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Global energy markets

What do African resource finds mean for global energy supply in relation to demand in coming years?

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1 Summary

Energy demand and supply scenarios have a long history and have become increasingly sophisticated over time. However, historically their record is not strong - many forecasts for U.S. energy demand covering two or more decades were found to be out by 100 per cent or more[1]. The failure of these forecasts was particularly due to underestimating the importance of surprises, for example the 1973 oil embargo, and the U.S. supply response to this. Such uncertainty is inherent in the future of global energy. **Given the difficulty of making predictions on the growth of one country even one year hence, and the dependence of energy supply on factors such as growth, medium to long-term energy scenarios should be treated with caution.**

However, modelling approaches have become more sophisticated over time. This includes models such as the International Energy Agency's (IEA) World Energy Model (WEM), used for generating annual World Energy Outlooks. The WEM has detailed modules by industry, by sector and by region, with modelling underpinned by a number of assumptions, on economic growth, population, prices, the likely path of regulation, as well as the rate of learning for new energy technologies, and the rate of energy efficiency improvements in transport and industry. But even with a model this sophisticated, it can only cope with uncertainty on a probabilistic basis. **As a result, medium term projections give a wide range of results. Three recent scenarios on energy growth for 2030, 2035 and 2040, all agree that it will continue to be large and led by the developing world, but worldwide annual energy growth varies from 0.9 per cent to 1.7 per cent in these models[2], projecting significant differences in future energy.**

Putting aside the uncertainty of future projections, much can be gained from looking at the existing picture and recent past in terms of consumption, production and reserves of energy resources. Energy demand tripled in the 45 years from 1966 to 2011. While demand increased across countries, there has been a big shift towards the Asia Pacific region, and to China in particular. Fossil fuels are dominant, making up 87 per cent of total energy demand[3]. **The reserves of these fossil fuels are finite[4]:**

- Global oil reserves are the most limited. Current proven global reserves amount to 1.5 trillion barrels. At current rates of consumption these reserves will last 47 years, however if consumption increases at the 2001-2011 average of 1.1 per cent, existing reserves will run out by the year 2049. Fortunately, new resources are continually found, although at a slower pace than production increases. Estimates of undiscovered resources take oil resources to 2060. **Adding all estimates of unconventional oil such as shale, would take oil resources to 2118, however there is massive uncertainty about these reserves and whether they are recoverable.**

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[1] Craig, P. P., A. Gadgil and J. G. Koomey (2002) What can history teach us? A retrospective examination of long-term energy forecasts for the United States, Ann. Rev. Ener Envi., 27, pp. 83-118.

[2] These are Exxon Mobil (2012) 2012 Outlook for Energy: A View to 2040, BP (2011) Energy Outlook 2030, and EIA (2011) International Energy Outlook

[3] BP (2012) Statistical Review of World Energy

[4] Estimates presented here for gas, oil and coal use production and reserves data from U.S. Energy Information Administration (EIA) International Energy Statistics. Website accessed October 2012. Previous decade production growth estimates from BP (2012) Statistical Review of World Energy. Undiscovered reserve estimates came from U.S. Geological Survey (USGS) (2012) An estimate of undiscovered conventional oil and gas resources of the world. Estimates of reserves of unconventional forms of oil and gas came from World Energy Council (WEC) (2010) 2010 Survey of Energy Resources.

- Global gas reserves are less limited than oil, with existing proven natural gas resources lasting 60 years at current rates of consumption. However, the average growth rate for gas consumption is higher than for oil at an average of 2.9 per cent in the previous decade. If this rate of increase continued, existing proven reserves of gas would be exhausted by 2046. Including the very large estimates of undiscovered conventional gas would take gas resources to just 2061. **Adding the still more abundant estimates of potential, recoverable reserves of unconventional gas such as shale, takes gas supplies to 2073.**
- Coal is by far the most abundant fossil fuel relative to current demand. Existing proven reserves of close to 1 trillion tonnes would meet current global demand for 119 years. However, the growth rate of coal use is also the greatest, at 4.6 per cent in the past decade, principally due to Chinese demand. In the (unlikely) event that this growth rate continued, current proven coal reserves would only last the world until 2051. **Including the potentially vast reserves estimated as undiscovered, would take the world's coal to just 2070.**

Fossil fuel reserves currently proven to exist do not take us much past the middle of the present century given the growing rate of world energy demand. As a result, in a generation's time, the world is likely to face a resource crunch. Even the substantial estimates of undiscovered resources and the exploitation of up-to-now marginal, difficult, and unconventional sources of fuels, is unlikely to extend resources to the end of the century. Furthermore, the CO_2 produced by the burning of these fuels is already leading to climate change, and projections of bodies such as the International Panel on Climate Change (IPCC) make further global warming a near certainty. If just half of estimated global fossil fuel resources were burned in total (including estimates of currently undiscovered and unconventional resources), global temperatures would be expected by IPCC estimates to rise by up to 5^0C, while sea levels would be estimated to rise by up to 3 metres[5]. **To avoid the consequences of such changes, and barring 'black swan' technological development such as the mass capturing of CO_2 from the air, carbon emissions and global warming put a limit on the fossil fuels that humankind can safely consume.**

As a result, governments worldwide have pledged to reduce emissions of CO_2, although the regulation, pricing and taxation that would allow such pledges to be meaningful are yet to be in place. As shown in the International Energy Agency's World Economic Outlook (WEO) in 2010, should the pledges already made be put in to place, all fossil fuels bar natural gas would eventually see demand falling by 2035. The fall would be supplanted with a big increase in renewable forms of energy - principally nuclear, hydroelectric and wind energy - together with increased energy efficiency worldwide. **However, even in the most optimistic scenario of the IEA, energy consumption increases by 22 per cent by 2035.**

The significance of African finds

[5] IPCC estimates of warming and sea levels from International Panel on Climate Change (IPCC) (2007) Climate Change 2007: Synthesis Report. The total production of CO_2 was estimated using data of the rate of CO_2 produced for each fossil fuel from U.S. EIA International Energy Statistics. Website accessed October 2012. This source was used for current proved reserves. Undiscovered reserve estimates came from USGS (2012) An estimate of undiscovered conventional oil and gas resources of the world. Estimates of reserves of unconventional forms of oil and gas came from World Energy Council (WEC) (2010) 2010 Survey of Energy Resources. Burning half of the total estimate for fossil fuel reserves including all these figures led to an estimate of CO_2 composition of 657 parts per million (ppm) of the atmosphere. This figure was then compared with the IPCC estimates.

Recent finds of oil, gas and coal in Africa vary in significance. While gas is the most significant resource by some way, these finds will not solve medium-term shortages of global energy from fossil fuels:

- Oil finds in Ghana and in Uganda may be significant for these countries, but together make up just 0.2 per cent of likely global reserves[6]. They are therefore not to be seen by any means as a solution to long-term supply. Furthermore, investment is at an early stage so the reserve estimates for these countries are still uncertain. **According to the U.S. Geological Survey there could be a large amount of 'undiscovered' oil in Africa, though this is mostly off the Atlantic Coast and likely to be in existing large producers – Angola and Nigeria for example[7]. The amounts could be very large but are inherently uncertain at this stage.**
- East African gas reserves are a much bigger deal. At higher estimates they could constitute as much as 5 per cent of global reserves[8]. As a result, the value of these gas resources would be extremely high if they can be exploited, equivalent to Africa's entire GDP in 2010[9]. But even under higher estimates, East African gas would only meet the world's current demand for natural gas for three years. So again, long-term supply shortages are only put off for a very short while. However, investors are clearly excited by the size of the opportunity and are willing to expend substantial resources in the infrastructure required to allow gas to be transformed to LNG and transported to Asia's growing markets. **The windfall for Mozambique and Tanzania, as well as Kenya and Madagascar, is likely to be huge relative to their current GDP. The political economy challenges could also therefore be difficult for these countries to deal with.**
- Mozambican coal is also a lucrative opportunity for global multinationals. African coal from South Africa is currently the cheapest source of coal on the planet, so should Mozambique's producers reach similarly low costs, they are likely to be highly competitive on international markets. This would primarily be as an export to Asian markets with high and growing demand for coal as a source for electricity. At about 1 per cent of likely global reserves and 1 per cent of global production should production meet higher estimates[10], this coal will be a bit player in global markets, and certainly not solve medium to long-term supply constraints. **But for Mozambique, the combination of coal and gas production and exports is likely to be transformative.**

In conclusion, East African gas and Mozambican coal are set to make significant inroads to transforming the region into a sizeable supplier of some of Asian energy demand over coming years. However, the overall picture remains one of an imminent resource crunch by the middle of the century, unless existing estimates of undiscovered and unconventional resources are far off the mark, or the GDP growth of the developing world goes into a prolonged slowdown. Furthermore, according to the science, the reality of climate change will only increase as an issue

[6] Using upper estimate of 1.8 billion barrels for Ghana from http://www.revenuewatch.org/countries/africa/ghana/overview and using upper estimate of 2.5 billion barrels for Uganda from Financial Times. "Tullow upgrades Kenya discovery". July 4, 2012.
[7] U.S. Geological Survey (USGS) (2012) An estimate of undiscovered conventional oil and gas resources of the world.
[8] Based on higher estimate of 371 trillion cubic feet of gas reserves from U.S. Geological Survey (USGS) (2012) An estimate of undiscovered conventional oil and gas resources of the world.
[9] Using current gas prices as reported by World Bank Pink Sheets accessed October 2012.
[10] Using reserve estimate of 23 billion tonnes and production estimate of 100 million tonnes within a decade from Mining Weekly "Mozambique coal output expected to jump to 100 Mt/y in next decade" June 8, 2012.

over time. To avoid catastrophic climate change, policy change is likely to be required that will effectively leave accessible proven reserves of fossil fuels in the ground. With the resource crunch combined with climate change, the pressure will grow on providers of renewable energy to meet future global energy demand. **Fossil fuel finds such as those recently made in East Africa will lead to booms for these countries and feed the growing demand in Asia in the short to medium-term, but they do not radically alter future scenarios for energy.**

1.1 The scope and structure of this paper

The paper will look at the current state of play in energy markets, in terms of production, consumption, reserves and the pipeline of investments. Projections will be presented including details up to 2050 (on further analysis, the best estimates available by leading international bodies are to 2035 or 2040). The size of recent finds in Africa will be compared to international quantities and trends to gauge their significance.

Having undertaken significant desk research, data collection and analysis, the structure of this paper presents the key findings. The structure used is as follows:

- ***Energy: the current state of play.*** Chapter 2 looks at the current level of consumption, recent trends for energy, and the energy mix by fuel type. It then looks at the nature and location of consumption, the level of international reserves of fossil fuels, and production levels including of electricity. Finally there is a discussion on climate change, CO_2 emissions, and the potential limit this places on future production and use of fossil fuels.
- ***Scenarios for energy markets in coming years.*** Chapter 3 firstly assesses the short-term investment outlook for energy markets using the best data available. It then looks at some high-level scenarios for energy demand and supply made up to 2030, 2035 or 2040. It describes how modelling is undertaken and the key assumptions that underlie scenarios. It then looks in detail at one publically available model and projections, namely, the World Energy Outlook 2010, built using the IEA's World Energy Model (WEM).
- ***The significance of new finds.*** Chapter 4 looks at recent finds of fossil fuels in Africa – including oil in Uganda and Ghana, East African gas and Mozambican coal. It aims to show how the size and potential of these finds compares to international supply and demand, and thus estimates the significance of these finds for world energy markets.

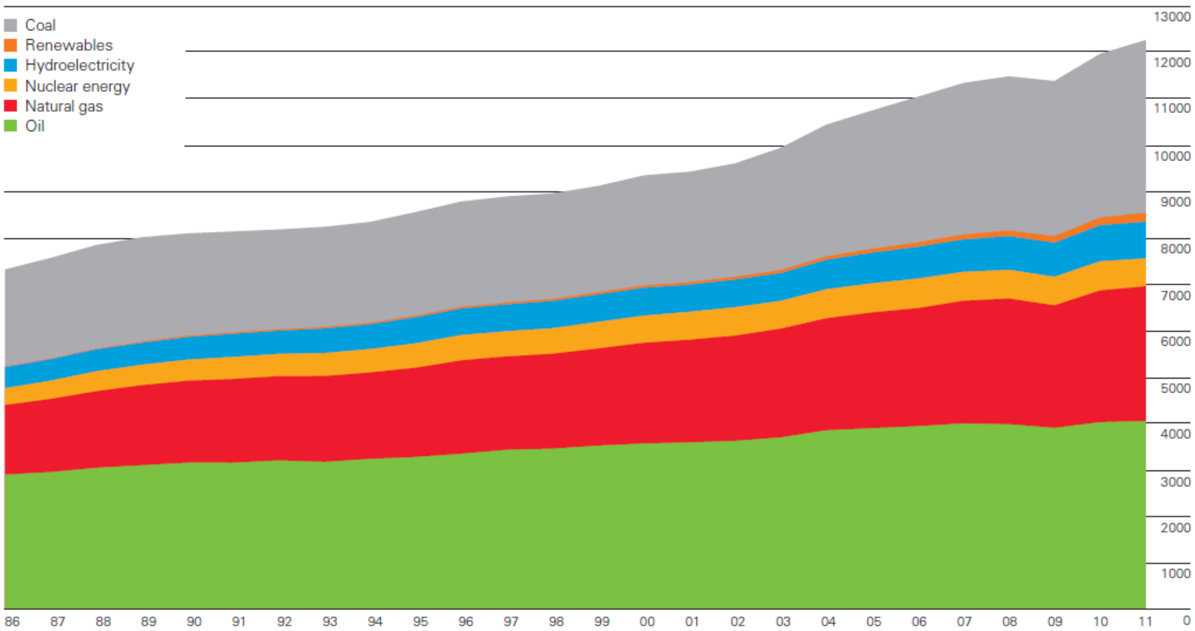
2 Energy: The current state of play

In 2011, the world consumed three times more energy than it did in 1966. The vast majority of this increase was via greater burning of fossil fuels, for electricity generation, directly in industry or as fuel for transportation. Despite improvements in efficiency, energy use has grown together with the world economy, but has shifted significantly between regions, particularly towards Asia Pacific and within that region, to China. Due to its versatility, oil has been the dominant fuel and with growing demand for transportation, may continue to be dominant. However, reserves of oil are smaller relative to demand than for either natural gas or coal; new finds come at a slower pace; the price of oil is higher; and production is more geographically centred. **For these reasons and others, natural gas is playing a greater role in global energy, while coal has become the dominant source of energy for the new economic behemoth, China.**

