UCL

Global Energy: Options and Implications

A presentation to the 5th Congress of the East Asian Association of Environment and Resource Economists (EAAERE)

August 6th 2015, Academica Sinica, Taipei

Paul Ekins
Professor of Resources and Environmental Policy
UCL Institute for Sustainable Resources
Deputy Director, UK Energy Research Centre

UKERC

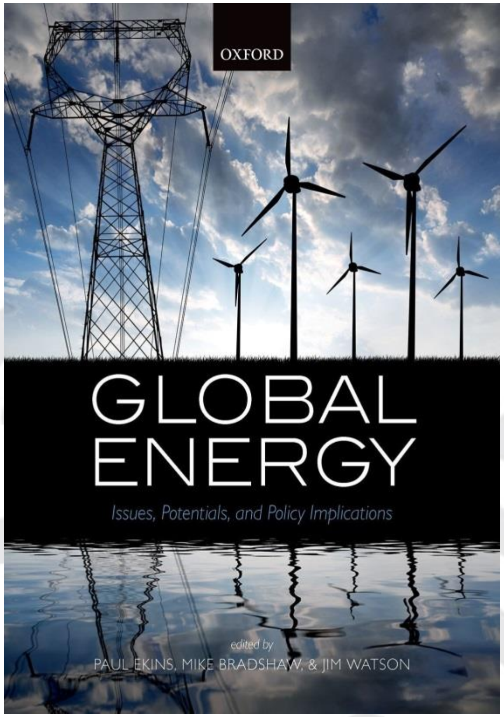
Global Energy

Issues, Potentials, and Policy Implications

Edited by Paul Ekins, Mike Bradshaw, and Jim Watson

This book is about energy and other resources, and the technologies that have been and are being developed to exploit them; to understand how the global energy system is developing, and how it might in the future.

- A comprehensive and clear account of the full range of energy issues, options, and choices
- Addresses the crucial question of what energy sources to use and how to ensure their availability
- Enables the reader to understand important issues in current affairs
- Examines the critical economic, social, political, and cultural issues that will determine which technologies are deployed
- Reviews the policies countries can use in order to influence the way their energy systems develop



Hardback | 978-0-19-871952-6 | **£95.00**

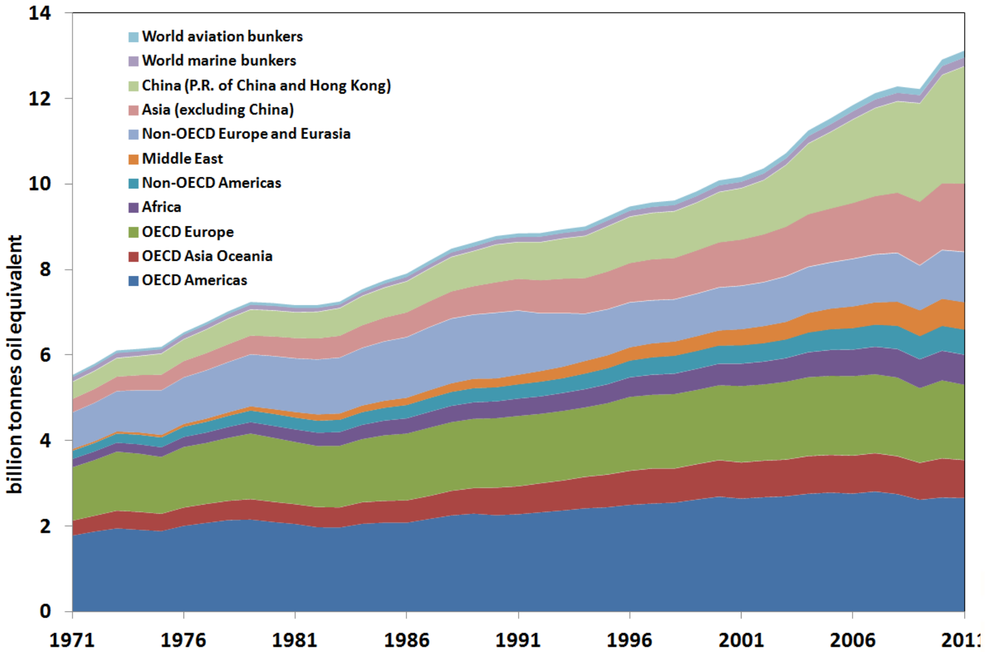
Paperback | 978-0-19-871953-3 | **£35.00**

Energy policy objectives (low carbon +)

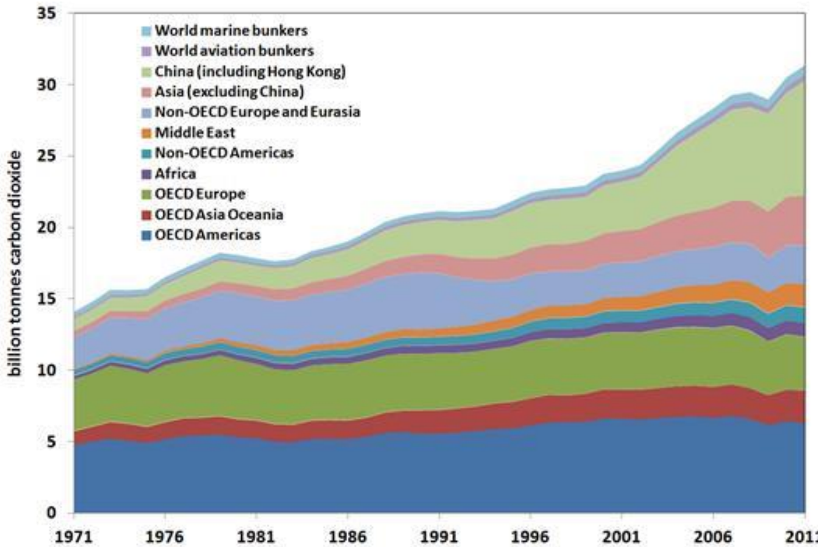
- The objectives of energy policy for many countries are basically three:
  - Transition to a low-carbon energy system (involving cuts of at least 80% in greenhouse gas (GHG) emissions by 2050, which will require the almost complete decarbonisation of the electricity system), and a wider ‘green economy’
  - Increased security and resilience of the energy system (involving reduced dependence on imported fossil fuels and system robustness against a range of possible economic, social and geo-political shocks)
  - Competitiveness (some sectors will decline as others grow – allow time for the transition) and cost efficiency (ensuring that investments, which will be large, are timely and appropriate and, above all, are not stranded by unforeseen developments) and affordability for vulnerable households (special arrangements if prices continue to rise)
- Only the first of these objectives is relatively recent.
- Outcomes on the other two will depend on how and how vigorously the decarbonisation objective is pursued.

The inexorable increase in energy use and CO_2 emissions

Global primary energy demand by region



Global CO2 emissions by region



Energy unequally consumed

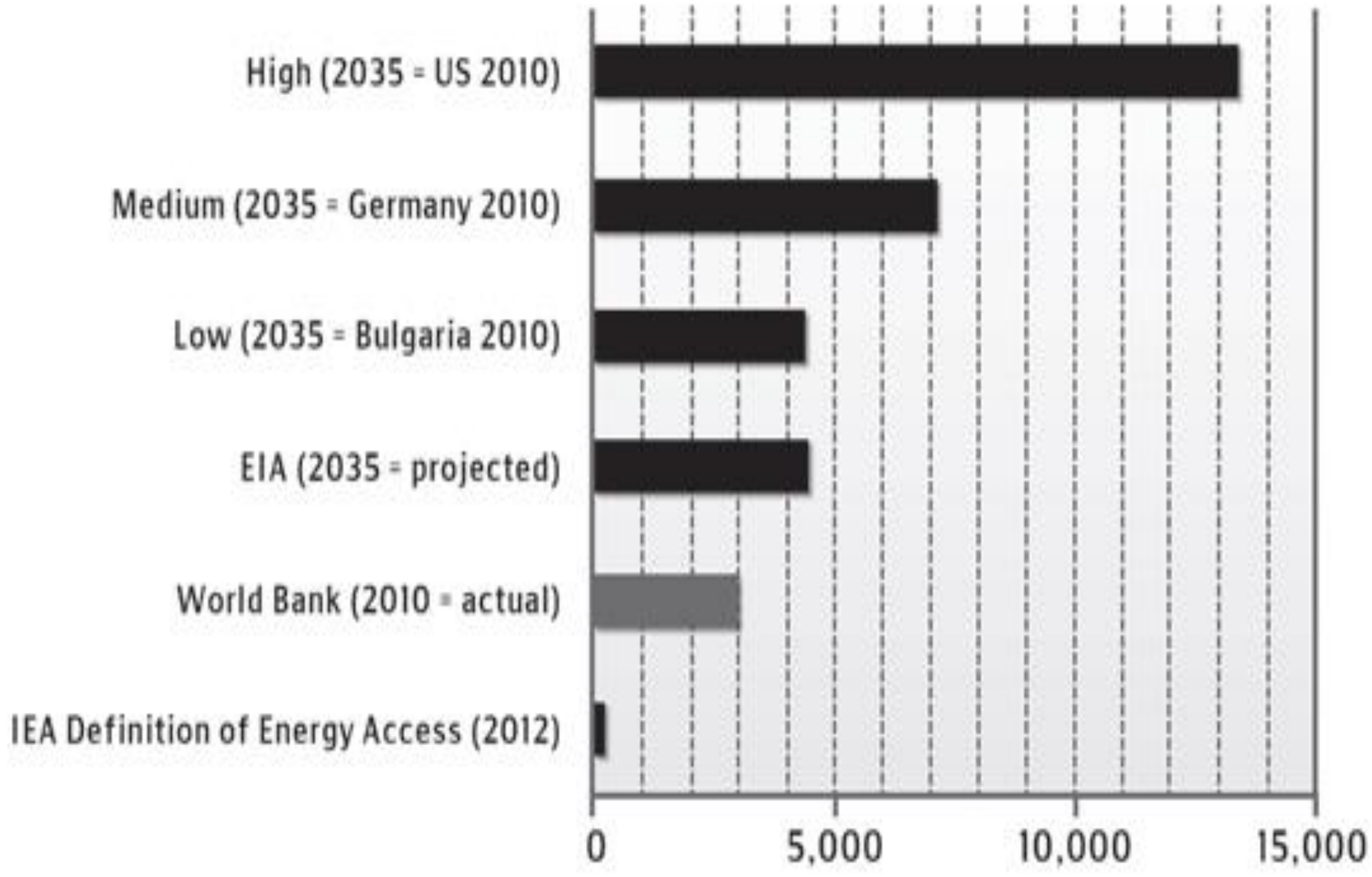
Primary energy consumption in selected countries in 2011
(tonnes of oil equivalent per capita)

