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# Fossil fuel risks: What remains unburnt when staying below 2°C?

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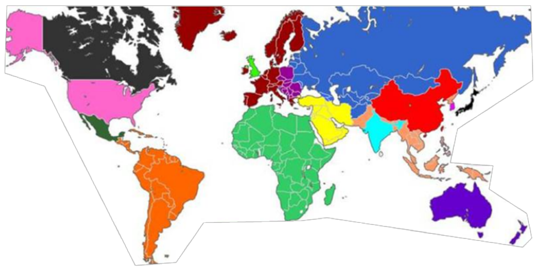
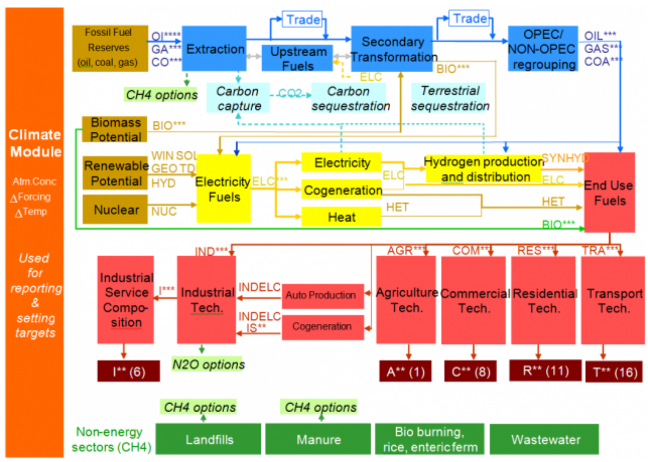
# Modelling future energy system developments

- Models are essential to determine outcomes of complex systems
- Model results depend on three crucial factors (in addition to the expertise of the users):
  - *Robustness of structure: TIMES* Integrated Assessment Model (TIAM-UCL)
  - *Plausibility of input assumptions*
  - *Data quality*
- Provides integrity of analysis so that work can be taken seriously

# TIAM-UCL finds the cost-optimal global energy system that meets energy demands within 16 individual regions

- Technologically-detailed, bottom-up energy system model
- Models the energy system by maximising global welfare over the duration of scenario
- Optimises energy service demands for 16 regions given available primary energy sources and technologies
- Calculates impact of selected primary energy sources on emissions and temperature rise





# The long-term future of energy systems is subject to numerous uncertainties

- Importance of different input assumptions
  - Regional and global population and GDP growth rates
  - Costs and rates of low-carbon technology deployment (carbon capture and storage, solar PV, electric vehicles etc.)
  - Fossil fuel production costs and availability
  - Alternative energy sources (bio-energy, hydrogen etc.)
  - Temperature rises
  - Climate policy
- Importance of being able to vary these assumptions in the model
- Need for sensitivity analysis to see which assumptions the model is most sensitive to