2.1 An energy overview

In 2011, world consumption of energy was 12.3 million tonnes of oil equivalent (see Annex 1 on measurements) up from 12 million in 2010[11]. This 2.5 per cent growth rate was close to the average trend of 2.7 per cent for the previous decade (2002-2011) and earlier (the growth rate for 1965-2001 averaged 2.6 per cent). At this rate, energy consumption doubles every 28 years. The recent growth trend is shown in Figure 1 by fuel type. Almost exactly a third of 2011 consumption was of oil itself, 30 per cent of energy came from coal, 24 per cent from natural gas, 6 per cent from hydroelectricity, 5 per cent from nuclear energy and 2 per cent from other renewables. **A total of 87 per cent of world energy therefore came from fossil fuels and the world is still very much dependent on this source of energy.**

Figure 1: World consumption of energy (million tonnes of oil equivalent)[12]

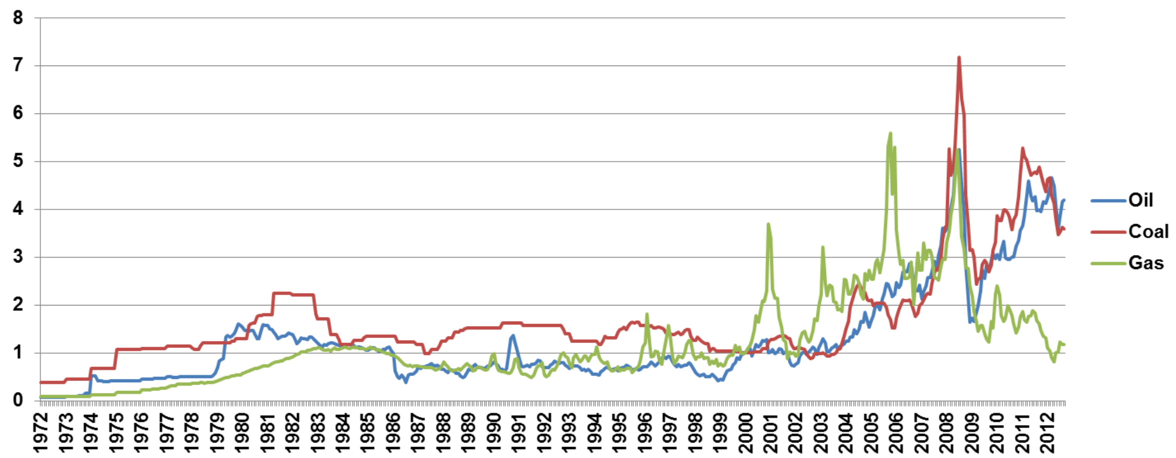


11 BP (2012) Statistical Review of World Energy. June 2012. Bp.com/statisticalreview
12 Ibid.

Prices

In recent years, the prices of fossil fuels have seen massive variability along with other commodities. As shown in Figure 2, oil, gas and coal prices have historically moved very closely and all saw large increases in the 2008 commodity price spike. However since then there has been a decoupling between oil and coal, which have continued to see high prices, and natural gas, which has seen its price fall to the level of year 2000 (oil and coal prices are both close to four times as high as in the year 2000). **Natural gas prices have decoupled from oil and gas due to growing trade of liquefied natural gas (LNG)[13], the abundant supply of unconventional gas in North America and to changes in the indexing of long-term supply contracts in Europe[14].**

Figure 2: Prices for oil, coal and gas (indexed at year 2000 = 1): 1972-2012[15]



2.2 Consumption

Energy consumption is not spread evenly across the world, either geographically or on a per capita basis; although significant shifts have taken place. In 1965, North America consumed 38 per cent of global energy, Europe and Eurasia 44 per cent, while Asia Pacific consumed 12 per cent, and Africa, the Middle East, and South and Central America, just 6 per cent between them[16]. By 2011, these shares had changed to 23 per cent for North America, 25 per cent for Europe and Eurasia, 39 per cent for Asia Pacific, and 13 per cent for the world's other regions. **The major story has therefore been a massive increase in energy consumption driven by a shift towards the developing world, in particular the Asia Pacific region, and within that region to China.**

Despite the rise of Asia Pacific, per capita consumption is still lower there than in the OECD. As shown in Figure 3, energy consumption is highest in North America, Norway and Saudi Arabia, followed by western Europe, Australasia, South Korea and Japan. While some in the developing world, such as China, are catching up, there is still a large gap in consumption. China consumes just under 2 tonnes of oil equivalent per capita compared to over 7 tonnes in the United States[17]. **If China were to catch the per capita energy consumption of the United States, world energy consumption would rise by 58 per cent.**

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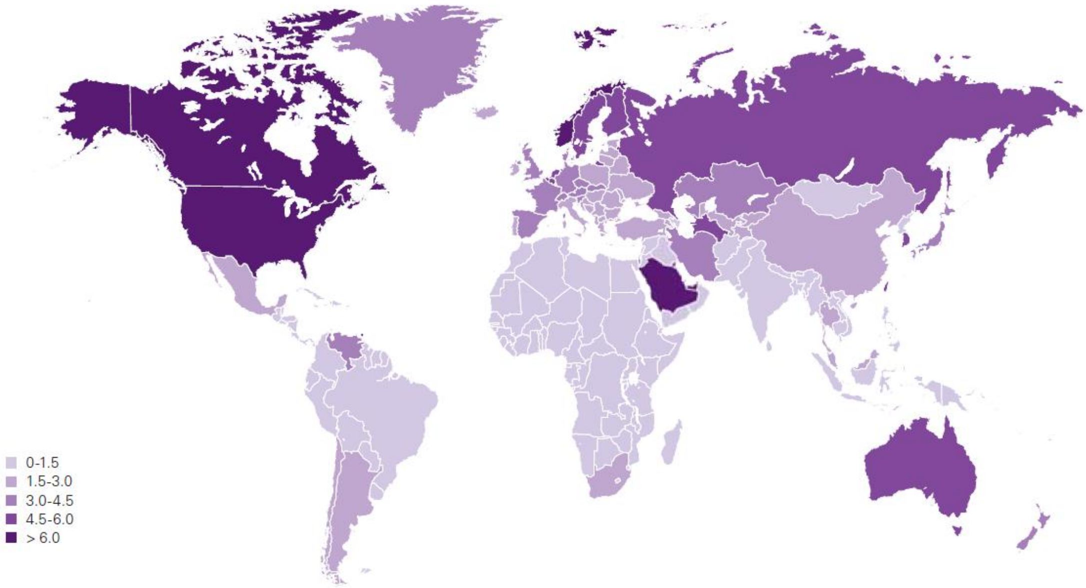
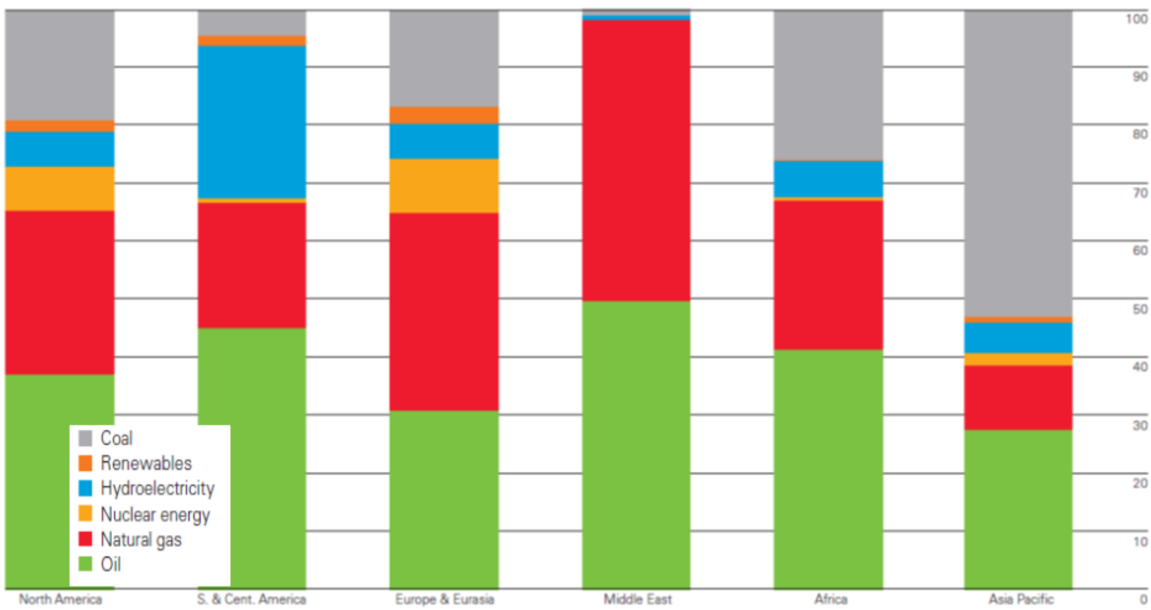
[13] LNG production capacity increased by 50 per cent during the five years prior to 2008. World Energy Council (2010) 2010 Survey of Energy Resources
[14] International Energy Agency and OECD (2010) World Economic Outlook 2010
[15] World Bank (2012) Pink Sheets October 2012
[16] BP (ibid.)
[17] BP (ibid.)

Figure 3: Energy consumption per capita in 2011 (tonnes of oil equivalent)[18]



In addition to the variance in consumption by region in absolute terms and on a per capita basis, there is also variance in terms of the source of energy by fuel type. As shown in Figure 4, consumption in the Asia Pacific region is dominated by coal, meeting 50 per cent of energy demand. In contrast, North America and Europe have larger shares for both oil and natural gas. South and Central America has a larger share of hydroelectricity than elsewhere, while the Middle East, unsurprisingly given its resources, consumes predominantly oil and gas. **Regional consumption patterns differ significantly, showing energy consumption is driven by different factors depending on geography and on each country's stage of development.**

Figure 4: Regional consumption patterns by fuel (%): 2011[19]



[18] BP (ibid.)
[19] BP (ibid.)

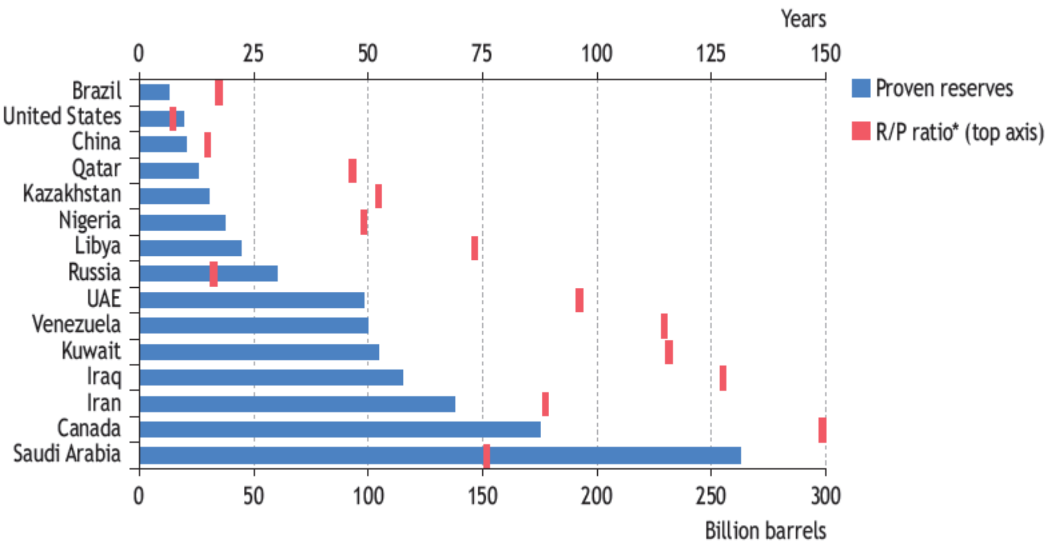
2.3 Reserves of fossil fuels

The growing demand for fossil fuels, driven by GDP and population growth, has led to the predominance of energy in the global economy. In 2012, eight out of the ten largest global corporations were either fossil fuel or electricity producers[20]. Energy corporations, private and public, together with smaller firms, have created an effective system for prospecting the earth for natural resources. The International Energy Agency (IEA) split reserves between *proven reserves*, the volume of oil or gas discovered for which there is a 90 per cent probability it can be extracted profitably on the basis of cost, geology, technology, and future prices; *proven and probable reserves*, including volumes with a 50 per cent probability of being produced profitably; and *ultimately recoverable resources*, the latest estimates of total volume of hydrocarbons judged likely to be ultimately producible commercially[21]. Due to changes in technologies and prices over time, resources considered unrecoverable can become recoverable. **As a result, there have continually been additions to the amount of reserves over the years, although these have not necessarily kept up with increases in fossil fuels demanded.**

Oil

Oil has been dominated by the Middle East for many years due to the remarkable quantities to be found there. An estimate of oil reserves for 2012 from the U.S. Energy Information Administration (EIA)[22] puts 52 per cent of the 1.5 trillion barrels of global reserves in the Middle East, while reserves outside of that region are concentrated in certain countries - 14 per cent of reserves are in Venezuela, while Canada has 11 per cent of reserves through its 'unconventional' tar sands. The degree to which these resources will last depends on the rate of extraction and reserve to production ratio (R/P ratio). As shown in Figure 5, the R/P ratio varies by countries. **Oil reserves are set to last longest in the Middle East, Canada and Venezuela.**

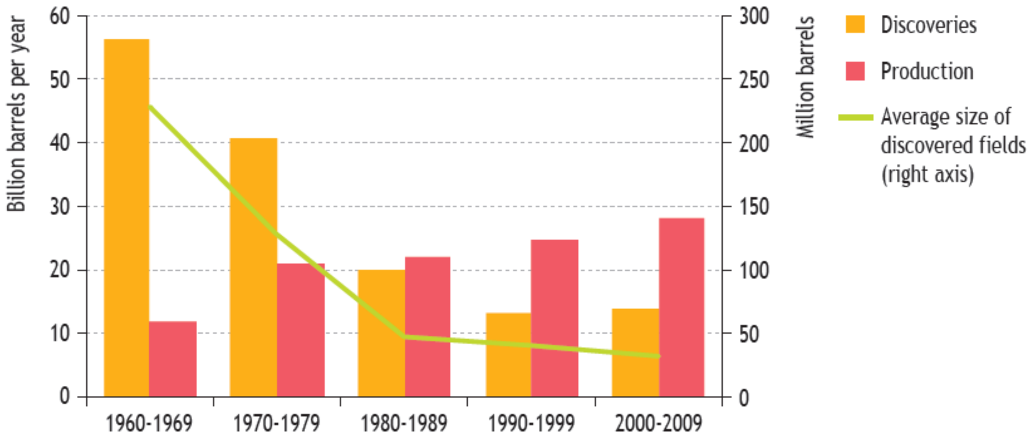
Figure 5: Proven oil reserves and R/P ratios in the top 15 countries, end-2009[23]



[20] This is from the 2012 Fortune Global 500. In order, the top 10 global corporations by revenue (fossil fuel or electricity-based companies in **bold**) are **Royal Dutch Shell, Exxon Mobil,** Wal-Mart, **BP, Sinopec, China National Petroleum, State Grid (China), Chevron, ConocoPhillips**, and Toyota.
[21] International Energy Agency (IEA) and OECD (2010) World Energy Outlook 2010
[22] U.S. Energy Information Administration (EIA) International Energy Statistics. Website accessed October 2012.
[23] International Energy Agency (IEA) and OECD (2010) Ibid.