High consuming countries		Major developed economies		Emerging economies		Lower-income countries	
Iceland	17.9	United States	7.0	South Africa	2.8	DR Congo	0.4
Qatar	17.8	Australia	5.4	PR China	2.0	Tajikistan	0.3
Trinidad and Tobago	15.5	Korea	5.2	Argentina	2.0	Nepal	0.3
Kuwait	11.5	Russian Federation	5.2	Thailand	1.7	Cameroon	0.3
Netherlands Antilles	10.9	Netherlands	4.6	Mexico	1.7	Haiti	0.3
Brunei Darussalam	9.3	France	3.9	Turkey	1.5	Yemen	0.3
Oman	8.9	Germany	3.8	Brazil	1.4	Myanmar	0.3
United Arab Emirates	8.4	Japan	3.6	Indonesia	0.9	Senegal	0.3
Luxembourg	8.0	United Kingdom	3.0	Nigeria	0.7	Bangladesh	0.2
Canada	7.3	Italy	2.8	India	0.6	Eritrea	0.1

Different interpretations of ‘energy access’

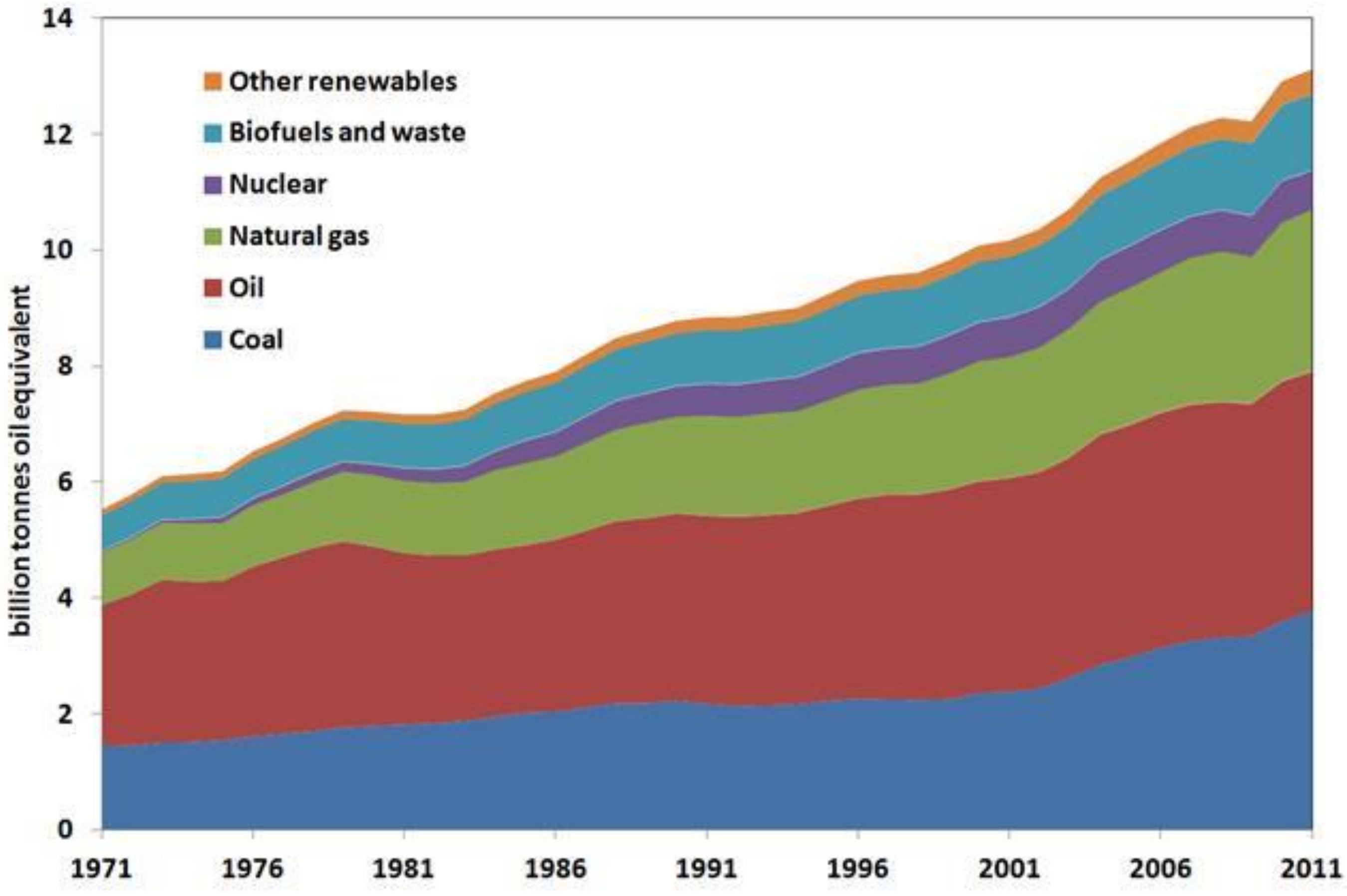
Source: Bazilian and Pielke 2013

Actual and projected global per capita electricity consumption (kWh/year)