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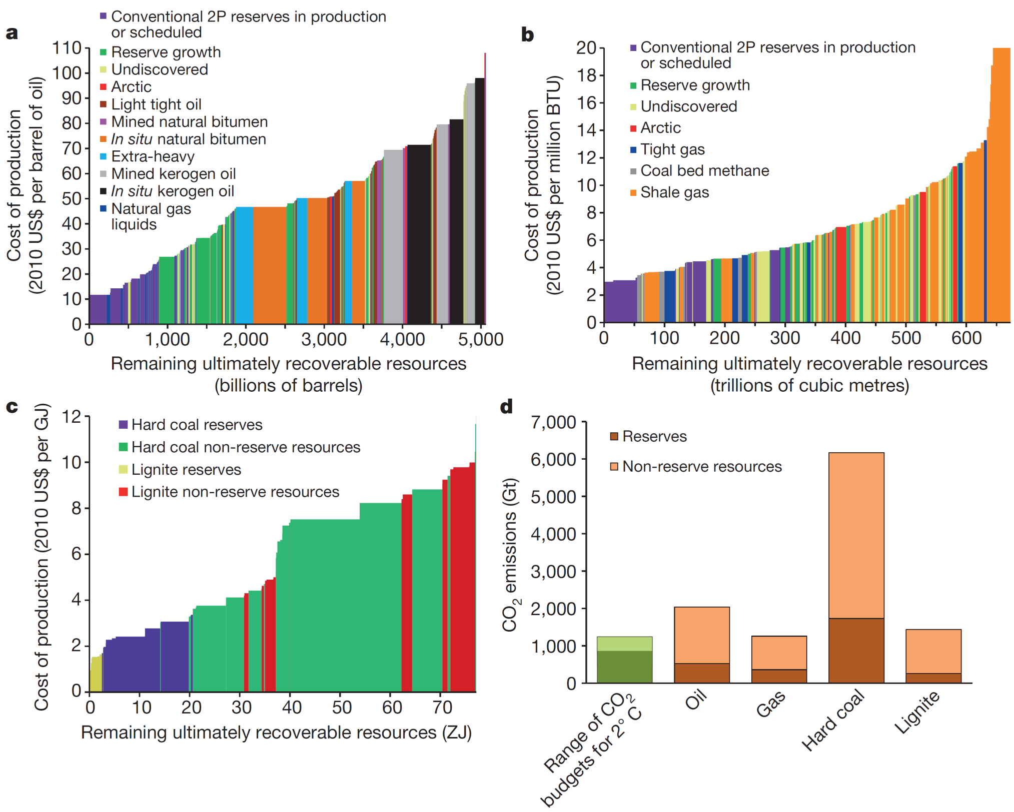
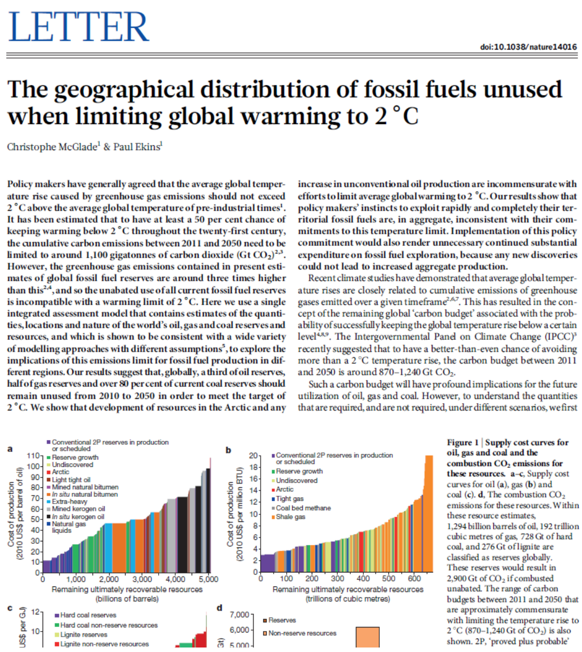
# Estimates of remaining fossil fuel reserves and resources and how these relate to 2 °C climate change budgets



# Which regions contain fossil fuels that should stay in the ground to stay within the 2°C carbon budgets?

- Burning all current fossil fuel reserves exceed the 2 °C 'carbon budget' by around three times
- But to date unknown which of oil, gas and coal are and aren't developed and who owns these
- Used TIAM-UCL to investigate this and examine who owns the fossil fuel reserves and resources that are 'unburnable'



LETTER

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The geographical distribution of fossil fuels unused when limiting global warming to 2 °C

Christophe McGlade[1] & Paul Ekins[1]

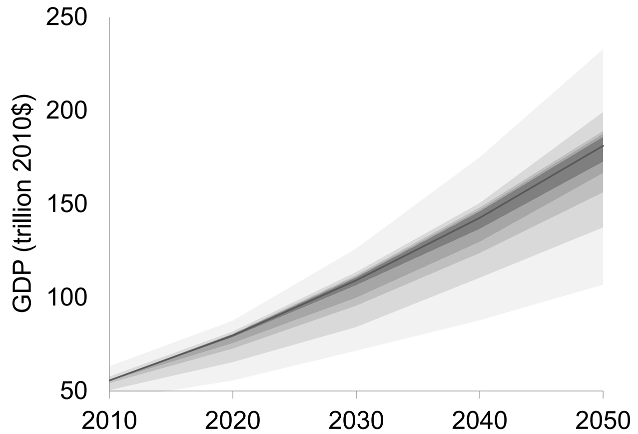
Policy makers have generally agreed that the average global temperature rise caused by greenhouse gas emissions should not exceed 2 °C above the average global temperature of pre-industrial times[1]. It has been estimated that to have at least a 50 per cent chance of keeping warming below 2 °C throughout the twenty-first century, the cumulative carbon emissions between 2011 and 2050 need to be limited to around 1,100 gigatonnes of carbon dioxide (Gt $CO_2$)[2,3]. However, the greenhouse gas emissions contained in present estimates of global fossil fuel reserves are around three times higher than this[2,4], and so the unabated use of all current fossil fuel reserves is incompatible with a warming limit of 2 °C. Here we use a single integrated assessment model that contains estimates of the quantities, locations and nature of the world's oil, gas and coal reserves and resources, and which is shown to be consistent with a wide variety of modelling approaches with different assumptions[5], to explore the implications of this emissions limit for fossil fuel production in different regions. Our results suggest that, globally, a third of oil reserves, half of gas reserves and over 80 per cent of current coal reserves should remain unused from 2010 to 2050 in order to meet the target of 2 °C. We show that development of resources in the Arctic and any increase in unconventional oil production are incommensurate with efforts to limit average global warming to 2 °C. Our results show that policy makers' instincts to exploit rapidly and completely their territorial fossil fuels are, in aggregate, inconsistent with their commitments to this temperature limit. Implementation of this policy commitment would also render unnecessary continued substantial expenditure on fossil fuel exploration, because any new discoveries could not lead to increased aggregate production.