Reserves are not static in time, with new finds and changes to technology bringing more reserves on stream all the time. However, the rate of increase for oil has slowed in recent years. According to the IEA[24], almost half of the increase in proven reserves in recent years has come from revisions to estimates of reserves in fields already in production, rather than new discoveries. Since 2000, more than half of all the oil that has been discovered is in deep water. Although some giant fields have been found, the average size of fields being discovered has continued to fall. **In 2000-2009, discoveries replaced only one out of every two barrels produced — slightly less than in the 1990s, but the reverse of what happened in the 1960s and 1970s, when discoveries far exceeded production as shown in Figure 6.**

Figure 6: Conventional oil discoveries and production worldwide[25]



Despite the slowdown in discoveries, there is thought to be a significant amount of oil still to be found. The U.S. Geological Survey (USGS) estimated in 2012 that there are 565 billion barrels of undiscovered, technically recoverable oil[26]. This oil is expected to come from a number of regions – including 20 per cent from the Middle East and North Africa, 20 per cent from sub-Saharan Africa (SSA) (three quarters of which from the Atlantic Ocean coast), 22 per cent from Latin America, 12 per cent from the former Soviet Union, and 15 per cent from North America. Adding these reserves to known reserves takes oil to over 2 trillion barrels or around 65 years of supply at current annual production rates. **If oil production continues to grow at current rates, total estimates of discovered and undiscovered conventional oil would last for just 48 years.**

In addition to known and undiscovered conventional oil resources, are unconventional sources. Some unconventional sources are already on-stream such as oil from the Canadian tar sands and are already included in the main figures above, but other sources are not. The biggest source of unconventional oil could come from oil shale. Due to the difficulty and technology involved, the cost of extraction of shale oil is high, however with high oil prices and with the reduction of conventional resources oil shale is likely to become more competitive over time. The World Energy Council (WEC) estimates that total world resources of shale oil amount to 4.8 trillion barrels, the majority of which (3.7 trillion) to be found in the U.S[27]. **The degree of recoverability of this shale oil is questionable, but were this resource to be tapped at even a ten per cent recovery ratio, the impact on global oil supplies would be significant.**

[24] Ibid.
[25] Ibid.
[26] U.S. Geological Survey (USGS) (2012) An estimate of undiscovered conventional oil and gas resources of the world.
[27] World Energy Council (WEC) (2010) 2010 Survey of Energy Resources

Natural gas

The amount of natural gas in the world significantly exceeds the amount of oil, relative to its use. Further, unlike for oil, finds of gas have outpaced production[28]. Known, recoverable resources of natural gas are estimated to amount to around 6,750 trillion cubic feet in 2012[29]. The two major hubs of natural gas reserves are in the former Soviet Union (32 per cent of reserves), particularly Russia, which holds 25 per cent global reserves, and in the Middle East (42 per cent), particularly in Iran with 17 per cent, and in Qatar with 13 per cent of global natural gas reserves. Africa is estimated to have 8 per cent of reserves, split between Algeria (2 per cent) and Nigeria (3 per cent), with smaller but significant amounts for Egypt (1 per cent), and now Mozambique (1 per cent) (see *Section 4. The significance of new finds*). **Known, recoverable gas reserves will last 67 years at current rates of extraction, or 34 years should fast rates of growth for gas use (2.9 per cent) continue.**

In addition to known reserves are significant estimates of yet to be discovered gas reserves. The USGS estimate that there are 5,600 trillion of undiscovered, recoverable gas reserves. The Arctic region is the biggest source, with roughly a quarter (17 per cent in the Soviet Arctic, 9 per cent in the American Arctic), followed by 20 per cent from the Middle East and 20 per cent for SSA. More than half of the SSA undiscovered resource is expected to be found in offshore east Africa - Tanzania, Mozambique, Madagascar, and the Seychelles (see *Section 4. The significance of new finds*). The USGS estimate of undiscovered reserves would take total gas resources to over 12,000 trillion cubic feet, or around 110 years-worth at current rates of extraction. **However, should rates of growth for gas use continue total gas resources would last for just 49 years.**

The total of future potential gas reserves are further swelled by unconventional gas reserves. Unconventional gas includes shale gas, tight gas and coalbed methane. According to the WEC[30], the share of shale gas in U.S. natural gas production rose from 1.6 per cent in 1996 to nearly 10 per cent in 2008. This is still small in terms of total gas supplies, but estimates suggest there could be over 16,000 trillion cubic feet of shale gas worldwide. The IEA World Energy Outlook (2009) assumed 40 per cent of this could be recoverable, which would add over 6,000 trillion cubic feet of gas to world supplies[31]. A recent study reported by the WEC states that in five major shale gas basins in the U.S., 475 trillion cubic feet is considered to be recoverable, while in two Canadian basins, another 240 trillion cubic feet is recoverable, and another 140 trillion cubic feet is considered recoverable from Sweden and Poland. Together, these would add 13 per cent to proven reserves. **In short, shale gas, if best estimates can be achieved and are recoverable, could extend gas reserves, but only to 61 years-worth given current growth rates**.

Coal

Coal is the world's most abundant fossil fuel relative to production, with proven reserves of close to 1 trillion tonnes[32]. However coal is the fastest growing fossil fuel in terms of production (4.6 per cent over the past decade). Should this continue, current reserves of coal would last for just 39 years. According to the WEC[33], there is at least an additional 1.5 trillion tonnes not currently

[28] International Energy Agency (IEA) and OECD (2010) Ibid.
[29] U.S. EIA. Ibid.
[30] WEC (ibid.)
[31] WEC (ibid.) notes that bottom-up assessments on a worldwide basis would be required in order to be able to test the validity of this estimate.
[32] U.S. EIA. Ibid. This estimate is for 2008, the only year for which the EIA have data for coal reserves.
[33] WEC (ibid.)

counted in proven reserves, including 1 trillion tonnes in the U.S. alone. Coal is also the most widely distributed of fossil-fuel resources, with 44 per cent of proven reserves in OECD countries[34] (including the U.S. with 27 per cent, Germany with 5 per cent, and Australia with 9 per cent). Other major reserves include 18 per cent in Russia, 13 per cent in China and 7 per cent in India. **Compared to other fossil fuels, coal reserves are larger, faster growing and more widespread.**

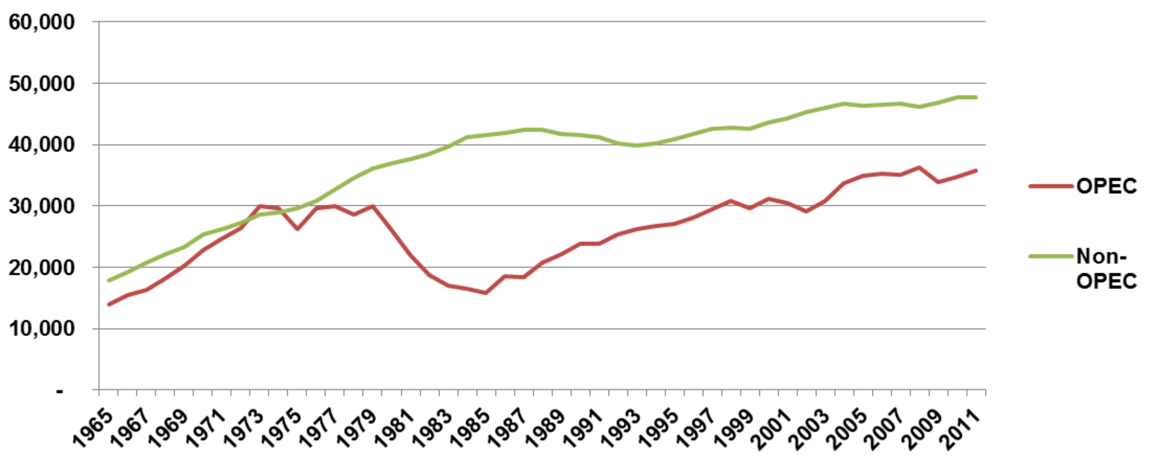
2.4 Production

Converting proven reserves of fossil fuels into sources of on-stream production is a complex process. This is in the technology of extraction, which gets more and more sophisticated as resources accessed become more marginal (deep sea resources for example, unconventional sources such as oil and gas shale, or Arctic resources). Furthermore, a transport network is required to ensure that produced quantities reach the locations of high demand. **Much of fossil fuel production is converted into energy as electricity, which further complicates the picture.**

Oil

Oil production has historically been dominated by the Organisation of the Petroleum Exporting Countries (OPEC)[35]. As shown in Figure 7, OPEC and non-OPEC production were level in the 1960s and 70s, but OPEC's share fell significantly in the early 1980s as a result of the Iran-Iraq War. Though they have caught up slightly since, in 2011 OPEC's share of oil production was 42 per cent[36]. Non-OPEC production is dominated by the former Soviet Union (17 per cent in 2011), and North America including Mexico (17 per cent). **In all, a relatively few countries dominate world oil supply.**

Figure 7: Worldwide oil production (thousands of barrel per day): OPEC and non-OPEC[37]



The raw material of oil is processed into a number of refined products. This is done in refineries, which are located predominantly in the developed world. In 2011, the U.S. had 19 per cent of the

[34] IEA and OECD (2010) Ibid.
[35] Founded in Baghdad in 1960 by Iran, Iraq, Kuwait, Saudi Arabia and Venezuela, these countries were later joined by Qatar (1961), Indonesia (1962), Libya (1962), the United Arab Emirates (1967), Algeria (1969), Nigeria (1971), Ecuador (1973), Gabon (1975) and Angola (2007). Gabon terminated its membership in 1995 and Indonesia suspended its membership in 2009 meaning that OPEC now has 12 Member Countries. Source - http://www.opec.org/opec_web/en/about_us/25.htm
[36] BP (Ibid.)
[37] Ibid.

world's refinery capacity[38], Europe including Russia had 26 per cent, and 31 per cent of refinery capacity was in the Asia Pacific region. **Thus, much of the value addition of oil takes place away from the oil producing countries in the developed world.**

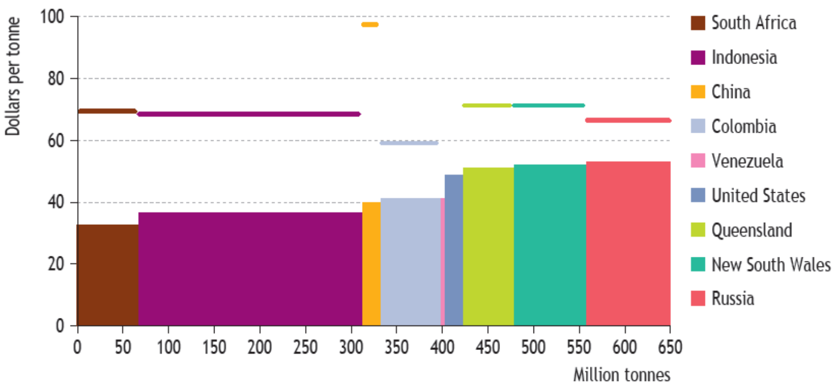
Natural gas

Natural gas production is more geographically spread than for oil. The U.S. is the world's largest gas producer with 20 per cent of global production in 2011, followed by 19 per cent in Russia, 5 per cent in Qatar and 5 per cent in Canada. For gas the largest issue has been how to transport it from regions in which there are reserves to markets where there is demand. Two principal means of transportation exist, pipelines, and shipping of liquid natural gas (LNG) (gas condensed and cooled to 1/600th of its volume). In 2011, 695 billion cubic metres of natural gas was traded via pipelines, while 330 billion cubic metres was traded via LNG[39]. The LNG share at 32 per cent was up from 21 per cent in the year 2000[40]. Japan and South Korea were by far the largest importers of LNG with 47 per cent between them, while the majority of pipelined gas imports were within Europe (68 per cent), mainly from Norway and Russia to Italy, France, Germany and the UK. LNG capacity is expensive to generate due to the need for LNG plants in exporting countries, specialised LNG vessels, and LNG receiving terminals in importing countries. **Geography therefore plays a big role in the viability of pipeline or LNG trade for natural gas, and large investments are needed to bring new resources on-stream.**

Coal

Coal production is dominated by China, which in 2010 produced 44 per cent of the global production of 8 billion tonnes[41]. The U.S. produced 14 per cent, while Europe produced 9 per cent, India 8 per cent and Australia 6 per cent, Indonesia and Russia both produced 5 per cent. South Africa produced 3.5 per cent of worldwide coal production, 98 per cent of Africa's total output. **According to data presented by the IEA, South Africa is the world's cheapest producer of coal, as shown in Figure 8, in terms of coal supply costs against trade prices.**

Figure 8: Coal supply costs and traded prices[42]



Note: Boxes represent costs and bars show FOB prices. Values adjusted to 6 000 kcal/kg.