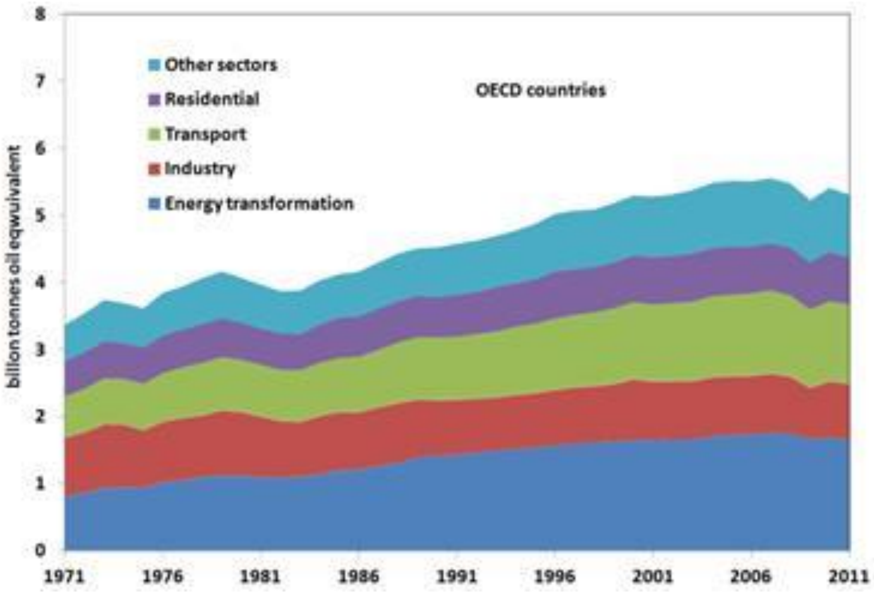
The dominance of fossil fuels

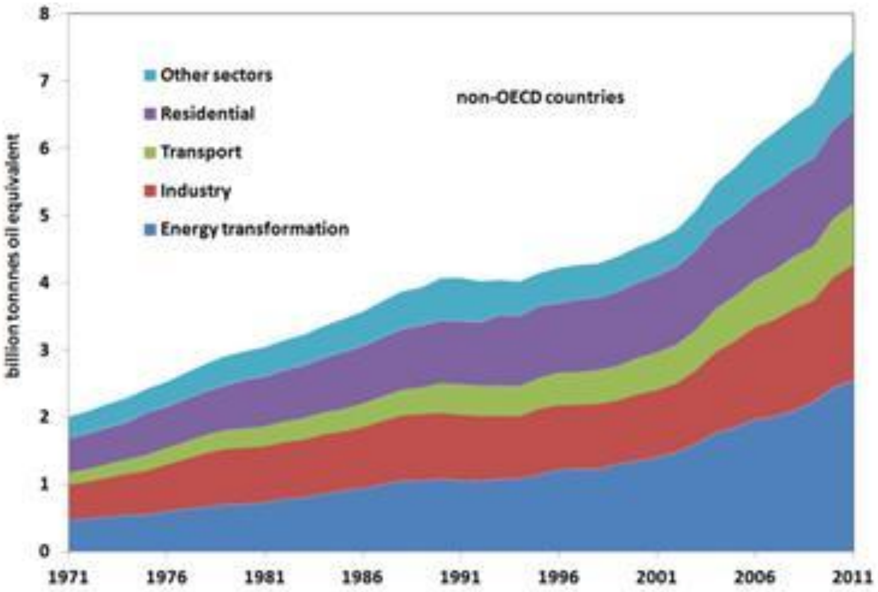
Global primary energy demand by fuel



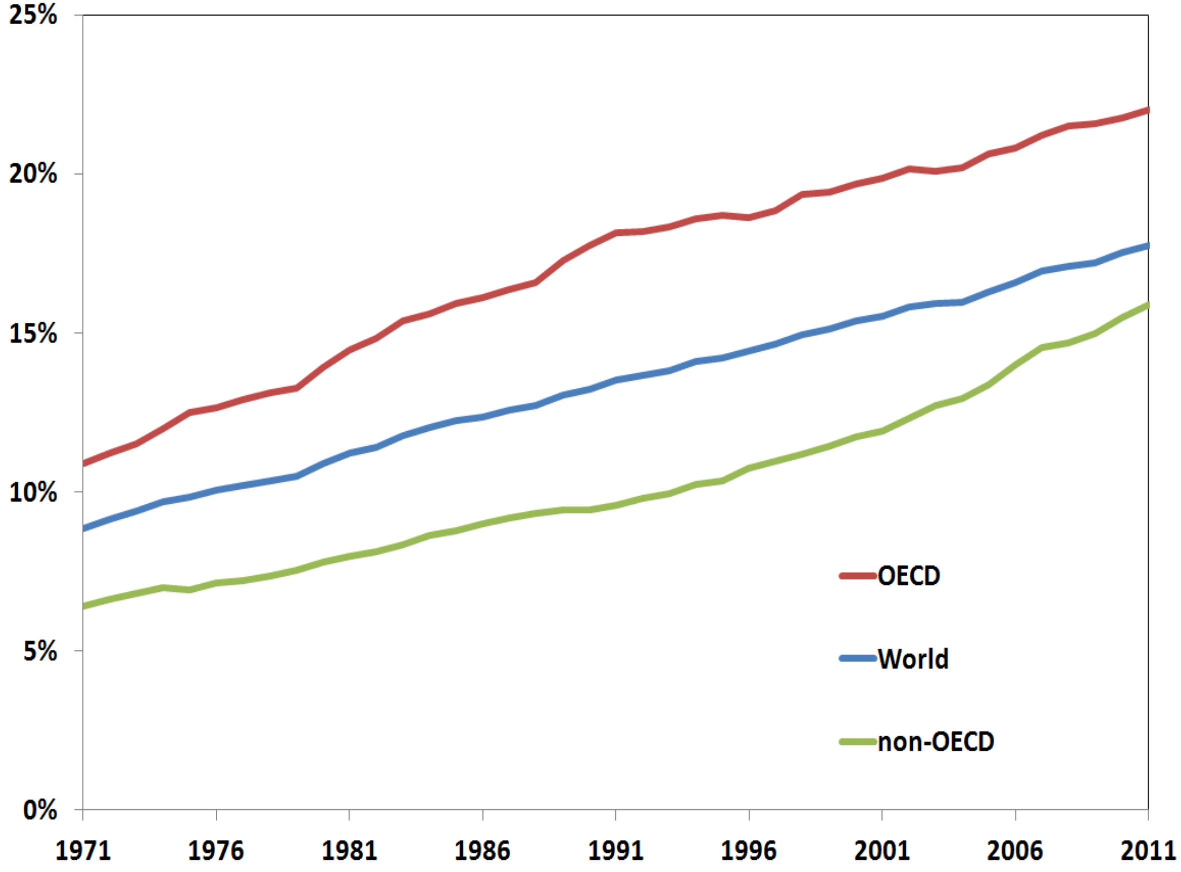
Energy use by sector

OECD and non-OECD countries

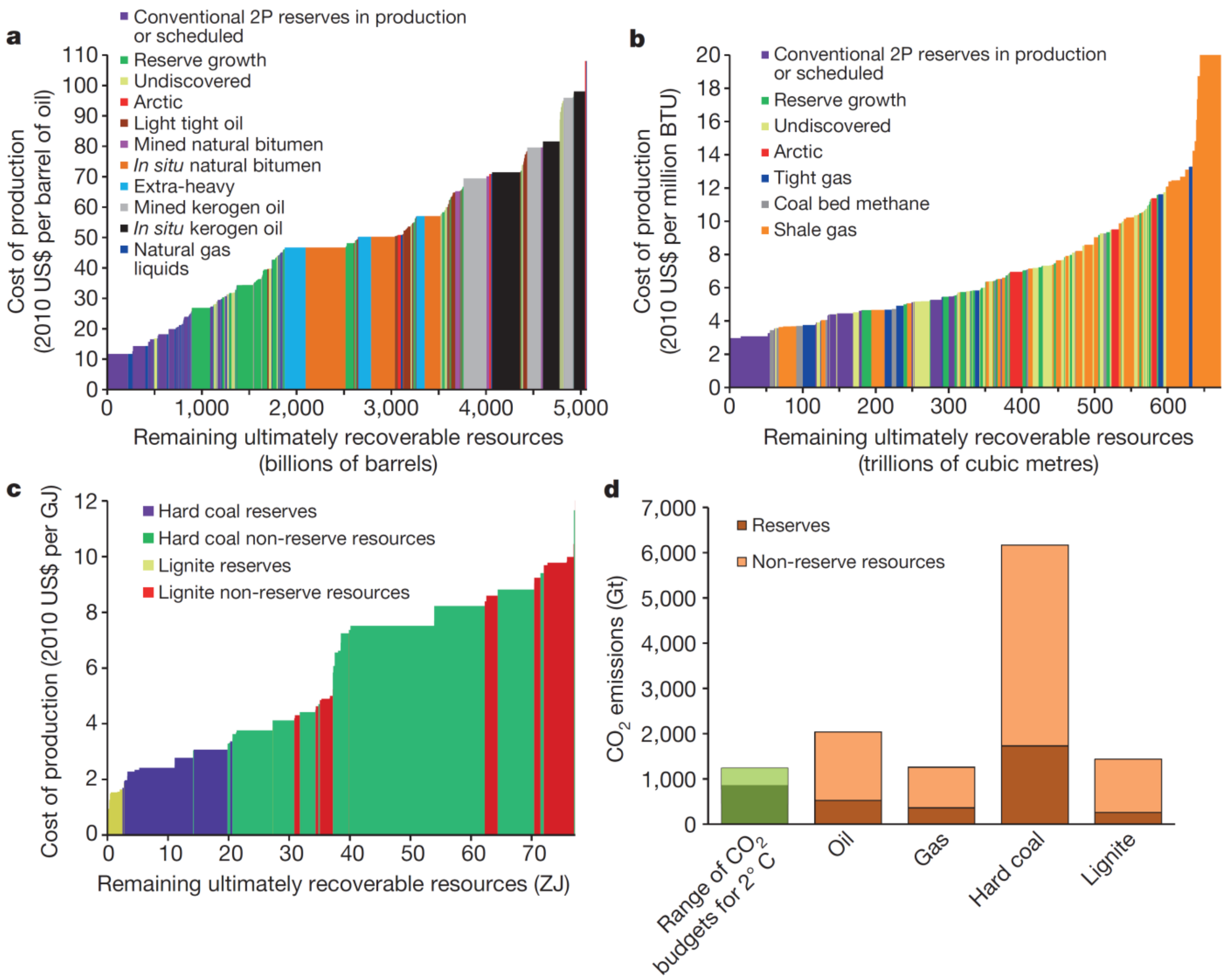




Proportion of demand met by electricity
OECD non-OECD countries

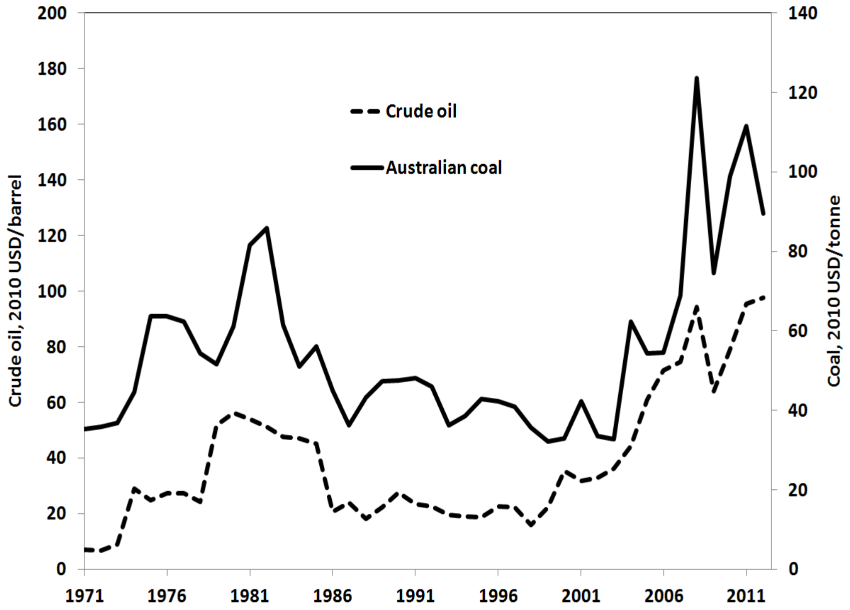


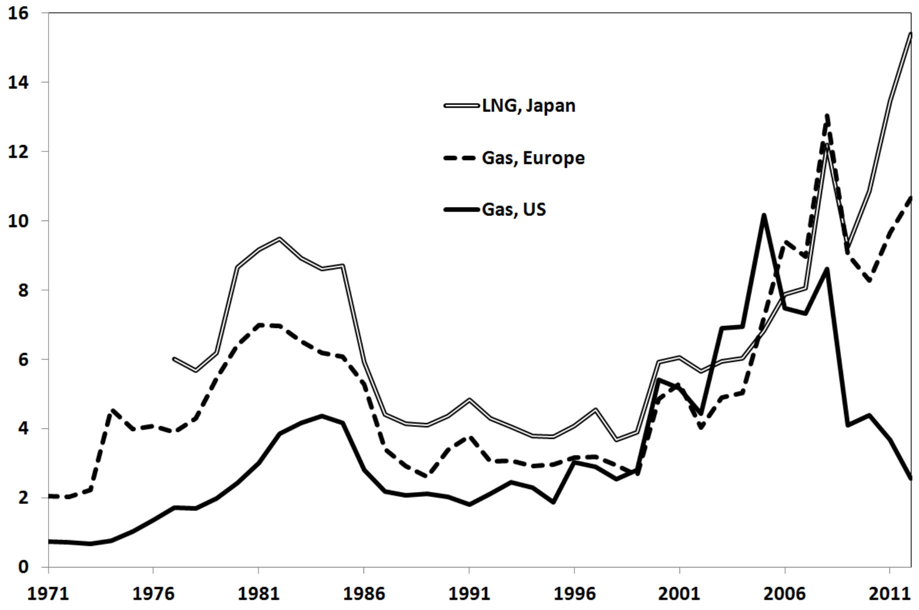
Reserves, resources and carbon budgets



Oil, coal and gas prices

(gas unit 2010 USD/million BTU)





Major possible, but uncertain, developments driven by decarbonisation (1)

Energy Demand: determines *how much* supply, and *what kind of* supply, is required

- **Demand reduction:** efficiency (rebound effect), lifestyles
- **Demand response:** smart meters/grids, load smoothing, peak/back-up reduction, storage, leading to implications for
- **Network design**
- **Key demand technologies:** most importantly likely be *electric vehicles* (with or without fuel cells), which could also be used for electricity storage/load smoothing, and *heat pumps*, both of which would use the decarbonised electricity. However, both technologies are in substantial need of further development and their mass deployment raises important consumer/public acceptability, as well as infrastructure, issues.