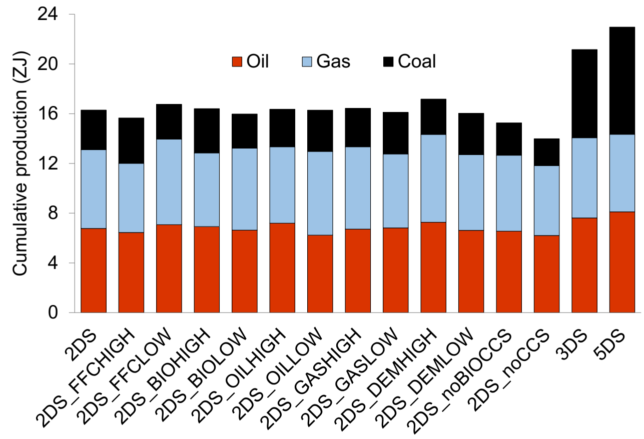
Recent climate studies have demonstrated that average global temperature rises are closely related to cumulative emissions of greenhouse gases emitted over a given timeframe[2,6,7]. This has resulted in the concept of the remaining global 'carbon budget' associated with the probability of successfully keeping the global temperature rise below a certain level[4,8,9]. The Intergovernmental Panel on Climate Change (IPCC)[3] recently suggested that to have a better-than-even chance of avoiding more than a 2 °C temperature rise, the carbon budget between 2011 and 2050 is around 870–1,240 Gt $CO_2$.

Such a carbon budget will have profound implications for the future utilization of oil, gas and coal. However, to understand the quantities that are required, and are not required, under different scenarios, we first

**Figure 1 | Supply cost curves for oil, gas and coal and the combustion $CO_2$ emissions for these resources.** **a–c**, Supply cost curves for oil (**a**), gas (**b**) and coal (**c**). **d**, The combustion $CO_2$ emissions for these resources. Within these resource estimates, 1,294 billion barrels of oil, 192 trillion cubic metres of gas, 728 Gt of hard coal, and 276 Gt of lignite are classified as reserves globally. These reserves would result in 2,900 Gt of $CO_2$ if combusted unabated. The range of carbon budgets between 2011 and 2050 that are approximately commensurate with limiting the temperature rise to 2 °C (870–1,240 Gt of $CO_2$) is also shown. 2P, 'proved plus probable'