[38] Ibid.
[39] Ibid.
[40] Sylvie Cornot-Gandolphe et al. (2003) The challenges of further cost reductions for new supply options. 22nd World Gas Conference, Tokyo.
[41] IEA and OECD (2010) Ibid.
[42] Ibid. FOB stands for Free on Board, the trade price prior to transport or customs charges.

Electricity

All of the fossil fuels discussed above have a role to play in the generation of electricity, although to varying degrees. Global electricity production was 22,000 terawatt-hours in 2011, increasing at an annual average rate of 3.3 per cent since the year 2000[43]. Coal is the dominant source of electricity generation worldwide, generating 41 per cent of global electricity in 2008[44]. This is followed by gas, with around 21 per cent. Hydro power comes next with around 16 per cent, then nuclear with 13 per cent, and oil with 6 per cent. Other sources are relatively miniscule with wind and biomass contributing around 1 per cent each. Again there is a difference between countries, with coal power plants dominant in China (79 per cent) and the U.S. (42 per cent)[45]. Gas plays a smaller role in China (5 per cent) than western countries such as the UK (35 per cent)[46]. Nuclear power contributes large shares in the U.S. (19 per cent) and UK (20 per cent) but is highest in France (79 per cent). Following the Fukushima nuclear disaster, Germany and Japan are scaling back their previously large use of nuclear power (previously at 22 and 30 per cent respectively)[47]. **Burning coal remains the dominant form of electricity generation, with gas contributing half as much; alternatives may be declining with the shrinking of nuclear's share.**

2.5 A natural limit on burning fossil fuels: CO_2 and climate

The burning of fossil fuels releases carbon dioxide (CO_2), a greenhouse gas that warms the planet. While detailed scientific monitoring of atmospheric composition only began in 1958, pre-industrial levels of CO_2 in the atmosphere are estimated to have been 278 ppm (parts per million of the composition of the atmosphere)[48]. By 1958, the level was 315 ppm. In May 2012, the level had reached 396.8 ppm[49]. There has therefore been a 33 per cent increase in the quantity of CO_2 in the atmosphere since pre-industrial times. **The increase in CO_2 in the atmosphere is the result of the burning of fossil fuels to meet global energy demand.**[50]

Relationship between CO_2 and global warming

The science relating CO_2 to global warming is complicated, since the planet is an extremely complex system with multiple feedback mechanisms both positive and negative. However, for the international body of scientists responsible for collecting together all the latest evidence in periodic reports, the International Panel on Climate Change (IPCC), the evidence has become stronger over time. The IPCC fourth Assessment Report (AR4) in 2007 stated that warming of the climate is "unequivocal" as evidenced from observed warming of global average air and sea

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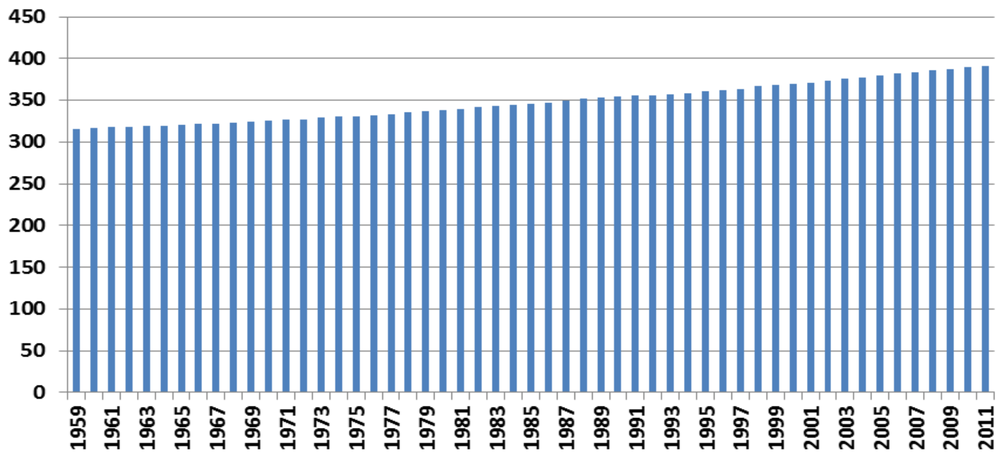
[43] BP (Ibid.)
[44] IEA and OECD (2010) Ibid.
[45] U.S. stat - EIA. China stat - "Capacity of China's straw-fueled power plants reaches 1.2 mln kw". Xinhua. 2007-01-16.
[46] China stat - http://en.in-en.com/article/html/energy_0943094342355502.html UK stat - Department of Energy and Climate Change. France stat - EnerPub (2007-06-08). "France: Energy profile". Spero News.
[47]Japan stat - http://www.world-nuclear.org/info/inf79.html Germany stat - http://www.bdew.de/internet.nsf/id/DE_20111216-PI-Die-Verantwortung-waechst?open&ccm=900010020010 Japan and Germany scaling back - http://www.economist.com/blogs/schumpeter/2011/06/energy-statistics
[48] United States National Oceanic and Atmospheric Administration (NOAA) - http://www.noaanews.noaa.gov/stories2005/s2412.htm
[49] NOAA (2012) Earth System Research Laboratory - Trends in Atmospheric Carbon Dioxide. Measurements from the Mauna Loa Observatory, Hawaii. In comparison, levels of CO2 varied little more than 7ppm (2.5 per cent) during the 800 years between 1000 and 1800 A.D.
[50] International Panel on Climate Change (IPCC) (2007) Climate Change 2007: Synthesis Report

temperatures and it was "very likely" (>90 per cent probability) to be caused by humans[51]. **Scientists have become increasingly alarmed by the threat of climate change.**

Figure 9: CO_2 in the Earth's atmosphere in parts per million (ppm): 1959-2011[52]



The IPCC's AR4 presents climate models projecting average temperature rises of up to 6.4^{0}C by 2100, and a range of 1.8^{0}C to 4^{0}C most likely, with warming at 0.2^{0}C per year for the next two decades. The quantity of warming is proportionate in climate models to how much CO_2 is eventually emitted[53]. For a range of 440-485ppm, the average temperature rise is estimated at 2.8^{0}C to 3.2^{0}C. At current rates of emission increase, CO_2 will reach 440ppm in less than 25 years[54], but given that energy demand increases year-by-year, CO_2 is likely to reach this level sooner. The warming impact experienced by countries will be higher than global averages, since the average includes seas and oceans, which warm more slowly than land surface temperatures. **The potential impacts of global warming include flooding, droughts, wildfires and ocean acidification[55]. As a result, climate change will continue to be at the forefront of global issues for the foreseeable future.**

Relationship between fossil fuel emissions and CO_2

The burning of fossil fuels in world energy markets is the principle driver of planetary CO_2 emissions. Fossil fuels are responsible for around 57 per cent of greenhouse gas emissions. Another 17 per cent is due to CO_2 from deforestation and decay of biomass, 14 per cent comes from methane from agriculture, waste and energy, while 8 per cent comes from nitrous oxide, again principally from agriculture[56]. In 2010 emissions from gas, coal and oil amounted to 32 Gigatonnes, equivalent to 4.2ppm[57]. However around half of CO_2 emissions is absorbed by the

[51] Ibid.
[52] Ibid.
[53] Or more specifically "CO2 equivalent" (CO2e) – this includes emissions of methane, nitrous oxide and F-gases, which have a far stronger warming impact than CO2 although are emitted in much smaller quantities.
[54] This is based on the average increase in emissions from 2002 to 2011 of 2.04 ppm per year.
[55] IPCC (ibid,).
[56] IPCC (ibid,).
[57] Approximately 7.5 Gigatonnes (Gt) of CO2 corresponds to 1 ppm according to John Quiggin (2011) Stabilizing the global climate: A simple and robust benefit cost analysis. *RSMG Working Paper Series.* Working Paper: C11_1.

oceans[58], and a fraction more in the land biosphere – so fossil fuel emissions contributed around 2ppm of CO_2 to the atmosphere in 2010. Emissions continue to rise and if just half of estimated global fossil fuel resources were burned in total (including estimates of currently undiscovered and unconventional resources), global temperatures would be expected by IPCC estimates to rise by up to 5^0C, while sea levels would be estimated to rise by up to 3 metres[59]. The consequences of such changes could be catastrophic[60]. **In order to avoid catastrophic costs associated with climate change, potentially over half of the World's total fossil fuels will need to be left in the ground. There is therefore a 'natural limit' on the amount of fossil fuels that humankind can safely use.**

Carbon pricing

Given the relationship between fossil fuel emissions and CO_2, CO_2 leading to global warming, and the massive potential costs of global warming, there is a strong economic case for the pricing of emissions. However with some exceptions, this is yet to have taken hold in global markets. The largest attempt yet to price carbon has been the European Union's Emission Trade Scheme (ETS). The ETS has put a price on carbon, but has been beset by problems – most notably the setting of quotas at too high a level leading to a crash in the carbon price[61]. The United Nations attempts to complement the scheme through the use of Carbon Credits, in which emissions reduction can effectively be outsourced to developing countries, has also faced problems with prices of carbon at a record low in July 2012[62]. The essence of the problem is a lack of international cooperation. Due to the global nature of the carbon 'externality', prices also should be global to be effective. For this to occur, large intransigent Governments such as the U.S. and China will need to take global leadership on the issue. **Given the long-timescales involved in climate negotiations, it is very unlikely that there will be a globally effective carbon price before 2020.**

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[58] 48 per cent of CO2 is absorbed by oceans according to Christopher L. Sabine et al. (2004) The Oceanic Sink for Anthropogenic CO2. *Science, 305(5682), 367–371*

[59] IPCC estimates of warming and sea levels from International Panel on Climate Change (IPCC) (2007) Climate Change 2007: Synthesis Report. The total production of CO_2 was estimated using data of the rate of CO_2 produced for each fossil fuel from U.S. EIA International Energy Statistics. Website accessed October 2012. This source was used for current proved reserves. Undiscovered reserve estimates came from USGS (2012) An estimate of undiscovered conventional oil and gas resources of the world. Estimates of reserves of unconventional forms of oil and gas came from World Energy Council (WEC) (2010) 2010 Survey of Energy Resources. Burning half of the total estimate for fossil fuel reserves including all these figures led to an estimate of CO_2 composition of 657 parts per million (ppm) of the atmosphere. This figure was then compared with the IPCC estimates.

[60] 5^0C warming has been estimated to lead to agricultural yields losses in most regions and potential doubling of world grain prices – National Research Council (2011) Climate Stabilization Targets: Emissions, Concentrations, and Impacts Over Decades to Millennia. A 3 metre sea level rise would impact 30 per cent of the population of Suriname and Guyana, 25 per cent of the population in Vietnam, 15 per cent of the population in Egypt, the Gambia and Mauritaina - World Bank (2007) The Impact of Sea Level Rise on Developing Countries: A Comparative Analysis, World Bank Policy Research Working Paper (WPS4136)

[61] Euractiv.com "EU emissions drop triggers carbon price freefall". April 3, 2012.

[62] Financial Times. "Carbon prices tumble to record low". July 18, 2012.

3 Scenarios for energy markets in coming years

Predicting future trends for energy demand and supply is important for companies producing energy and planning investments, as well as for policy makers for deciding upon public sector investments and designing regulation. Furthermore, as energy is the fundamental input for most economic activities, understanding the path of the future economy is intrinsically intertwined with the future of energy markets. Scenario modelling for energy can range in sophistication, but will always be highly sensitive to assumptions on the path for economic growth. Short-term projections for energy are easier to make than medium or long-term projections, since what it is possible to produce in three or four years' time is set out by investments today. **The IEA find that oil and gas investment increased by 9 per cent in 2011 as shown in Figure 10.**

Figure 10: Oil and gas industry investment by company: 2010 and 2011[63]

	Upstream			Total		
	2010 ($ billion)	2011 ($ billion)	Change 2010/2011	2010 ($ billion)	2011 ($ billion)	Change 2010/2011
Petrochina	23.6	27.9	18%	42.7	53.3	25%
Petrobras	23.9	24.0	0%	43.4	52.3	21%
ExxonMobil	27.3	28.8	6%	32.2	34.0	6%
Gazprom	26.9	24.8	-8%	29.2	27.0	-8%
Royal Dutch Shell	21.2	19.4	-9%	23.7	26.0	10%
Chevron	18.8	22.6	20%	19.6	26.0	33%
Pemex	17.4	18.9	9%	20.8	22.2	7%
BP	17.8	19.3	9%	18.4	20.0	9%
Total	14.8	16.0	8%	18.0	20.0	11%
Sinopec	8.2	8.3	1%	16.7	19.1	14%
Eni	12.9	12.9	0%	18.4	18.4	0%
Statoil	12.6	14.4	14%	14.0	16.0	14%
ConocoPhillips	8.5	12.0	41%	9.8	13.5	38%
Rosneft	6.1	8.0	31%	8.9	11.0	23%
Lukoil	4.9	6.9	41%	6.8	9.0	32%
CNOOC	5.1	8.8	73%	5.1	8.8	73%
BG Group	5.9	6.0	2%	7.7	8.4	9%
Apache	4.2	6.4	51%	5.4	8.1	51%
Repsol YPF	4.1	4.5	11%	6.8	7.5	11%
Suncor Energy Inc.	4.8	5.4	13%	5.8	6.8	17%
Occidental	3.1	4.9	56%	3.9	6.1	56%
Devon Energy Corp	5.9	5.5	-7%	6.5	6.0	-7%
Anadarko	4.7	5.2	12%	5.2	5.8	12%
Chesapeake	4.9	5.8	17%	4.7	5.8	22%
EnCana	4.5	4.4	-2%	4.8	4.7	-2%
Sub-total 25	292.0	320.9	10%	378.3	435.6	15%
Total 70 companies	408.3	446.7	9%	n.a.	n.a.	n.a.
World	**505.1**	**552.6**	**9%**	**n.a.**	**n.a.**	**n.a.**