Major possible, but uncertain, developments driven by decarbonisation (2)

- **Decarbonisation of electricity** (and its use for personal transport and residential heat). This depends on the development and deployment of four potentially important low-carbon options:
  - *Large-scale renewables*: issues of incentives, deployment, supply chain, storage technologies, intermittency, market design (zero marginal cost)
  - *Small-scale renewables*: issues of planning, institutions (distribution networks)
  - *Nuclear power*: issues of demonstration, cost, risk (accident, attack, proliferation, waste, safety, decommissioning), public acceptability
  - *Carbon capture and storage (CCS)*: issues of demonstration, feasibility, cost, risk (storage, liability)

Major possible, but uncertain, developments driven by decarbonisation (3)

Bioenergy - thorny issues related to:

- *Carbon reduction*: how is biomass produced?
- *Environmental sustainability*: issues of land use, biodiversity
- *Different uses of biomass*: competition between bioenergy and food
- *Social issues*: issues of power, livelihoods, ownership and control

Major possible, but uncertain, developments driven by decarbonisation (4)

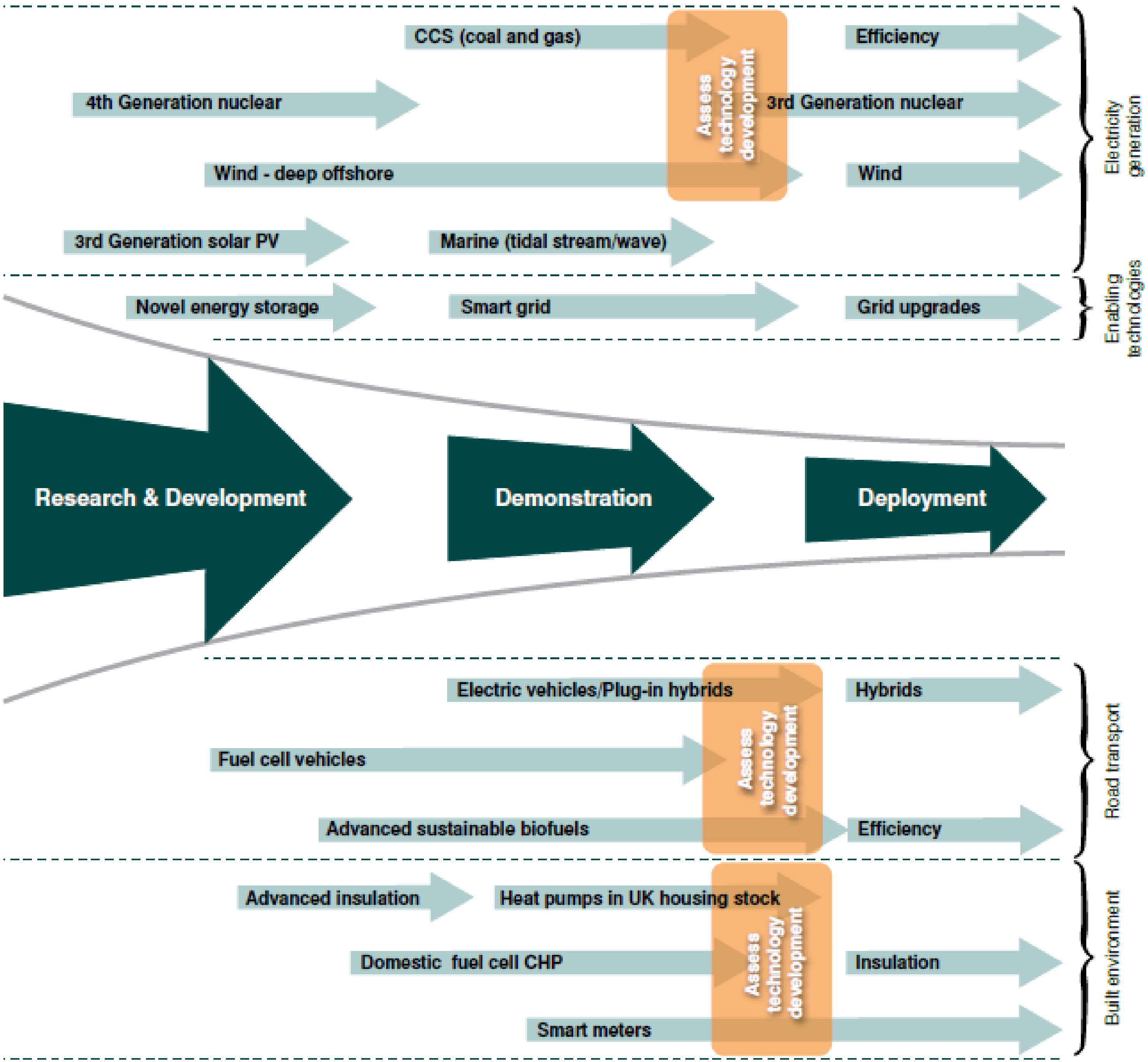
Internationalisation in relation to:

- *Technology*: e.g. global research, innovation, technology transfer. Balance between competition and co-operation
- *Trade*: e.g. bioenergy, electricity, carbon, border taxes
- *International integration*: grids (e.g.high-voltage DC electricity), markets (European Roadmap 2050)

Pipeline of selected energy technologies showing progress required by 2020

Source: Energy Research Partnership 2010 *Energy innovation milestones to 2050*, March, ERP, London

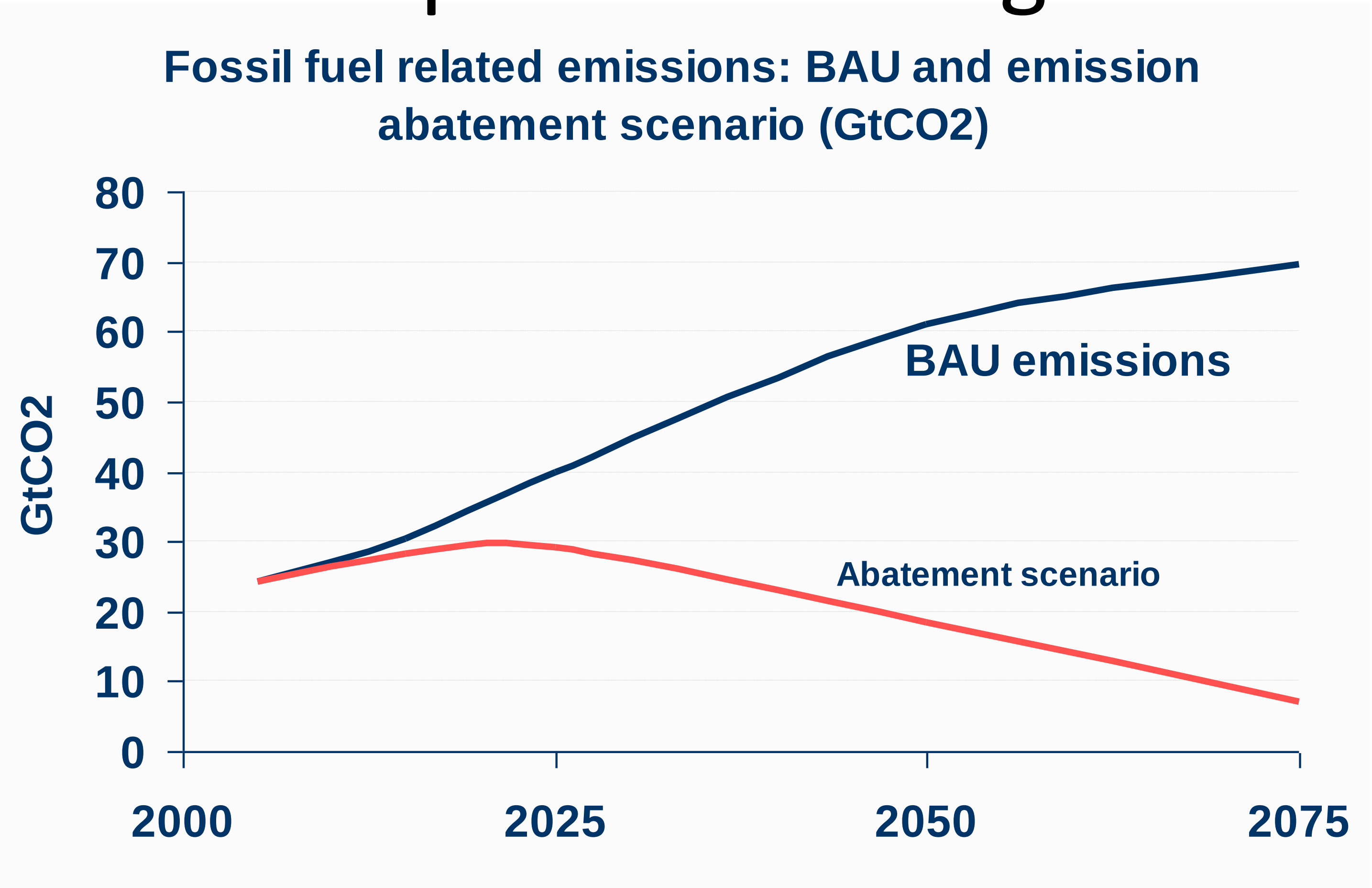
www.energyresearchpartnership.org.uk/tiki-download_file.php?fileId=233


CCS (coal and gas)
Efficiency
4th Generation nuclear
Assess technology development
3rd Generation nuclear
Wind - deep offshore
Wind
3rd Generation solar PV
Marine (tidal stream/wave)
Electricity generation
Novel energy storage
Smart grid
Grid upgrades
Enabling technologies
Research & Development
Demonstration
Deployment
Electric vehicles/Plug-in hybrids
Hybrids
Fuel cell vehicles
Assess technology development
Advanced sustainable biofuels
Efficiency
Road transport
Advanced insulation
Heat pumps in UK housing stock
Domestic fuel cell CHP
Assess technology development
Insulation
Smart meters
Built environment

Options and choices

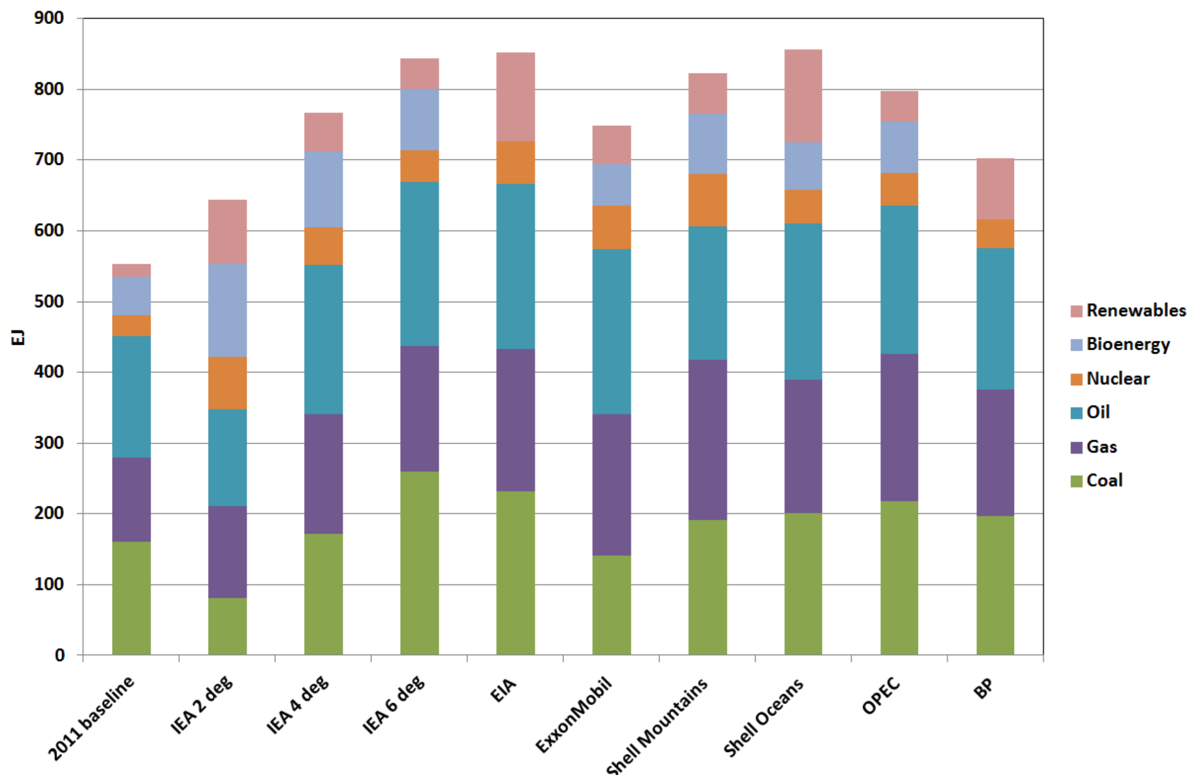
- Different countries have different options and are likely to make different choices across all these dimensions, depending on their energy history, culture, resource endowments and international relations.
- Choices are essentially political (though industry will be inclined to argue that the country concerned ‘needs’ their favoured option).
- The options will play out differently in terms of energy security and cost
- The economic and political consequences of making the wrong choices are potentially enormous
- Balance between developing portfolios (diversity) and going to scale (picking winners – economic as well as energy).
- Importance of demand side (historically supply needs have been substantially over-estimated)
- Need for immediate decarbonisation and avoidance of future carbon lock-in

