insights that can be drawn, while Section 4 provides a discussion of these results looking in particular at the policy implications and concludes.

2. Approach

This section provides a brief description of TIAM-UCL and BUEGO, including their strengths and weaknesses, and how the hybrid approach adopted in this work mitigates many of the latter. A more detailed description of the two models is provided in the Appendix. This section also describes the two alterative scenarios run in this work and the manner in which they have been developed.

2.1. TIAM-UCL

TIAM-UCL is an adapted version of the TIMES Integrated Assessment Model (ETSAP-TIAM), a linear programming partial equilibrium model developed and maintained by the Energy Technology Systems Analysis Programme (ETSAP) (Loulou and Labriet, 2007). TIMES is an acronym for 'The Integrated MARKAL–EFOM System', with MARKAL and EFOM themselves also acronyms standing for 'MARket ALLocation' and 'Energy Flow Optimisation' models.

The new 16-region TIAM-UCL model breaks out the UK from the previous Western Europe region in the 15-region ETSAP–TIAM model and contains an enhanced representation of oil and gas resources and production mechanics. TIAM-UCL is technology-rich, bottom up,

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[1] There is no standard for reporting fossil fuel reserves and resources that is globally accepted and employed by all analysts, which explains much of the unnecessary confusion that can arise when discussing fossil fuel availability. This work relies upon the following definitions throughout: reserves can be reported according to their probability of production (1P – proved, 2P – proved and probable, and 3P – proved, probable and possible corresponding to volumes with a 90%, 50% and 10% chance of being exceeded respectively), with 2P being the most useful estimate. *Reserves* are only one element within the more encompassing *resource* base which can be reported as economically (available in current economic conditions), technically (available with current technology), or ultimately (available with current and future technology) recoverable. *Resources* are themselves a subset of the fossil fuel in place which includes volumes that will never be recovered. See McGlade, 2012 for a more detailed explanation.

[2] In this work we use the word category to distinguish between the individual elements of oil that can be identified that make up the global resource base. For oil these comprise: existing 2P reserves, reserve growth, undiscovered, Arctic oil, light tight oil, and natural gas liquids, which here are assumed all to be conventional oil, and natural bitumen, extra-heavy oil, and kerogen oil, which are taken here to be unconventional oil. The exact definitions of these terms are given in McGlade, 2012.

[3] The phrase 'low-carbon energy system' is used to refer to an energy system that results in an evens chance of limiting the global average temperature rise to 2 °C.