# Scenarios were run under a wide range of assumptions on both supply and demand sides and climate change



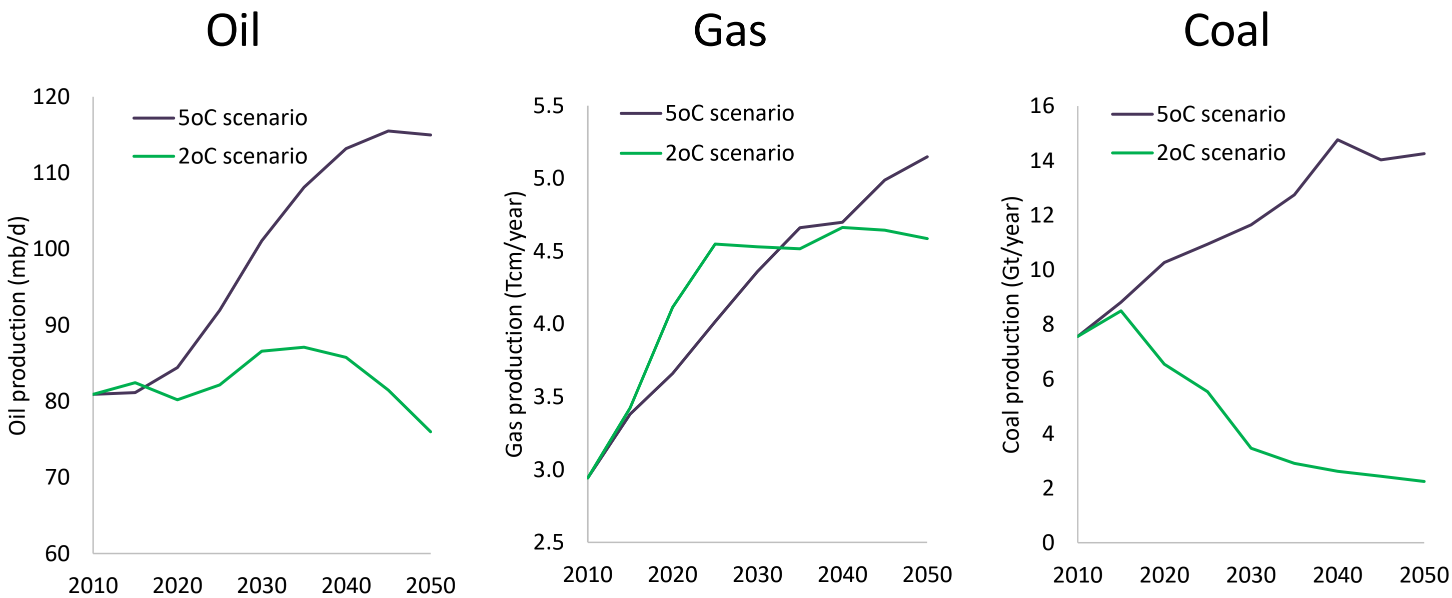




- Left panel shows range in projected global GDP from all scenarios used in the IPCC 5$^{th}$ Assessment Report
- Right panel shows cumulative fossil fuel production for different temperature scenarios (2 $^{o}$C, 3 $^{o}$C, 5 $^{o}$C) and sensitivity of 2 $^{o}$C scenario to assumptions on fossil fuel costs, bioenergy, oil and gas availability, demand (GDP) and carbon capture and storage (CCS)

# Regional distribution of reserves unburnable before 2050 to stay below 2$^{o}$C

| Region | Oil | | Gas | | Coal | |
|---|---|---|---|---|---|---|
| | Gb | % | Tcm | % | Gt | % |
| Africa | 23 | 21% | 4.4 | 33% | 28 | 85% |
| Canada | 39 | 74% | 0.3 | 24% | 5.0 | 75% |
| China | 9 | 28% | 2.6 | 75% | 116 | 61% |
| C & S America | 58 | 39% | 4.8 | 53% | 8 | 51% |
| Europe | 5.0 | 20% | 0.6 | 11% | 65 | 78% |
| FSU | 27 | 18% | 31 | 50% | 203 | 94% |
| India | 0.4 | 7% | 0.3 | 27% | 64 | 80% |
| Middle East | 263 | 38% | 46 | 61% | 3.4 | 99% |
| OECD Pacific | 2.1 | 37% | 2.2 | 56% | 83 | 93% |
| ODA | 2.0 | 9% | 2.2 | 24% | 10 | 34% |
| United States | 2.8 | 6% | 0.3 | 4% | 235 | 92% |
| Global | 431 | 33% | 95 | 49% | 819 | 82% |