Emissions trajectory to limit temperature change



Source: Stern Review, Part III, Chapter 9

Primary energy demand in different global energy scenarios/projections for 2040



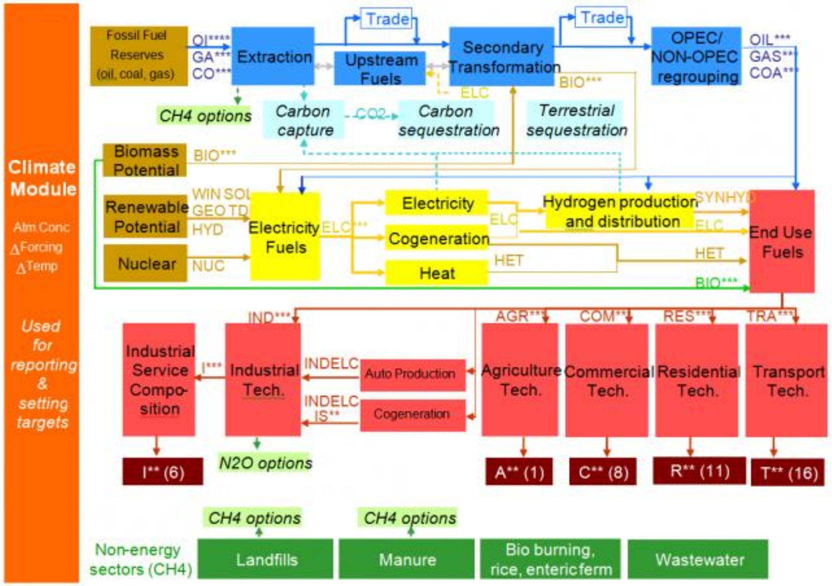
a)

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

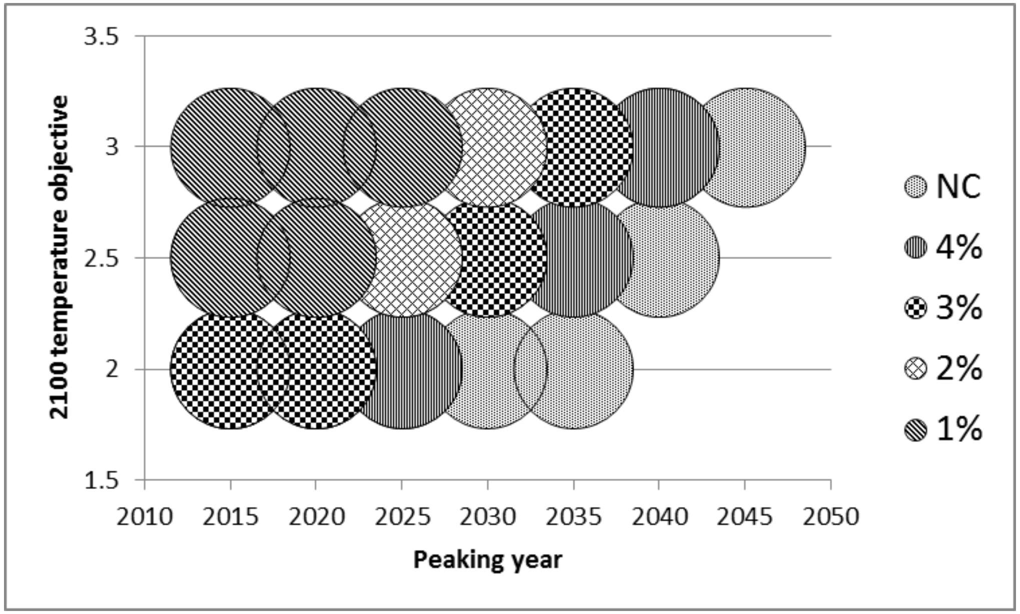


The long-term future of energy systems is subject to numerous uncertainties

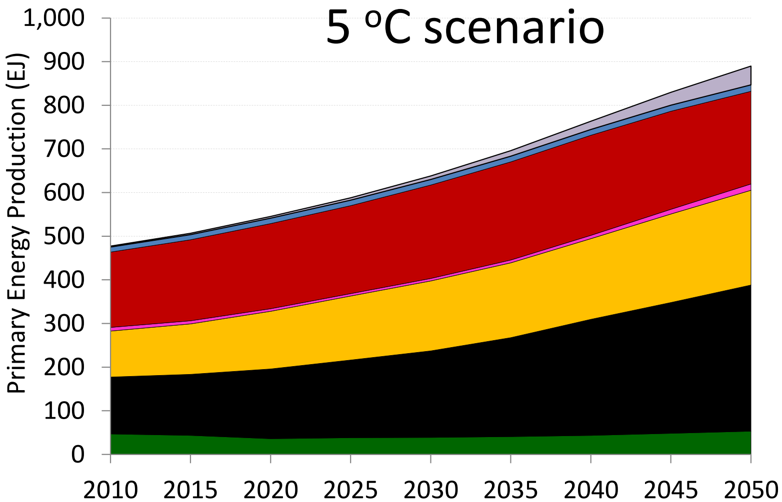
- Importance of different input assumptions
  - Regional and global population and GDP growth rates
  - Costs and rates of low-carbon technology deployment (carbon capture and storage, solar PV, electric vehicles etc.)
  - Fossil fuel production costs and availability
  - Alternative energy sources (bio-energy, 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

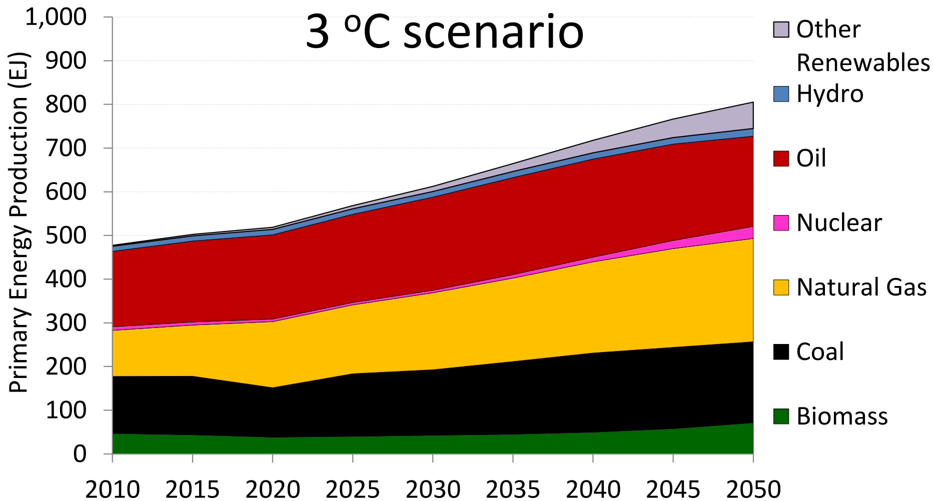
How long can we delay action while limiting climate change?

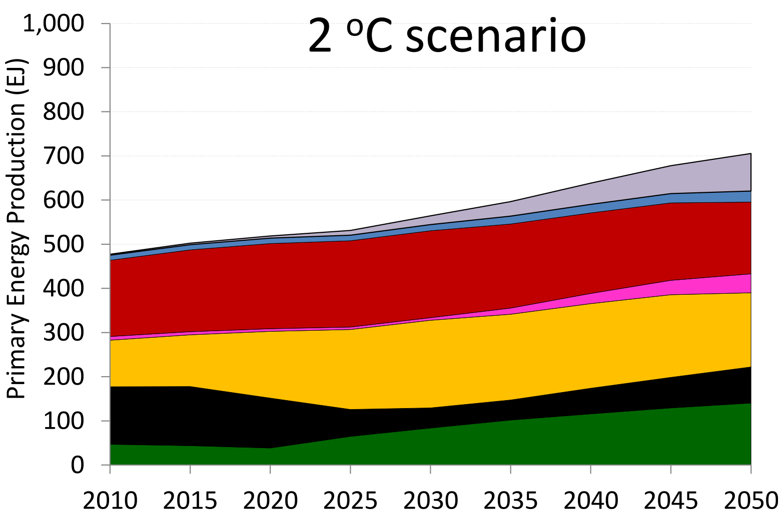
- Can using integrated assessment models to examine climate and energy system dynamics in conjunction
- When must global emissions peak and how quickly they must they decline to stay within temperature limits?
- The 2°C target is now only achievable if annual global CO_2 emissions can fall by at least 3% per year
- It is not possible for emissions to peak after 2035 and still restrict the temperature rise to 2°C.