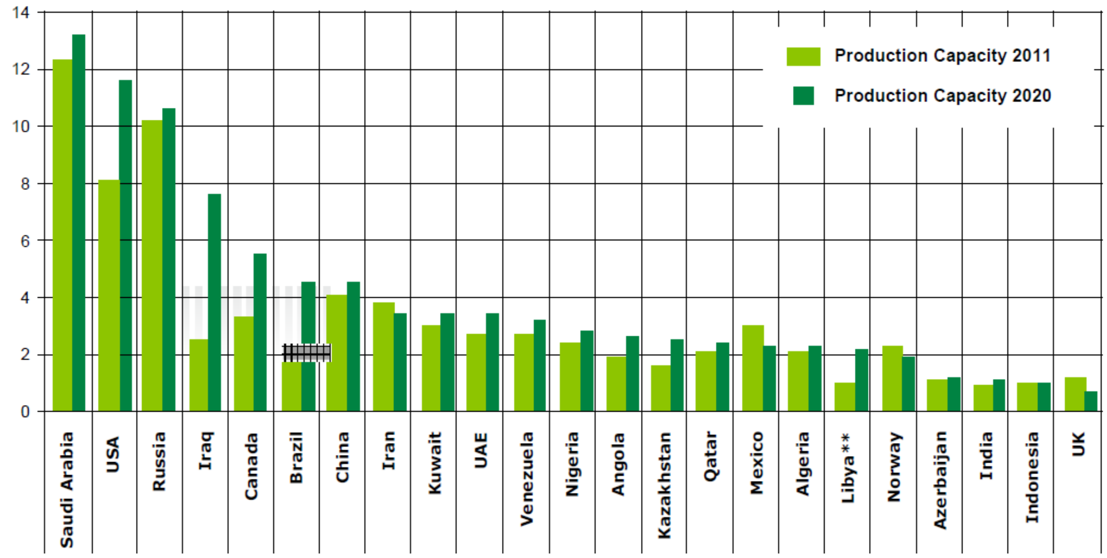
[63] IEA and OECD (2011) Ibid.

3.1 Investment and short-term outlook

Oil

Research for the Harvard Kennedy School suggests that large-scale investment in oil is providing *"the largest potential addition to the world's oil supply capacity since the 1980s."* [64] Money is now flooding into new oil: a trillion dollars was spent in 2010 and 2011 combined, and a record $600 billion lined up for 2012. Based on bottom-up, field-by-field analysis of most oil exploration and development projects in the world, the research suggests additional production of more than 49 million barrels per day of oil targeted for 2020 (compared to existing capacity of 93 million barrels). After adjusting this figure for risk, additional production is estimated at 29 billion barrels by 2020. Factoring in depletion rates of currently producing oilfields and their "reserve growth", net additional production capacity by 2020 is estimated to be 18 million barrels per day. **As shown in Figure 11, the majority of oil production increases by 2020 come in the U.S, Canada, Brazil, and a massive increase in Iraq.**

Figure 11: Country-by-country evolution of oil production capacity to 2020[65]



At these rates of growth, oil supply capacity could outpace consumption. This could lead to a glut of overproduction and a steep dip in oil prices. The investments required to make this boom happen depend on a long-term price of $70 a barrel[66]. Price falls would lead to significant volatility in investment expenditure. Furthermore, most of U.S. unconventional shale oil is said to be profitable at a price of oil ranging from $50 to $65 per barrel. **The short-term outlook for oil is for large increases in production capacity, though this is likely to depend on the outlook for prices and whether the likes of OPEC use rationing in order to maintain prices.**

Gas

As mentioned above, natural gas prices have seen a degree of 'decoupling' from oil prices in recent years, particularly due to the boom in US shale gas production and growth of LNG. A U.S. boom in shale gas production, with a 300 per cent increase in production in ten years, has

[64] Leonardo Maugeri (2012) Oil: The next revolution – the unprecedented upsurge of oil production capacity and what it means for the world. Harvard Kennedy School. The Geopolitics of Energy Project.
[65] Ibid.
[66] Ibid.

reduced and even largely eliminated U.S demand for LNG imports, leading to downward prices in other regions[67]. The shale gas boom, with the additional motivation of 'energy security' has stimulated the exploration of shale gas in Europe (Austria, Germany, Hungary, Poland, Sweden, and the U.K), China, Canada, and India[68]. The outlook for gas markets will very much depend on the speed of development for such sources. **Lower prices for natural gas point to a glut in gas supply worldwide. The short-term outlook for gas suggests this will continue.**

Coal

The rise in coal in recent years has been driven by investment in China, particularly in coal power plants. This has spurred a coal boom with record prices for the energy source. However, the past year has seen some signs of a slow-down. Stockpiles of coal have been building at Chinese ports with Chinese prices falling 10 per cent in the past year[69]. Furthermore, investment in coal power plants in China fell for the first time in five years in 2011 by 26 per cent.[70] This has principally been put down to the Chinese State's regulation of electricity prices. **Chinese coal demand has fallen slightly, the outlook for coal will very much depend on whether this trend continues.**

3.2 Methodologies used for making energy market projections

The development of scenarios for energy supply and demand has a long history, but modelling efforts do not have a brilliant track record. Craig et al. (2002) discuss forecasts of energy use in the United States for the year 2000 looking at only predictions covering two or more decades[71]. They find that most of the forecasts overestimated energy demand by 100 per cent or more. Forecasters in the 1950–1980 period underestimated the importance of surprises; for example the failure to foresee the ability of the United States economy to respond to the oil embargos of the 1970s by increasing efficiency. **The massive uncertainties involved make any medium and long-term projections very difficult, and predictions made have often been wide of the mark.**

As shown in Bhattacharyya et al. (2009), a review of energy demand forecasting approaches, a large variety of techniques have been used by different sets of users[72]. Earlier work, such as that used for energy forecasting in the UK used the "energy ratio" (now known as "energy intensity") and the "energy coefficient" (i.e. the elasticity of energy demand with respect to national income or GDP). This practice was discontinued only in the early 1980s when the reliance on sophisticated models started to rise, but the approach has still been used in the past decade in India and China. It has been noted however that such simple models can sometimes yield results as accurate as more complicated techniques[73], while sophisticated models also retain simple metrics such as GDP elasticities in some of their sub-components. **The virtue of simple models is**

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[67] Reinout De Bock and José Gijón (2011) Will Natural Gas prices decouple from oil prices across the Pond? IMF Working Paper. WP/11/43.

[68] Ibid.

[69] Financial Times. "China coal: piling high as growth slows". June 6, 2012.

[70] CleanBiz Asia. "First drop in China coal power investment for five years". June 29, 2012.

[71] Craig, P. P., A. Gadgil and J. G. Koomey (2002) What can history teach us? A retrospective examination of long-term energy forecasts for the United States, Ann. Rev. Ener Envi., 27, pp. 83-118.

[72] Bhattacharyya, Subhes C. and Govinda R. Timilsina (2009) Energy Demand Models for Policy Formulation: A Comparative Study of Energy Demand Models. World Bank Policy Research Working Paper 4866.

[73] Armstrong, JS, 2001 (ed), Principles of Forecasting: A handbook for researchers and practitioners, Norwell, MA: Kluwer Academic.

that the skill and data requirement is low and such models are more tractable rather than the hidden assumptions of complex models[74].

Sophisticated modelling approaches for energy scenarios are often separated between top-down models and bottom-up models; top-down models focussing on an aggregated level of analysis and bottom-up models identifying activities or end uses for which demand is forecast. The most sophisticated models for projecting future energy scenarios tend to be 'hybrid' using a combination of top-down and bottom-up modelling. These models can deal with changes to policies, subsidies to different energy types or uses, carbon prices, and changes to technology. Models include the Prospective Outlook on Long-term Energy Systems (POLES) used for long-term energy policy analysis by the European Union and the French government; the World Energy Model (WEM), the model used for the IEA's World Energy Outlooks; and the System for the Analysis of Global Energy Markets (SAGE) used by the U.S. Department for Energy for analysing global energy markets in its International Energy Outlook. **These energy models all have modules for supply in terms of power generation, fossil fuels and renewables, as well as modules for demand including for residential, industrial, commercial, and transportation energy usage.**

Assumptions of the World Energy Model (WEM) - Elasticity

The elasticity of energy demand with respect to income is still the main variable driving much of energy projections. Unsurprisingly, energy demand tends to grow in line with GDP, though typically at a lower rate. According to the IEA, between 1980 and 2008, world primary energy demand increased by 0.59 per cent each year on average for every percentage point of GDP growth (expressed in terms of purchasing power parity)[75]. There is variation in this elasticity, it fell from 0.64 in the 1980s to 0.46 in the 1990s and then rebounded to 0.67 in 2000-2008, mainly due to rapid expansion of energy-intensive manufacturing in China. The World Energy Model (WEM) uses elasticity of electricity demand estimates to model future electricity demand. They find income elasticities across all end-use sectors, using per-capita GDP as a proxy for income, ranging from 0.4 to 1.3[76]. Elasticities are generally highest in non-OECD regions: where electricity demand rises faster than income. **This difference in elasticity reflects saturation effects in the OECD and catching-up by the poorer developing countries, and is modelled by WEM.**

Assumptions of the World Energy Model (WEM) - Population

Population is also an extremely important factor driving energy demand. For the WEM, rates of population growth for each region are based on the most recent medium-fertility variant projections contained in the United Nations Population Division report, World Population Prospects. In WEO-2011, world population was projected to grow by 0.9 per cent per year on average, from 6.8 billion in 2009 to 8.6 billion in 2035. Population growth slows over the projection period. The WEM model also uses estimates of the rural/urban population split for each region, taken from the United Nations Population Division report, World Urbanisation Prospects. **The total population figures and urban-rural split are key inputs to the WEM.**

Assumptions of the World Energy Model (WEM) - GDP Growth

Economic growth assumptions for the short to medium term in the WEM model are based largely on those prepared by the OECD, IMF and World Bank. Over the long term, growth in each region

[74] Bhattacharyya et al. (Ibid.)
[75] IEA and OECD (2010) Ibid.
[76] International Energy Agency (IEA) and OECD (2011) World Energy Model – Methodology and assumptions

is assumed to converge to an annual long-term rate. The rate modelled is dependent on demographic and productivity trends, macroeconomic conditions and the pace of technological change. In the WEO-2011 world GDP was expected to grow on average by 3.6 per cent per year over the projection period. Growth was assumed to drop from 4.2 per cent in 2009-2020 to 3.1 per cent in 2020-2035. India and China were expected to continue to grow faster than all other regions, followed by the Middle East and Africa. The economies of many regions were expected to shift away from energy-intensive heavy manufacturing towards lighter industries and services, though the pace of this process is variable. **GDP growth is perhaps the foremost factor in driving energy growth projections.**

Assumptions of the World Energy Model (WEM) - Prices

Another key driver of scenario development is the prices of energy, which are underpinned by assumptions and then used to drive relative demand and supply. The WEM uses historical time-series data for coal, oil, gas, electricity, heat and biomass prices. For each sector and region, a representative price is derived taking into account the product mix in final consumption and differences between countries. International price assumptions are then applied to derive average pre-tax prices over the projection period. Average pre-tax electricity prices are derived from changes in marginal power-generation costs. Excise taxes, value added tax rates and subsidies are taken into account in calculating average post-tax prices for all fuels. In all cases, the tax rates on fuels are assumed to remain unchanged over the projection period. These average end-user prices are then used as an explanatory variable in the modelling directly or as a lag. **Prices in the WEO 2010 are predicted to rise over time whatever happens in terms of policies, but if policies stay the same, by 2035, gas prices in the U.S. rise by 294 per cent, oil prices by just 19 per cent and coal prices by 142 per cent[77].**

Assumptions of the World Energy Model (WEM) – Technology and energy efficiency

Energy demand and supply are both subject to future technological change and the potential for efficiency savings. The WEM builds cost databases on current and future technology costs of different vehicles in transport – conventional, hybrid, electric cars, hydrogen fuel cells etc. – as well as electricity generation. Where *"the pace of technology cost reductions is then calculated using learning curves at various different learning rates."* The model also looks at[78]:

- Efficiency in energy supply, in industry and in the household – for example how the cost to consumers of investing in more energy-efficient equipment compares with the savings they make through lower expenditure on energy bills.
- Estimates of the capital costs for investing in more energy efficiency, for example including using detailed figures from Airbus/Boeing on the need for new planes and the increased capital cost of increasing efficiency in the aviation sector.
- Detailed figures used to assess development of a global renewable model to calculate global learning by technology – where supply curves are produced for 16 renewable technologies in each global region.

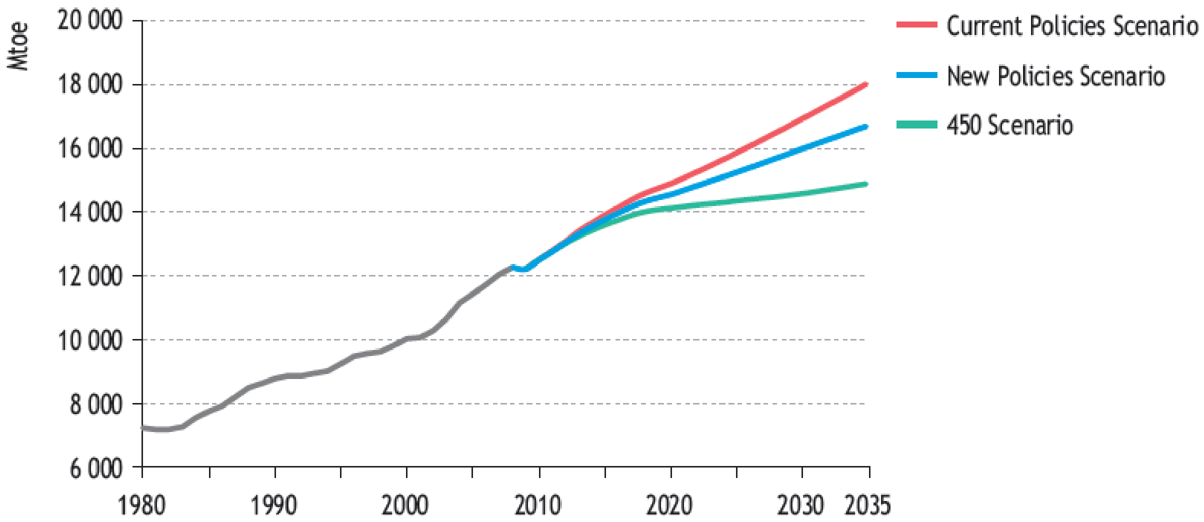
Technological variables are extremely uncertain, beset by *black swan* uncertainty - in terms of technology that could be available but is currently unimaginable. As a result, technological learning used in scenario modelling tends to be very linear compared to reality.