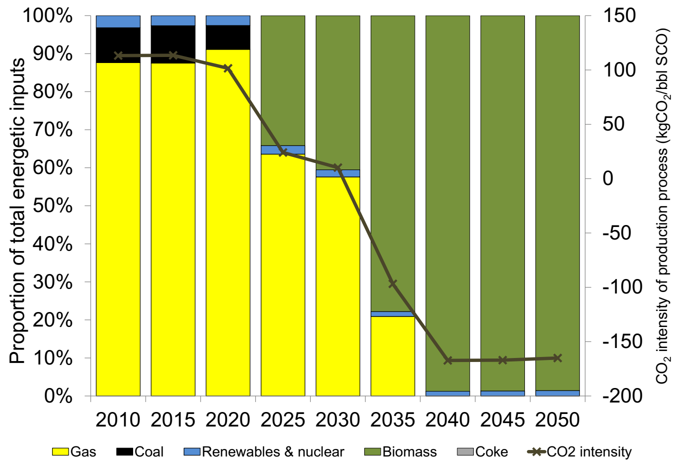
# Oil and coal consumption significantly different between 2°C and 5°C scenarios but gas acts as a 'transition' fuel



# Limited effect of CCS on unburnable reserves, energy inputs for oil sands must be decarbonised, and all Arctic resources are unburnable

Unburnable reserves with and without CCS

| | Oil | | Gas | | Coal | |
|---|---|---|---|---|---|---|
| | Gb | % | Tcm | % | Gt | % |
| With CCS | 431 | 33% | 95 | 49% | 819 | 82% |
| No CCS | 449 | 35% | 100 | 52% | 887 | 88% |




- CCS has only a modest effect on the production of reserves
- Production of oil sands in Canada continues but this is accompanied by a rapid and total de-carbonization of the auxiliary energy inputs required
- No development of oil or gas resources in the Arctic

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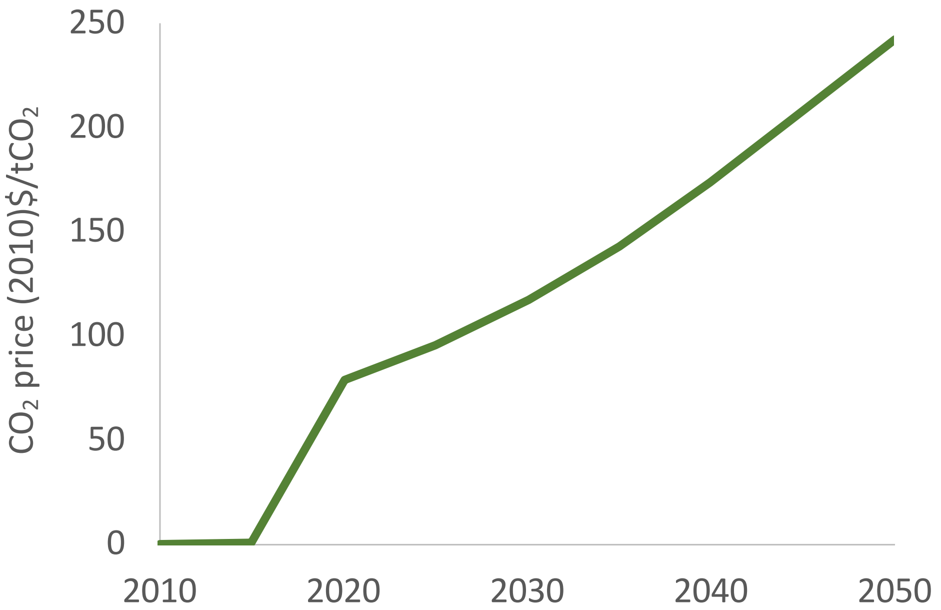
# $CO_2$ price trajectory in 2 ºC scenario from ‘*The geographical distribution of fossil fuels unused when limiting global warming to 2 °C*’



# Factors for consideration

- Politics: Inconsistency of stated commitments to 2 $^{o}$C
  - Climate change as well as economic and (geo-) political implications
  - Licensing constraints for fossil fuel exploration?
- Corporates: Justification for E&P financing
  - New discoveries cannot lead to increased aggregate production (e.g. European shale gas)
  - At the limit may be too risky for delivery of long-term returns
- Other models existing (BUEGO oilfield model) or under development (gas field model) should identify corporate or state ownership of different resources

# Conclusions

- Modelling tools can provide a holistic analysis of system-wide implications of a wide range of energy futures
- Addressing uncertainty: wide range of possible outcomes and developments can often be better assessed through scenarios than short-term deterministic 'forecasts'
- Such uncertainties are exacerbated by the uncertainty surrounding the severity of future efforts to address climate change
- There is a huge amount at stake: economically, socially, politically and environmentally
- We will be developing and extending these tools in order to contribute further insights to the future possibilities for and implications of global, regional and national energy systems