Global primary energy production varies according to temperature thresholds

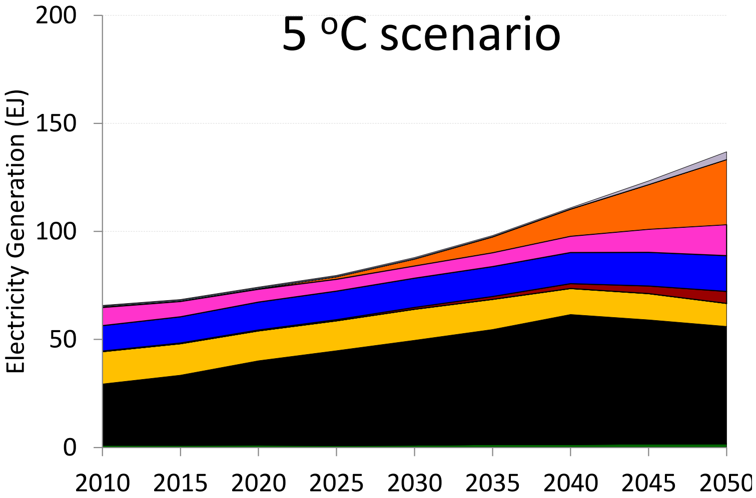


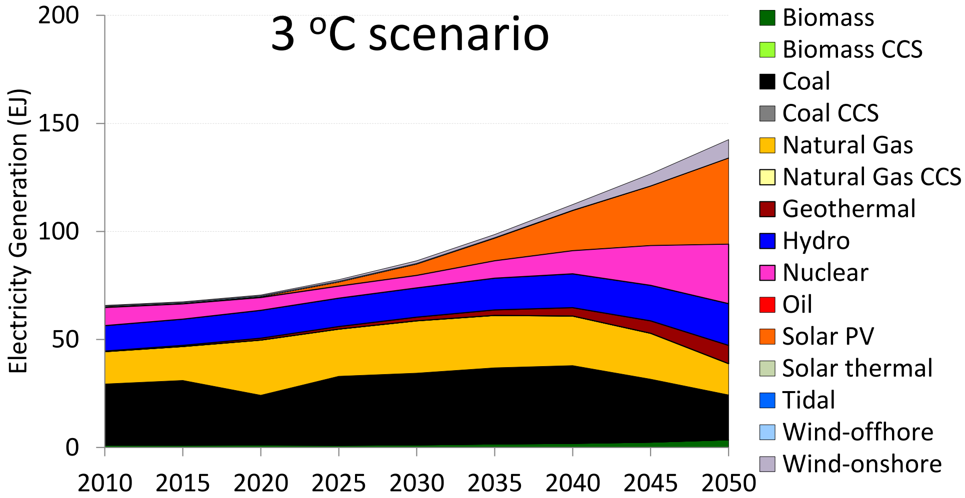


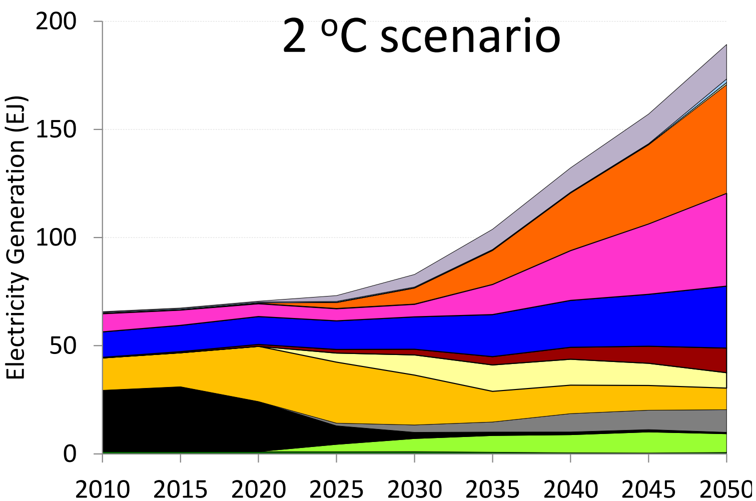


- Fossil fuels' share of primary energy in 2°C scenario drops from 85% to less than 60% by 2050
- Gas consumption is greater in the 2°C scenario over medium timescale (2010 – 2035) than in 5 °C scenario
- Gas can play an important role as a 'bridging fuel' but dependent on rapid reduction in coal consumption and availability of carbon capture and storage

Electricity generation is much higher when mitigating emissions and rapidly shifts to low-carbon technologies

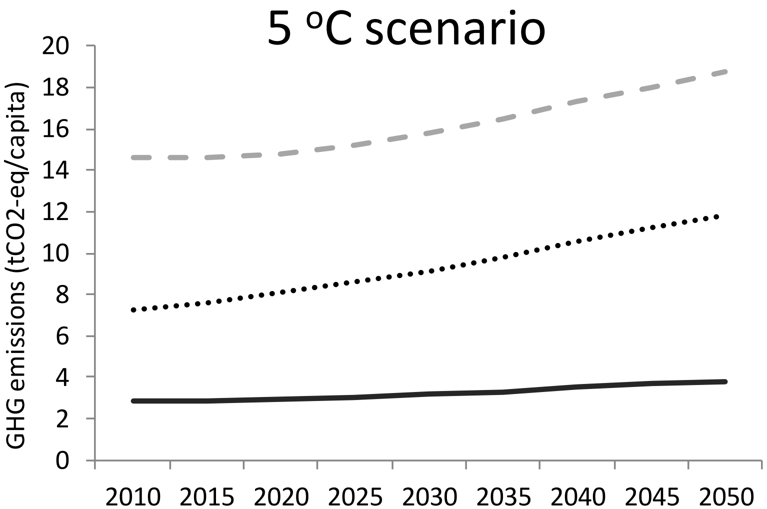


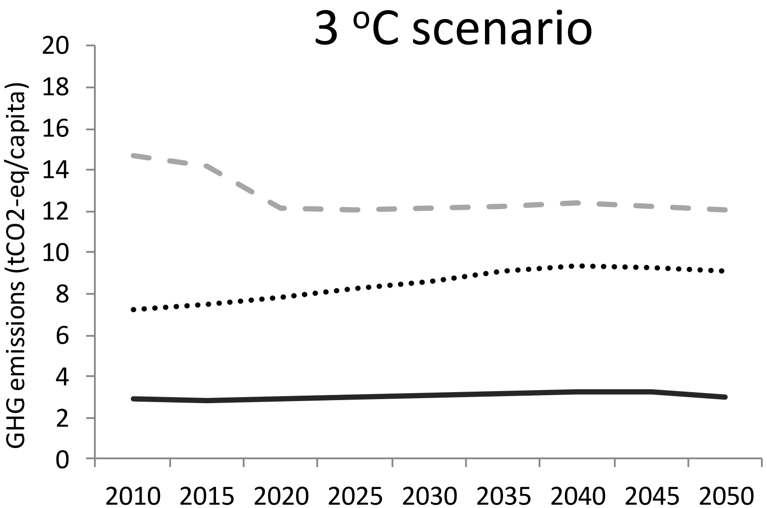


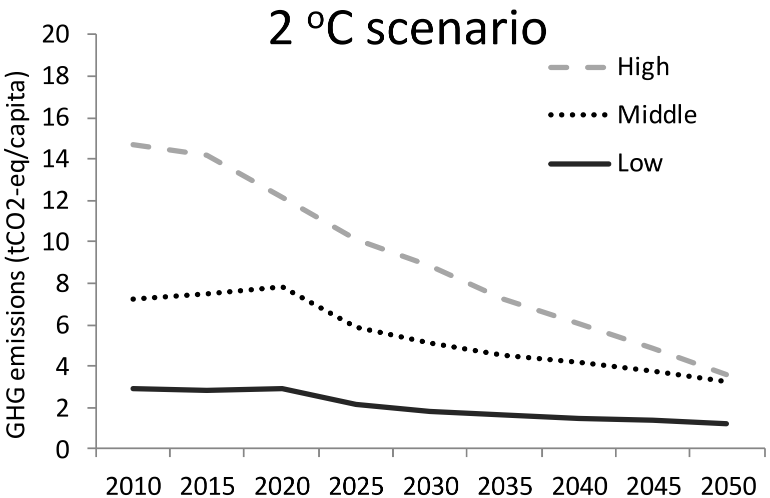


- Under 2 °C scenario emissions from the electricity sector drop over the 2020s, so that they are almost zero by 2030
- GHG-negative electricity is the most cost-effective manner to decarbonise many end-use sectors so overall production is much higher
- Electricity-sector emissions also fall significantly in 3 °C scenario

Per capita emissions fall in all economic regions in mitigation scenarios

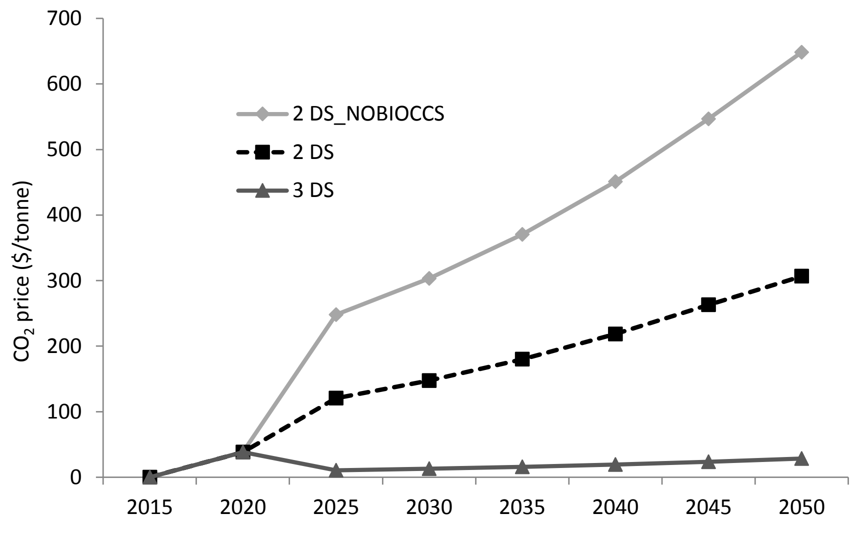


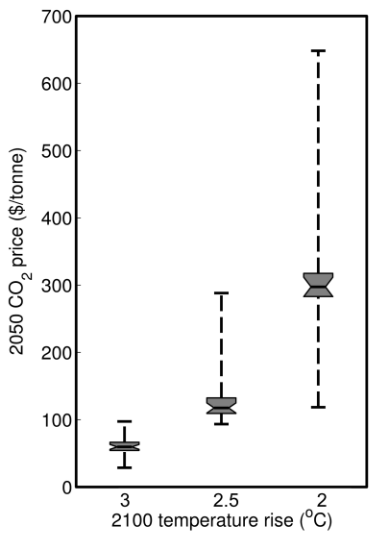




- Regions grouped according to current incomes (as given by World Bank)
- Per capita emissions fall in all income groups under 2°C. By 2050 high-income regions per capita emissions drop to less than a quarter of their 2010 level
- But high and middle-income countries have higher relative levels of difficult-to-decarbonise sectors (e.g. aviation) so they maintain a higher level of emissions