[77] Prices projected for 2035 in the Current Policies Scenario in WEO 2010. Compared to prices as of October 2012, as reported in World Bank Pink Sheets.
[78] International Energy Agency (IEA) and OECD (2011) World Energy Model – Methodology and assumptions

3.3 High level energy scenarios

A number of high-level energy scenarios have been developed in recent years, usually spanning out to between 2030 and 2040. The most sophisticated modelling publicly available is that of the WEM, but before discussing the scenarios developed there, a couple of others are worth a mention. Exxon Mobil project that global energy demand will be about 30 per cent higher in 2040 compared to 2010[79], almost all of which driven by non-OECD countries. BP project higher growth in a model [80] - built *"to the best of our knowledge, reflecting our judgement of the likely path of global energy markets"* to 2030 – with growth of 39 per cent over the next 20 years. The U.S. EIA in their International Energy Outlook 2011 in a model which does not incorporate prospective legislation or policies that might affect energy markets, world marketed energy consumption grows by 53 per cent from 2008 to 2035[81]. Energy growth is again driven by non-OECD nations, increasing by 85 per cent compared to 18 per cent for the OECD economies. **Three recent scenarios on energy growth therefore all agree that it will continue to be large and led by the developing world, but annual energy growth varies from 0.9 per cent to 1.7 per cent in these models, reflecting significant uncertainty.**

Figure 12: World primary energy demand by scenario for WEO 2010[82]

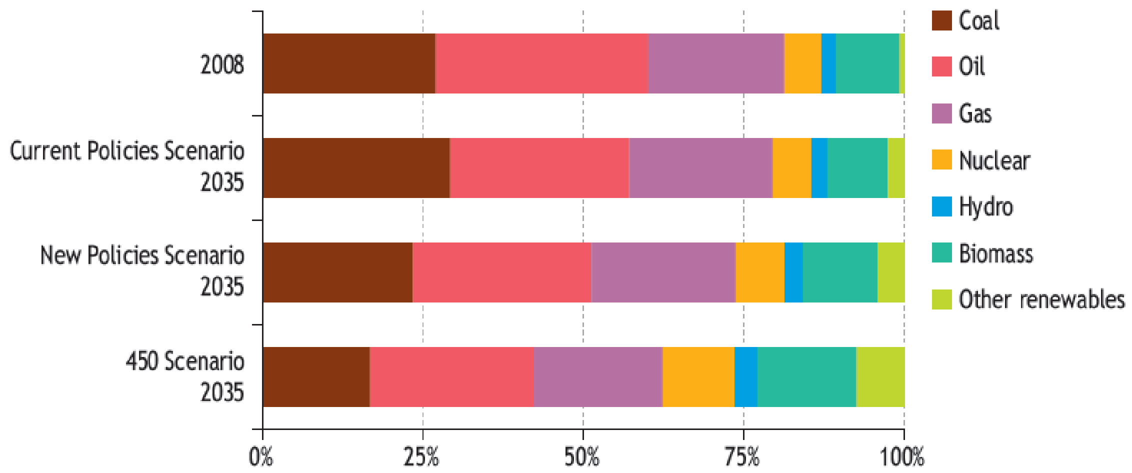


The IEA's World Energy Outlook (WEO) 2010 is based on the WEM and includes three different scenarios[83]. The *Current Policies Scenario* takes into consideration only those policies that had been formally adopted by mid-2010; the *New Policies Scenario*, takes account of policy commitments already announced and assumes cautious implementation of national pledges to reduce greenhouse-gas emissions by 2020 and to reform fossil-fuel subsidies; the third scenario, *the 450 Scenario*, assumes implementation of the high-end of national pledges and stronger policies after 2020, including the near-universal removal of fossil-fuel consumption subsidies, to achieve the objective of limiting the concentration of greenhouse gases in the atmosphere to

79 Exxon Mobil (2012) 2012 Outlook for Energy: A View to 2040
80 BP (2011) Energy Outlook 2030
81 EIA (2011) International Energy Outlook
82 IEA and OECD (2010) Ibid. Energy in tonnes of oil equivalent (Mtoe).
83 IEA and OECD (2010) Ibid.

450 ppm of CO_2-equivalent[84] and global temperature increase to 2°C. As shown in Figure 12, the WEO's projections for energy demand by 2035 depend very much on policies implemented ranging from a 47 per cent increase in energy demand in the *Current Policies Scenario* down to a 22 per cent increase in energy demand for the *450 Scenario*. Furthermore, the energy mix is also variable depending on policies, with a significant shift away from coal to renewables in the scenarios with a stronger environmental approach as shown in **Error! Not a valid bookmark self-reference.. In summary, energy projections are extremely sensitive to policy, but projections remain upwards.**

Figure 13: Shares of energy sources in world primary demand by scenario[85]



3.4 WEO projections to 2035: Oil

The outlook for oil demand is seen to depend on the stringency of policies and differs across regions. All of the increase in world oil demand between 2009 and 2035 comes from non-OECD countries in each scenario, as OECD demand drops. In the New Policies Scenario, OECD demand falls by over 6 million barrels per day (mb/d) between 2009 and 2035, but this is offset by an almost 19-mb/d increase elsewhere. Demand falls in OECD are driven by projected improvements in vehicle fuel efficiency, spurred by high fuel costs and government fuel-economy mandates. In non-OECD regions, GDP and population growth outweigh efficiency gains in transport. The biggest increase in demand occurs in China, where it jumps from just over 8 mb/d in 2009 to more than 15 mb/d in 2035. Other emerging Asian economies, notably India, and the Middle East also see rapid rates of growth. Oil demand changes to 2035 for each scenario are shown in

Figure 14, and composition of growth in the New Policies Scenario is shown in Figure 15. **The scale of oil demand to 2035 will depend on policies, but be driven by transportation, and particularly in the developing world and China.**

[84] The New Policies Scenario includes U.S. pledge for 15 per cent share of renewables in electricity generation, and a 25 per cent reduction in greenhouse gas (GHG) emissions compared with 1990 in the European Union, a 15 per cent reduction in GHG emissions in Russia compared with 1990, and reductions of CO2 intensity in China and India. The 450 Scenario includes pledge for a 17 per cent reduction in GHG emissions in the U.S. relative to 2005, 25 per cent reuduction in GHG in Japan relative to 1990, and a 15 per cent share of renewables and nuclear power in primary energy demand in China, among other falls in emissions.
[85] Ibid.

Figure 14: World primary oil demand by scenario (excluding biofuels) for WEO 2010[86]

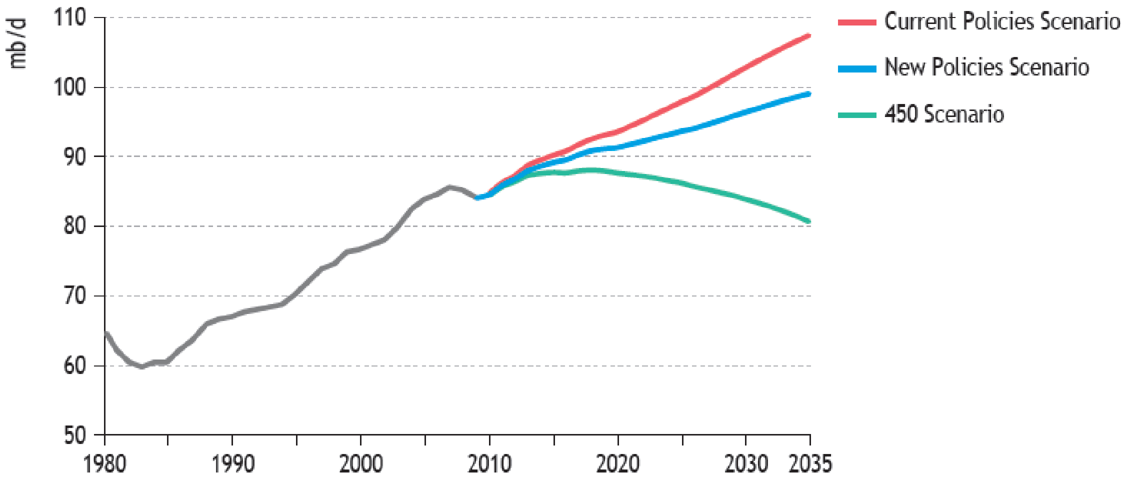
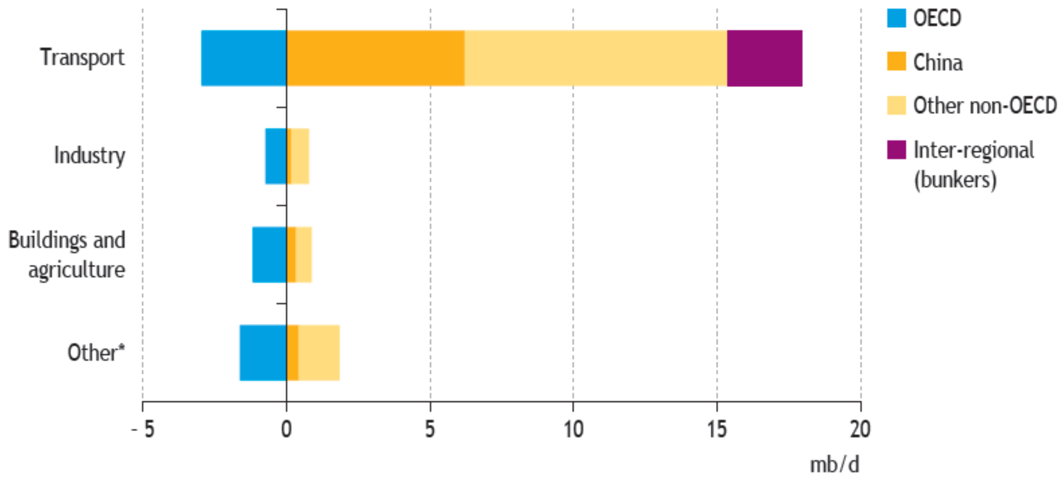


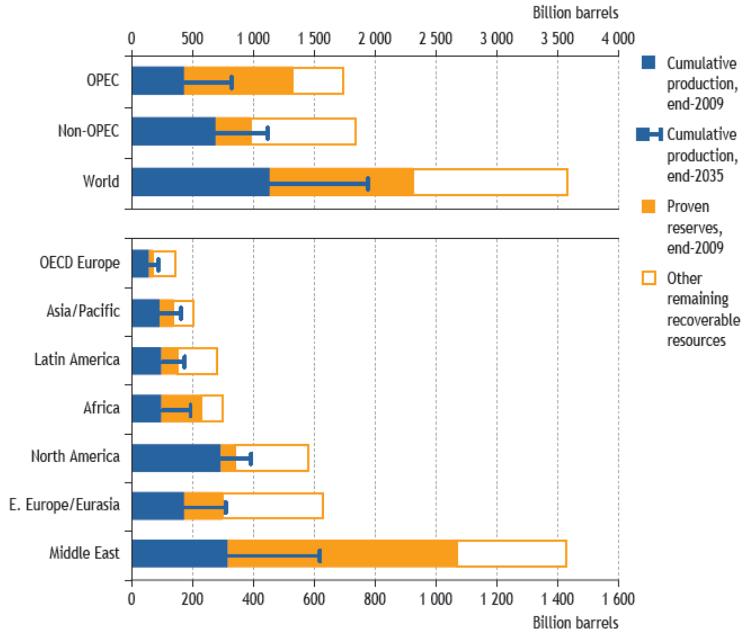
Figure 15: Oil demand change by sector and region in New Policies Scenario: 2009-2035[87]



The supply of oil will continue to cut into the limited reserves that exist. As shown in Figure 16, the world with have reached over half of the entire supply of oil in cumulative production by the end of 2035, even in the New Policies Scenario (in which demand falls). The world at this point will therefore be dependent on other remaining recoverable resources (yet to be confirmed reserves), as well as any amounts of unconventional oil discovered by then. Production increases will also be driven by OPEC countries, where reserves are larger and will last for longer. **Oil supply will begin to eat into yet to be discovered resources by 2035, with OPEC playing a more dominant role in global oil markets.**

86 International Energy Agency (IEA) and OECD (2010) World Energy Outlook 2010
87 Ibid.

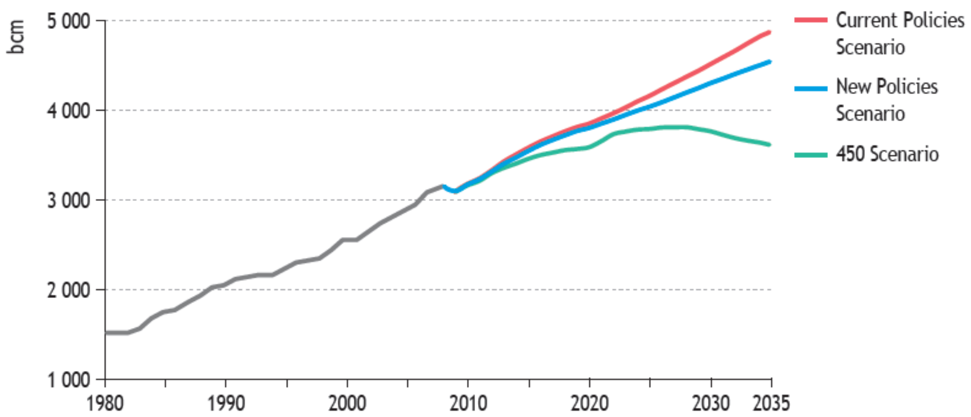
Figure 16: Proven reserves, recoverable resources and production by region in New Policies Scenario[88]