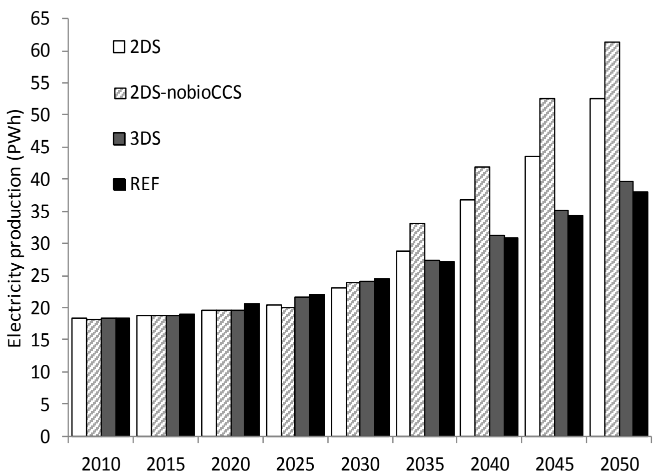
Under 2 °C, CO_2 price rises to \$300/tonne in 2050, but this can vary significantly depending on assumptions

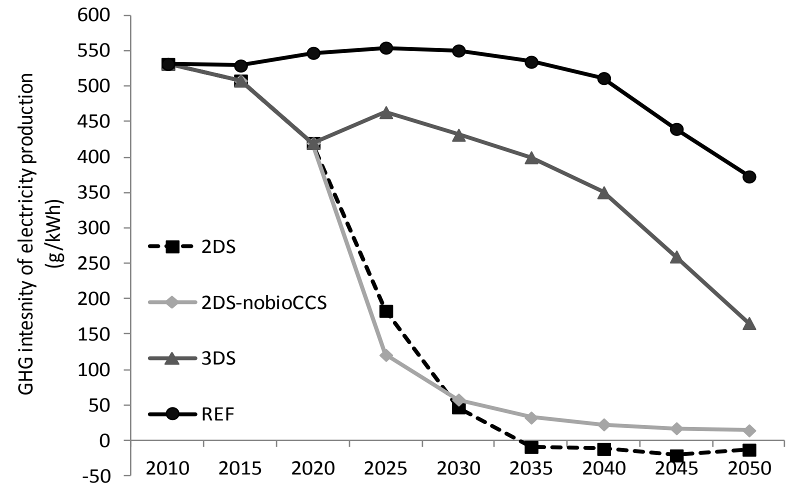


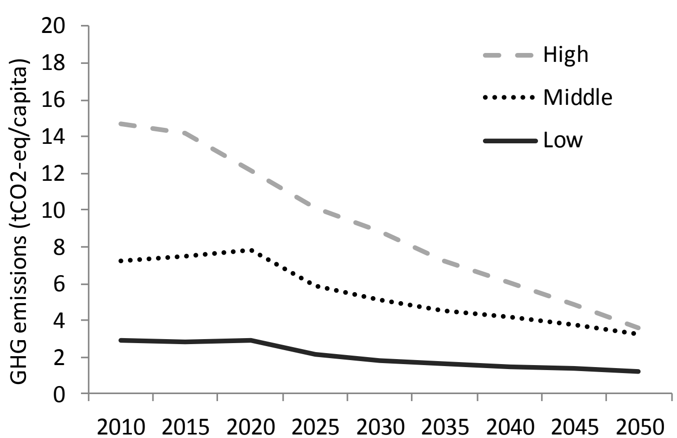


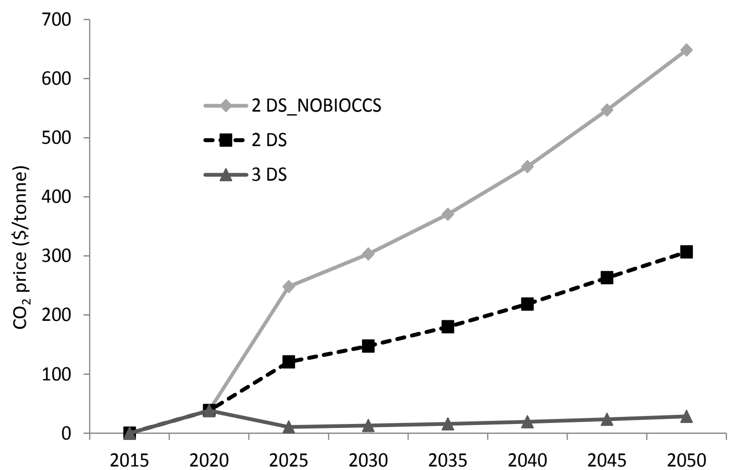
- CO_2 price in 2 °C scenario reaches over a \$100/tonne in 2025 & increases at around 4%/year
- If negative emission technologies are not allowed, CO_2 price more than doubles to over \$600/tonne by 2050.
- CO_2 prices, however vary according to the delay in implementing global emissions reduction (i.e. the later the date on which global emissions peak); the longer the delay, the greater the required level of emissions reduction later

Global electricity generation in the four scenarios (left) and its GHG intensity (right), per capita emissions (2DS, bottom left), CO2 prices (bottom right)

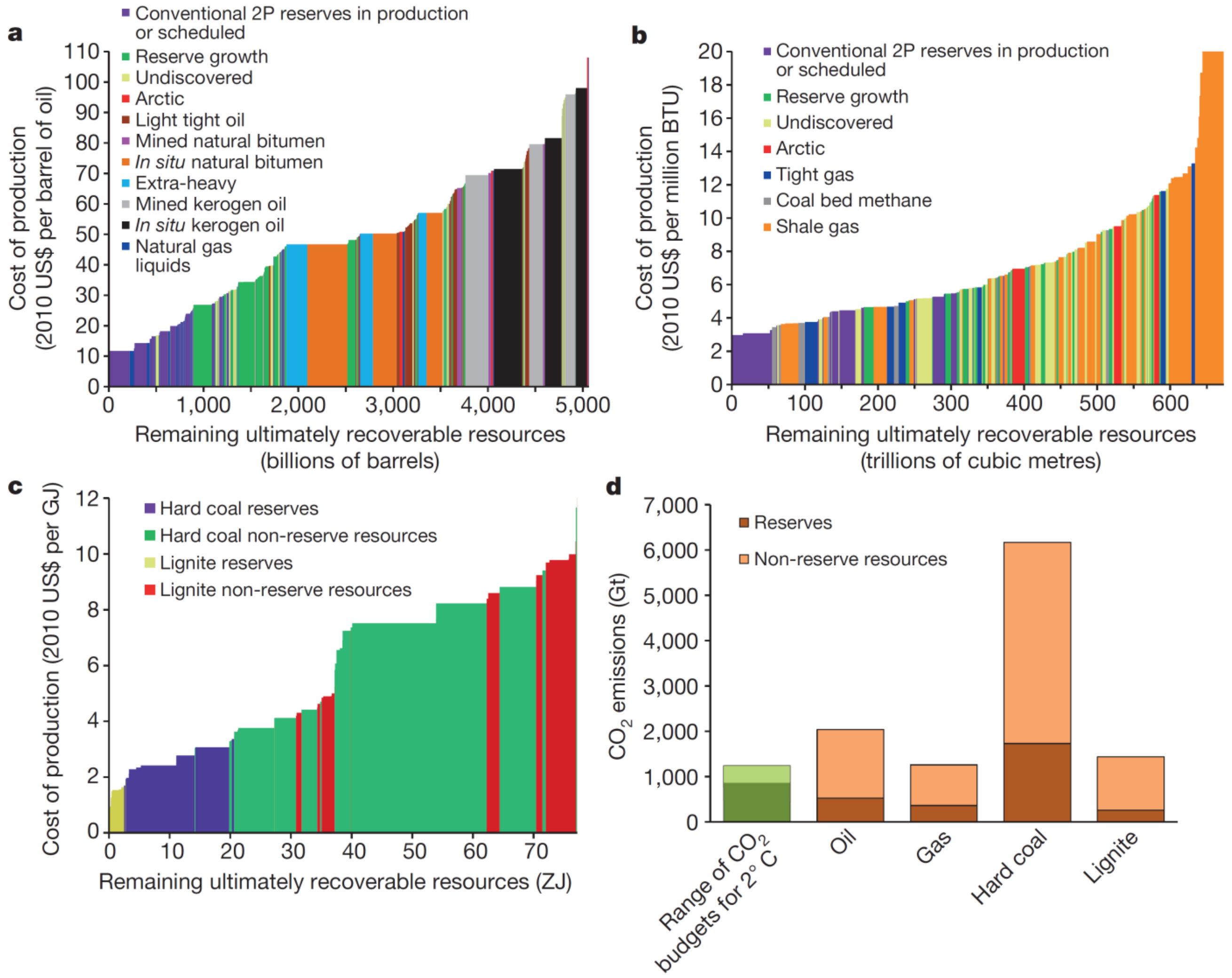






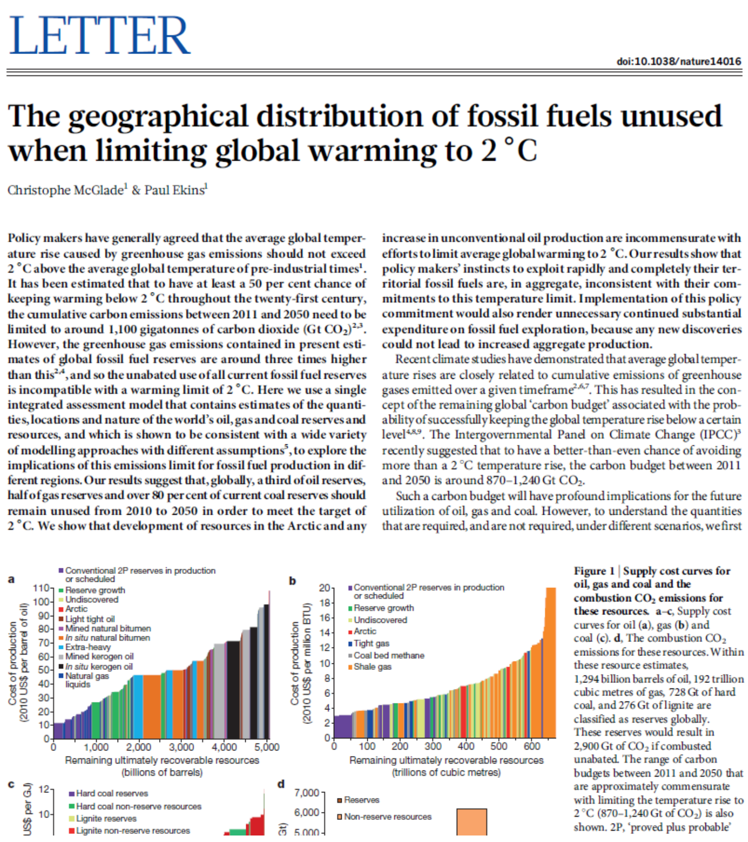


Estimates of remaining fossil fuel reserves and resources and how these relate to 2 °C climate change budgets



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

doi:10.1038/nature14016

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

Christophe McGlade[1] & Paul Ekins[1]

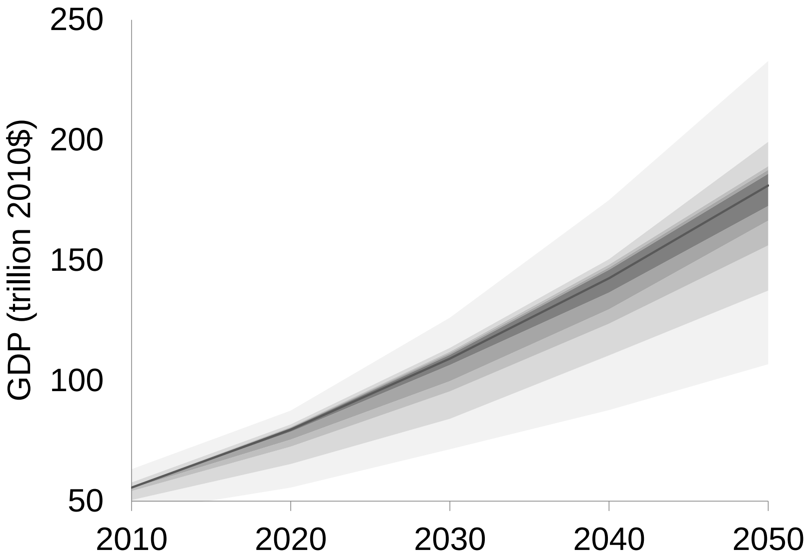
Policy makers have generally agreed that the average global temperature rise caused by greenhouse gas emissions should not exceed 2 °C above the average global temperature of pre-industrial times[1]. It has been estimated that to have at least a 50 per cent chance of keeping warming below 2 °C throughout 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.

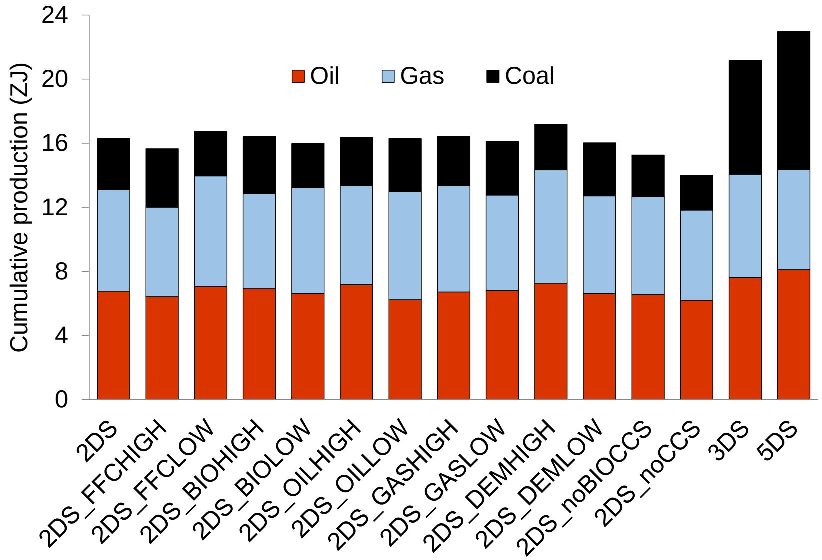
Recent climate studies have demonstrated that average global temperature rises are closely related to cumulative emissions of greenhouse gases emitted over a given timeframe[2,6,7]. This has resulted in the concept of the remaining global 'carbon budget' associated with the probability of successfully 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





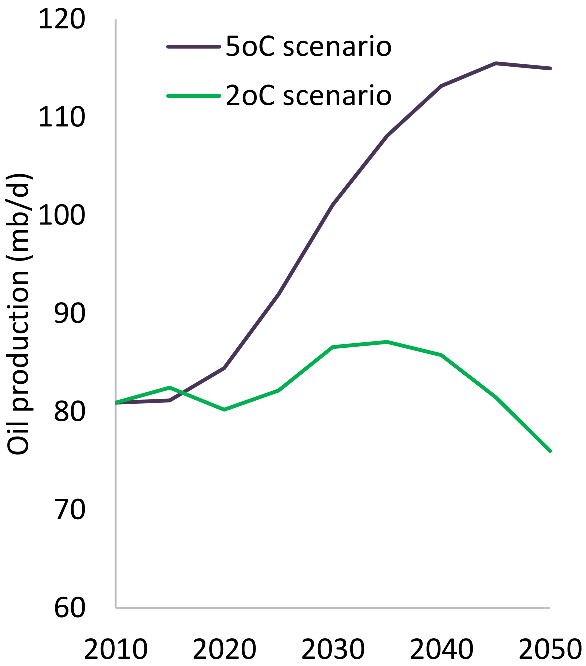
- Left panel shows range in projected global GDP from all scenarios used in the IPCC 5th Assessment Report
- Right panel shows cumulative fossil fuel production for different temperature scenarios (2 °C, 3 °C, 5 °C) and sensitivity of 2 °C scenario to assumptions on fossil fuel costs, bioenergy, oil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

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

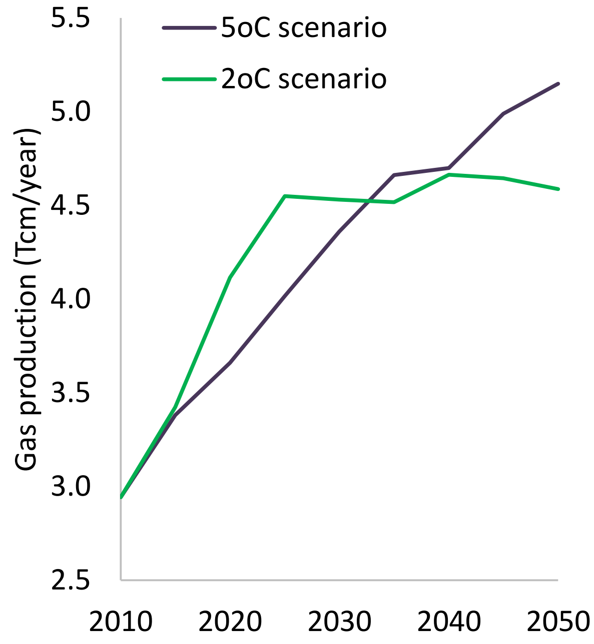
Region	Oil		Gas		Coal	
	Gb	%	Tcm	%	Gt	%
Africa	23	21%	4.4	33%	28	85%
Canada	39	74%	0.3	24%	5.0	75%
China	9	28%	2.6	75%	116	61%
C & S America	58	39%	4.8	53%	8	51%
Europe	5.0	20%	0.6	11%	65	78%
FSU	27	18%	31	50%	203	94%
India	0.4	7%	0.3	27%	64	80%
Middle East	263	38%	46	61%	3.4	99%
OECD Pacific	2.1	37%	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 2ºC and 5ºC scenarios but gas acts as a 'transition' fuel

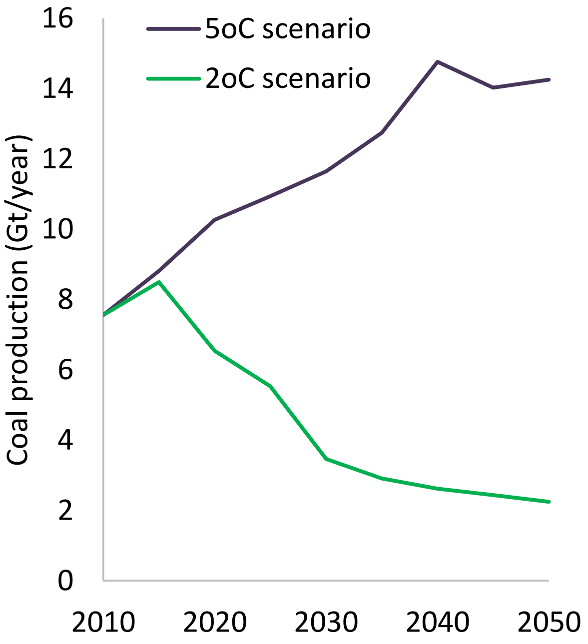
Oil



Gas



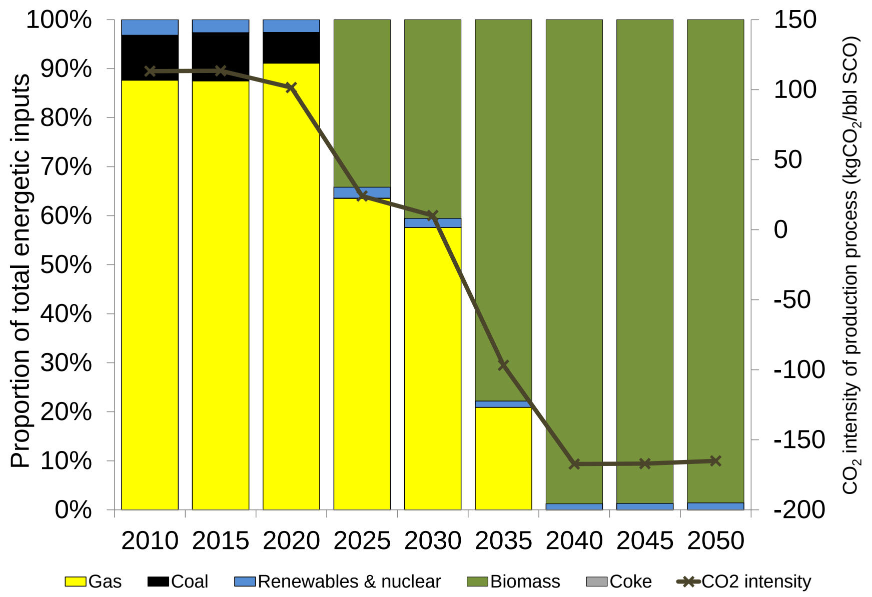
Coal



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

Conclusions (1)

- 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
- For 2 ^{o}C scenarios:
  - Politics: Inconsistency of stated commitments to
    - 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

Conclusions (2)

- Effective climate policy (i.e. keeping to 2 ^{o}C) will depend on a combination of factors:
  - Political will – recognition that costs of climate change are likely to greatly exceed its costs of mitigation
  - Recognition that co-benefits (especially health) of reducing fossil fuel use reduce net mitigation costs further (cf IMF, Lancet Commission studies)
  - Further cost reductions in low-carbon technologies
  - Desire in importing countries to limit exposure to fossil fuel exporters (i.e. energy security)
  - So the limiting factor in ultimate fossil fuel consumption will be on the demand rather than the supply side

Thank you

p.ekins@ucl.ac.uk

www.bartlett.ucl.ac.uk/sustainable