3.5 WEO projections to 2035: Natural gas

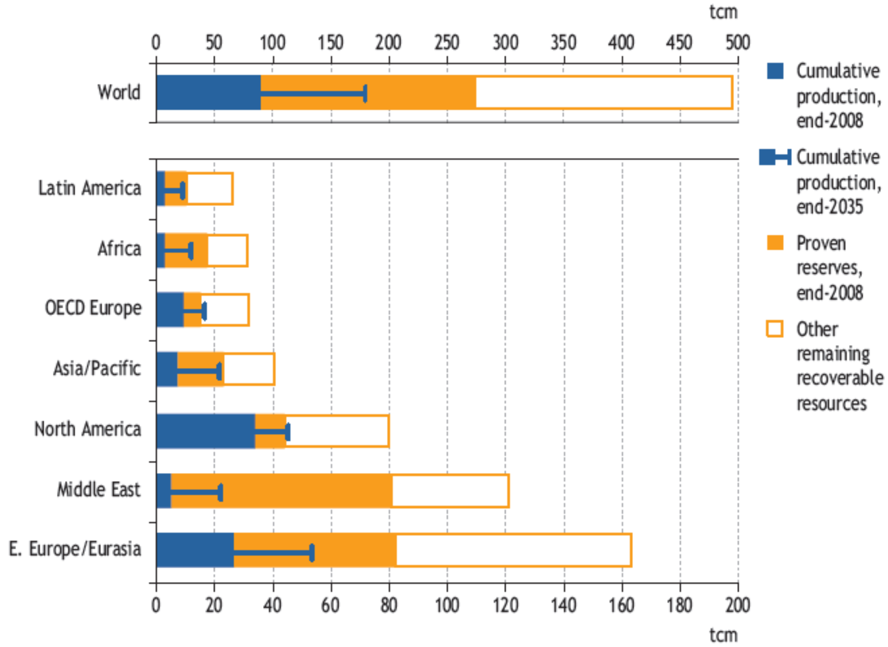
Global natural gas demand grows across the three scenarios in WEO 2010 as shown in Figure 17, though the rates of growth are variable, reflecting the differing impact of energy and environmental policies. In the New Policies Scenario, demand growth increases 44 per cent by 2035. In the Current Policies Scenario, demand growth is even higher. Gas is the only fossil fuel for which demand is higher in 2035 than in 2008 in this scenario. Non-OECD countries drive gas demand growth; in the New Policies Scenario, accounting for 84 per cent of the increase in demand between 2008 and 2035, led by China. The increase is set to be met by production in a number of regions, particularly Eastern Europe and the Middle East, Africa also sees large increases in production. As shown in Figure 18, gas supplies will require large increases of reserves and unconventional sources, which will see their share rise from 12 to 18 per cent in the period[89]. **Gas is projected to grow quickly over the period driven by plentiful supplies.**

Figure 17: World primary natural gas demand by scenario for WEO 2010[90]



[88] Ibid.
[89] All from Ibid.
[90] Ibid. In billions of cubic metres (bcm)

Figure 18: Proven reserves, recoverable resources and production of gas by region[91]

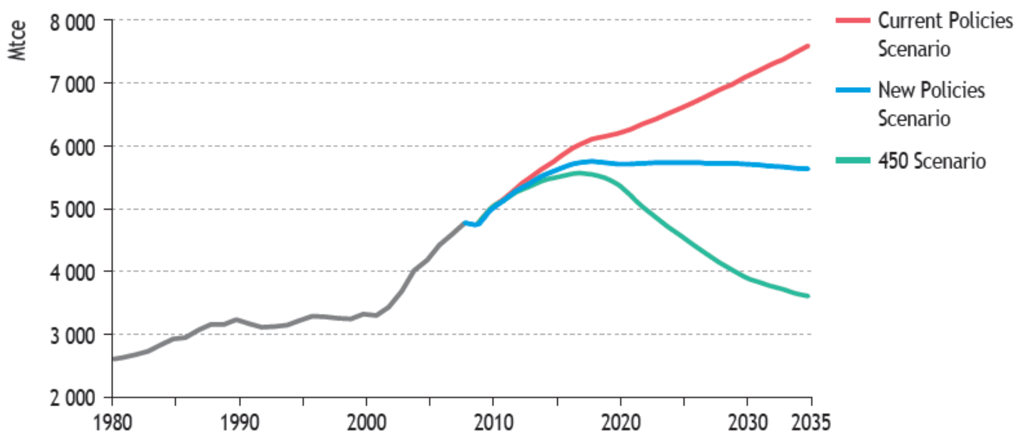


3.6 WEO projections to 2035: Coal

The world demand for coal is more sensitive than gas or oil to policies aiming to bring down emissions of CO_2, due to the higher emissions from coal. This leads to extremely variable demand for coal over the three different scenarios in WEO 2010, as shown in Figure 19. China, as now, leads the growth for coal demand, making up over 90 per cent of the growth of coal demand for the 2008 to 2035 period, as shown in

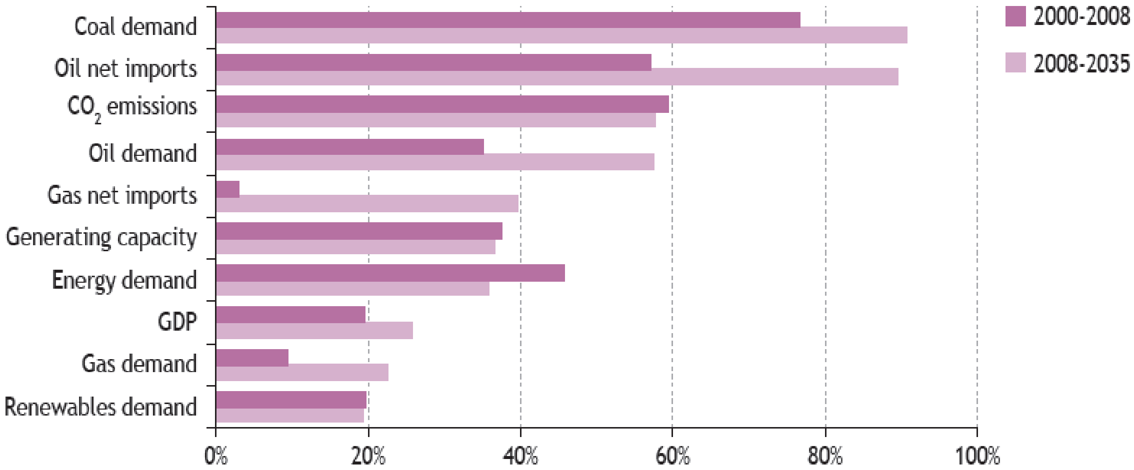
Figure 20. Most of the growth for coal production is projected to come from non-OECD countries, particularly from China to meet its own demand, India and Indonesia. **Coal demand is sensitive to policies around CO_2, but China is likely to continue to lead trends around coal with increases in demand and supply.**

Figure 19: World primary coal demand by scenario for WEO 2010[92]



[91] Ibid. Resources shown in trillions of cubic metres (tcm). These projections are for the New Policies Scenario.
[92] Ibid. Figures include for hard coal. Million tonnes of coal equivalent (Mtce)

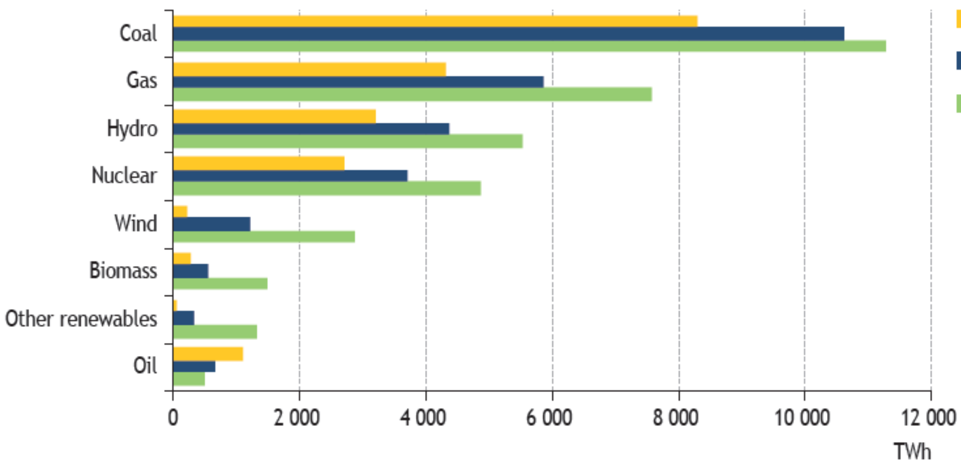
Figure 20: China's share of the projected net global increase for selected indicators[93]



3.7 WEO projections to 2035: Electricity, renewable energy and carbon

Projections for the composition of electricity generation by 2035 are again extremely dependent on the policies carried out. Targets for reductions of CO_2 would most likely only be possible with a significant increase in the share of renewable forms of electricity generation, principally nuclear energy, wind and hydroelectric power. As shown in Figure 21, projections under the New Policies Scenario show supply for every type of electricity rise by 2035 except for oil. Significant rises for coal, gas, hydro, nuclear and wind are all achieved under the scenario. In all this is to meet rising energy demand of 2.7 per cent to 2020 and 1.8 per cent from 2020 to 2035. Coal is expected to lose market share in OECD countries due to environmental concerns, and rise in elsewhere, particularly in China and India. Carbon capture and storage (CCS) technology is expected to be deployed on a limited scale, but only reach 1.5 per cent of energy supply by 2035. Gas generation growth is led by the U.S. and Europe. Nuclear growth is set to rise due to concerns over energy security, but this may be offset by safety concerns following Fukushima. **Overall, electricity is set to see significant growth, with gas and coal seeing the largest increases in demand as a result. Renewables growth will depend on the stringency of the policy environment put in place in coming years.**

Figure 21: World electricity generation by type in the New Policies Scenario[94]



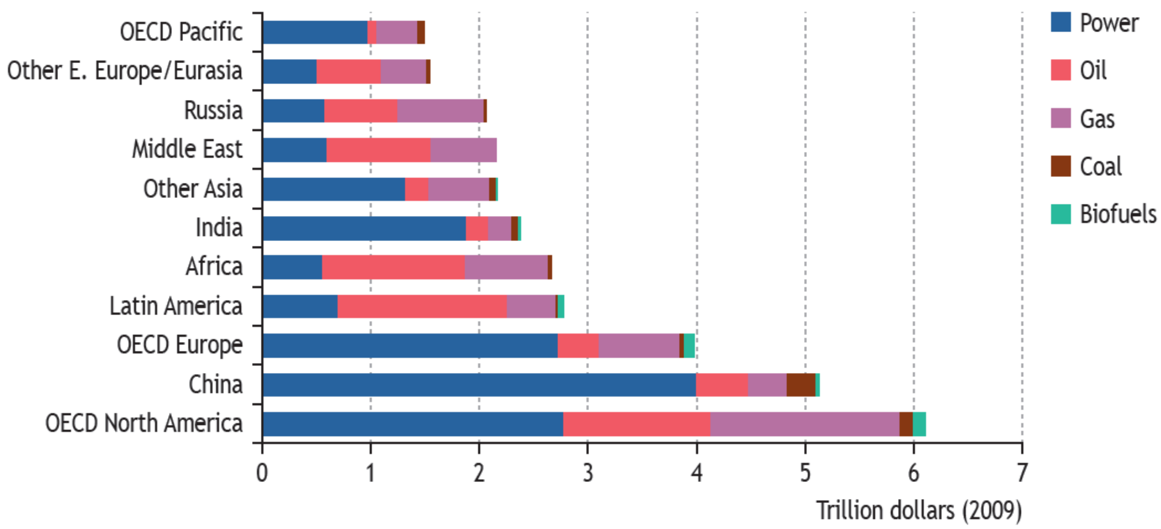
[93] Ibid.
[94] Ibid. In Terawatt hours (Twh).

Following the New Policies Scenario, the long-term concentration of greenhouse gases is projected to reach 650 ppm CO_2 equivalent, compared to 450 ppm for the 450 Scenario and 1000 ppm for the Current Policies Scenario. Given that the 450 Scenario would require the largest political capital and is therefore the least likely scenario, the New Policies Scenario may be seen as more realistic. As concentrations reach such a higher level, the average global temperature rise is likely to be also be higher. The consequences of this are extremely difficult to predict in any great detail but world temperature rises of over 4^0C could be expected. How this rising trend will interact with the global economy, global emissions, and global policy, is completely unpredictable, since it involves the intersection of three vastly complex systems – the economy, the climate, and the human brain. **As a result, all projections beyond 2020 should be taken with a sizable pinch of salt.**

4 The significance of new finds

Recent resource finds in Africa have garnered lots of coverage, in particular gas finds in East Africa. As this paper has shown, the global outlook for natural resources over the medium-term varies by energy type. However, the overall pattern is one of significant growth in energy demand, tempered only by high prices and by the policy and regulatory environment, particularly around emissions of CO_2. As noted above, worldwide, the rate at which reserves of oil have been found has been slower than the annual increase in production for the past two decades, while the opposite has been true for natural gas. For coal, existing resources are so large that the availability of additional resources is unlikely to be the key constraint in production, but rather relative cost will be the key driver, together with Chinese demand. Further, all fossil fuel demand projections are dependent on the policy environment. As shown in Figure 22, huge quantities of investment in energy infrastructure are projected in the 2010-2035 period including close to 3 trillion dollars in Africa. Gas supply cumulative investment from 2010 to 2035 is estimated $7 trillion (in 2009 USD), including $764 billion in Africa. **Africa is projected to play a key role in the expansion of energy supply up to 2035.**

Figure 22: Cumulative investment in energy infrastructure by region and fuel in New Policies Scenario: 2010-2035[95]



Projections for oil supply to 2020 have been criticised as being too optimistic including the research for the Harvard Kennedy School suggesting net additional production of 18 million barrels per day by 2020[96], with large increases in the U.S, Canada, Brazil, and Iraq. The controversy around these projections is that the analysis is alleged to underestimate the decline in existing reservoirs[97]. Furthermore, new oil supplies tend to be dirtier with greater environmental hazards, for example the heavily polluting Canadian oil sands, technologically challenging such as deeper water oil as shown in the BP Gulf of Mexico disaster in 2010, and in Arctic areas where there are significant challenges, not least the displacement of indigenous people. **Such factors could generate greater political opposition and slow the rate of growth of oil supply.**

The outlook for gas is much rosier. The WEO 2010 has it as the fastest growing fuel source, due to demand growth, its status as a cleaner fuel than oil and coal, and the supply of abundant

[95] Ibid.

[96] Leonardo Maugeri (2012) Oil: The next revolution – the unprecedented upsurge of oil production capacity and what it means for the world. Harvard Kennedy School. The Geopolitics of Energy Project.

[97] Financial Times "The popular story of abundant energy supplies has yet to be realised" October 8, 2012

unconventional sources. This led WEO-2011 to proclaim a potential *'golden age of gas'*. The proliferation of LNG plants has led to a surge of a demand in Asia, Japan has shifted much of its energy to gas following the Fukushima disaster, and American shale gas has made LNG elsewhere cheaper. One complicating factor for the gas outlook will be whether cheaper gas discourages investment in this energy source. For example if abundant shale gas in the U.S could discourage investment elsewhere. **However, it is clear that worldwide gas supplies are rising and set to continue to rise at an increasing rate.**

4.1 Recent changes and their scale

In oil, significant undiscovered resources are being found which increase international reserves. The largest new potential reserve base is likely to be in the Arctic, where as much as 90 billion barrels of oil reserves could be available[98]. African finds are somewhat smaller. This includes in Ghana, which has produced more than 37 million barrels of oil since production started at the Jubilee field[99] in 2010. According to the U.S. EIA, reserves in Ghana are 660 million barrels, though they may be up to 1.8 billion barrels[100]. Production is set to rise to 120,000 barrels per day (b/d) by 2013 and 600,000 b/d by 2018 according to the Ghana National Petroleum Company[101]. If output reaches higher levels, the Ghanaian resource will be very short lived (at 120,000 b/d, resources would run out in 40 years, at 600,000 b/d, resources would run out in 8 years). **Unless more finds are made, Ghana will not be a major player in world oil supplies in coming years.**

East African oil finds are larger than in Ghana, but not of a major scale relative to other recent finds, or to Africa's existing big oil producers – Libya, Nigeria, Algeria and Angola. The find in Uganda's Albert Rift Basin has led to an estimated 2.5 billion barrels in the country[102]. Tullow Oil in collaboration with China's CNOOC and Total, are investing $10 billion to develop the resource, with production expected to start in 2017 and reaching up to 230,000 b/d by 2020[103]. At this rate the Ugandan resources would last up to 2050, at current prices generating over $1 billion per year of oil. Tullow Oil has claimed that Kenyan oil could be larger than in Uganda, although solid data is not yet available.[104] **East African oil will provide a boost to exports and to Government revenues, but is unlikely to make a major impact on global supplies.**

More significant than East African oil is East African gas. This is predominantly located off the coast of Tanzania and Mozambique, and also Kenya. The largest gas reserves are estimated to be off the coast of Mozambique with estimates of 80 trillion cubic feet (tcf)[105] to 130 tcf[106], in addition to between 15 tcf and 29 tcf in Tanzania[107] and at least 5 tcf in Kenya[108]. The USGS has estimated that as much as 371 tcf may lie off the coast of these countries together with Madagascar and the Seychelles[109]. Though not as large as the 1,670 tcf estimated in the Arctic regions, the East Africa projections would add over 5 per cent to existing global reserves of natural gas. This would be a

98 U.S. Geological Survey (USGS) (2012) An estimate of undiscovered conventional oil and gas resources of the world.
99 Reuters. "UPDATE 3-Ghana's economic growth slows as oil output falls" September 26, 2012
100 http://www.revenuewatch.org/countries/africa/ghana/overview
101 Reuters. "TEXT-Fitch affirms Ghana at 'B+'; outlook stable". September 21, 2012
102 Financial Times. "Tullow upgrades Kenya discovery". July 4, 2012
103 The Wall Street Journal "Total sees Uganda oil output one year later than hoped". September 28, 2012
104 Financial Times. "Tullow upgrades Kenya discovery". July 4, 2012
105 Financial Times. "'Embarrassment of riches' hard to exploit". October 8, 2012
106 Ventures Africa. "Kenya's gas discovery to boost East Africa's reserves". September 10, 2012.
107 Reuters. "Tanzania gas reserves nearly triple on new finds" June 19, 2012.
108 Ventures Africa. "Kenya's gas discovery to boost East Africa's reserves". September 10, 2012.
109 U.S. Geological Survey (USGS) (2012) An estimate of undiscovered conventional oil and gas resources of the world.

major addition, worth over $1.7 trillion at current prices, equivalent to roughly the entire GDP of Africa in 2010. **East African natural gas could see the region become a significant player in global gas markets with total potential reserves greater than those of Saudi Arabia.**

The veracity of these estimates and the timing of exploitation of the resource will depend on the scale of investment that takes place. As mentioned earlier, gas markets are a difficult logistical proposition. East African gas will need to be transformed into LNG, through which it will be able to enter lucrative Asian markets. Massive investments in infrastructure are required. Tanzania signed a $1.2 billion loan agreement with China in September 2012 for the construction of a 532-kilometre pipeline from the south of the country to Dar es Salaam[110], while Kenya plans to upgrade its ports and build at least one new facility, with oil terminals and pipelines, at Lamu in the next few years[111]. Mozambican gas with ENI of Italy and the U.S.'s Anadarko the biggest players, could bring in $70 billion in investment in coming years[112] – the two firms are likely to join forces on one single, large LNG plant[113], before seeking to sell much of their stake to big oil majors. Among the many risks in developing the resource is regional political difficulties as the maritime boundaries between Madagascar, and the Comoros further north have never been definitively fixed[114]. A conflict already is brewing between war-torn Somalia in the Horn of Africa, where significant oil strikes are expected, and neighboring Kenya over their maritime border[115]. **East African gas is a major challenge for investors, but the size of the find means they are likely to persist and undertake the large investment necessary to develop the resource.**

Mozambique is seeing large investment in addition to gas, in its coal. It is estimated that coal production could bring in another $10 billion of investment to the country in coming years[116], with major investors so far including Brazil's Vale, Anglo-Australian giant Rio Tinto, and India's Jindal Steel and Power (JSPL). JSPL has plans to produce 10 million tonnes per annum from its mine at peak level, and is also looking to set up a 2,640 MW thermal power plant in the African nation[117]. Rio Tinto has already shipped its first coal shipment[118]. The coal, from one of two Rio Tinto mines in Tete province, is bound for India's Tata Steel, which owns a 35 per cent stake in the mine. The Zambeze coal basin, which underlies Tete, is believed to hold some 23 billion tonnes of coal[119]. While the country's final coal output is expected to jump to around 40-million tonnes a year in five years' time and 100-million tonnes in a decade[120]. The value of this higher quantity would meet 1 per cent of 2010's global annual demand, and at current prices would be worth $9 billion per annum, almost equivalent to the country's current GDP. Coal, along with gas, is set to transform Mozambique. Already this has been singled out for its potential to generate internal conflict - *"There's now a strong sentiment, even within the elite, that not everybody is benefiting from the current development,"* according to Fernando Lima, head of Mediacoop, an independent media company[121]. **Coal from Mozambique is set to play a significant role in the international market, although is set to be a much bigger deal for the country itself.**

110 Reuters. "Tanzania gas reserves nearly triple on new finds" June 19, 2012.
111 UPI.com "Mozambique gas find hikes East Africa boom" May 16, 2012
112 Financial Times. "Mozambique poised for coal boom" March 12, 2012
113 Financial Times. "'Embarrassment of riches' hard to exploit". October 8, 2012
114 UPI.com "Mozambique gas find hikes East Africa boom" May 16, 2012
115 Ibid.
116 Financial Times. "Mozambique poised for coal boom" March 12, 2012
117 The Economic Times. "JPSL to begin production from Mozambique coal mine by year-end" 17 October 2012
118 News.com.au "Rio Tinto exports first Mozambican coal". August 2, 2012
119 Mining Weekly "Mozambique coal output expected to jump to 100 Mt/y in next decade" June 8, 2012
120 Ibid.
121 Financial Times. "Mozambique poised for coal boom" March 12, 2012

4.2 Conclusion

Recent finds of oil, gas and coal in Africa vary in significance. Oil finds in Ghana and in Uganda may be significant for these countries, but together make up just 0.2 per cent of likely global reserves[122]. They are therefore not to be seen by any means as a solution to long-term supply. There may be 'undiscovered' resources to be found, and the USGS seems to suggest that there may be significant amounts in Africa, although principally off the Atlantic Coast. But such reserve estimates do not yet exist and are massively uncertain. While this is also true for East African gas reserves, the higher estimates suggest they may constitute as much as 5 per cent of global reserves[123]. As a result, the value of these resources is extremely high, equivalent to Africa's entire GDP in 2010. But even under higher estimates, East African gas would only meet the world's current demand for natural gas for three years, so again, long-term supply shortages are only put off for a short while. Further, with gas demand booming, particularly from Asia, demand is set to grow. With such strong demand, investors are clearly excited by the size of the opportunity and thus willing to expend the substantial resources in the infrastructure required to allow gas to be transformed to LNG and transported to Asia's growing markets. Mozambican coal is also a lucrative opportunity for miners – African coal from South Africa is the cheapest source of coal on the planet – so should producers reach similar efficiencies, Mozambican coal is likely to be highly competitive on international markets, particularly as an export to Asian markets with high and growing demand for coal as a source for electricity. But again, at about 1 per cent of likely global reserves and 1 per cent of global production at higher estimates, it will still be only a bit player in global markets.

In conclusion, East African gas and Mozambican coal are set to make significant inroads to transforming the region into a sizeable supplier of some of Asian energy demand over coming years. However, the overall picture remains one of an imminent resource crunch by the middle of the century, unless existing estimates of undiscovered and unconventional resources are far off the mark, or the GDP growth of the developing world goes into a prolonged slowdown. Furthermore, according to the science, the reality of climate change will only increase as an issue over time. To avoid catastrophic climate change, policy change is likely to be required that will effectively leave accessible proven reserves of fossil fuels in the ground. With the resource crunch combined with climate change, the pressure will grow on providers of renewable energy to meet future global energy demand.

[122] Likely global reserves here includes current proven reserves of 1.5 trillion barrels according to U.S. EIA plus the USGS estimate of undiscovered resources of 568 billion barrels.
[123] This is of currently proven reserves. Including USGS estimate of undiscovered reserves, the 371 tcf estimate of reserves would make up around 3 per cent of total global reserves. Including unconventional reserve potential estimates, East African gas would amount to 1 per cent of total reserves.

Annex 1: Measurement of energy

The following conversion factors table is taken from BP (2012) Statistical Review of World Energy. June 2012.

Crude oil*

From	To: tonnes (metric)	kilolitres	barrels	US gallons	tonnes per year
	Multiply by				
Tonnes (metric)	1	1.165	7.33	307.86	–
Kilolitres	0.8581	1	6.2898	264.17	–
Barrels	0.1364	0.159	1	42	–
US gallons	0.00325	0.0038	0.0238	1	–
Barrels per day	–	–	–	–	49.8

*Based on worldwide average gravity.

Products

	To convert: barrels to tonnes	tonnes to barrels	kilolitres to tonnes	tonnes to kilolitres
	Multiply by			
Liquefied petroleum gas (LPG)	0.086	11.6	0.542	1.844
Gasoline	0.118	8.5	0.740	1.351
Kerosene	0.128	7.8	0.806	1.240
Gas oil/diesel	0.133	7.5	0.839	1.192
Fuel oil	0.149	6.7	0.939	1.065

Natural gas (NG) and liquefied natural gas (LNG)

From	To: billion cubic metres NG	billion cubic feet NG	million tonnes oil equivalent	million tonnes LNG	trillion British thermal units	million barrels oil equivalent
	Multiply by					
1 billion cubic metres NG	1	35.3	0.90	0.74	35.7	6.60
1 billion cubic feet NG	0.028	1	0.025	0.021	1.01	0.19
1 million tonnes oil equivalent	1.11	39.2	1	0.82	39.7	7.33
1 million tonnes LNG	1.36	48.0	1.22	1	48.6	8.97
1 trillion British thermal units	0.028	0.99	0.025	0.021	1	0.18
1 million barrels oil equivalent	0.15	5.35	0.14	0.11	5.41	1

Units

1 metric tonne	= 2204.62lb = 1.1023 short tons
1 kilolitre	= 6.2898 barrels = 1 cubic metre
1 kilocalorie (kcal)	= 4.187kJ = 3.968Btu
1 kilojoule (kJ)	= 0.239kcal = 0.948Btu
1 British thermal unit (Btu)	= 0.252kcal = 1.055kJ
1 kilowatt-hour (kWh)	= 860kcal = 3600kJ = 3412Btu

Calorific equivalents

One tonne of oil equivalent equals approximately:

Heat units	10 million kilocalories 42 gigajoules 40 million British thermal units
Solid fuels	1.5 tonnes of hard coal 3 tonnes of lignite
Gaseous fuels	See Natural gas and liquefied natural gas table
Electricity	12 megawatt-hours

One million tonnes of oil or oil equivalent produces about 4400 gigawatt-hours (= 4.4 terawatt-hours) of electricity in a modern power station.

1 barrel of ethanol = 0.57 barrel of oil
1 barrel of biodiesel = 0.88 barrel of oil