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Nedbank Sustainability Outlook

UNIVERSITY OF CAMBRIDGE
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Researched by University of Cambridge Programme for Sustainability Leadership

Sustainability rests on a simple premise: the interconnectedness of all things.

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INTRODUCTION

Choosing an energy pathway for a national economy such as that of South Africa is a decisionmaking task like few others. It has to answer two questions simultaneously: How do we provide a reliable, affordable supply of energy services to the country's households and businesses up to the middle of this century? And how do we do that without compromising social viability through environmental degradation, particularly that associated with climate change? This analysis attempts to show that there are rational grounds for making technology choices based on information already available, and that this information may best be assessed by viewing it through the lens of a framing logic that has emerged from the field of climate science and climate change policy.

A CASELOAD OF BASELOAD

The capture and conversion of energy has been one of the primary enablers of human development. In his book *Why the West Rules – For now* (2011), Stanford professor Ian Morris describes energy capture as one of the key traits defining social development and one of the most prominent factors explaining the 'great divergence' between the West and the rest over the last 250 years. The industrial revolution of the 18th century had at its core an energy revolution that enabled a social revolution. Through the steam engine humanity was able to connect the hitherto separate realms of thermal and kinetic energy, and that changed everything.

In the last few centuries humankind has enjoyed unprecedented and virtually continuous improvement in incomes and living standards, fuelled by cheap energy. And this energy, by and large, came from burning fossil fuels. It has long since been understood that the concomitant CO_2 emissions resulting from burning fossil fuels would lead to an enhanced greenhouse effect, which would in turn cause warming of the earth. The Danish physicist Svante Arrhenius calculated in 1896 that a doubling of atmospheric CO_2 concentrations would probably lead to eventual warming of about 2,1 °C, a calculation that has proved remarkably resilient. What Arrhenius grossly underestimated, however, was how long it would take to reach a doubling in atmospheric CO_2 concentrations – he predicted it would take more than a thousand years. However, humanity is on course to cause that doubling in a mere 150 years from Arrhenius's day, and not stop there.

Society is thus currently in a bind – our ever-expanding energy system has driven much of the progress over the last couple of centuries, but this same energy system is now leading to a disturbance of the biophysical system that can have potentially massive negative impacts. Consequently, we need to find a way of maintaining or growing our supply of energy services while at the same time drastically reducing our carbon emissions.

Enter renewable energy. Numerous reports[1] have argued that the world can rely almost entirely on a mixture of solar, wind, hydro, wave, geothermal and biomass sources to meet its energy needs. Conceptually this is correct as David Mackay of Cambridge University brilliantly illustrated in his book *Sustainable Energy without the Hot Air*. The May 2011 report by the Intergovernmental Panel on Climate Change (IPCC) shows how we could get up to 77% of the energy we need in 2050 from renewable-energy sources.[i] Locally it has been calculated that parts of the Northern Cape receive on average more than 2 500 kWh/m² per year in solar irradiation,[ii] meaning it would require less than 100 km² to replace most of South Africa's electricity generation.[iii]

Overall global energy demand can roughly be broken up into four areas: domestic heating (supplied by fossil fuels or biomass), industrial processes, electricity and transport. Electricity as a percentage of final global energy demand is currently 17%. In South Africa electricity plays a more significant role and it accounts for about 41% of final energy demand.[2] Electricity production accounts for 32% of total global fossil fuel use and 41% of total energy-related CO_2 emissions. Globally electricity generation has increased by 67% since 1990, totalling 19 800 TWh in 2007.[iv] In order for renewable energy to supply a greater proportion of overall final energy demand many energy services, such as heating and transport, need to be electrified, as renewable sources typically generate electricity. Reducing greenhouse gas emissions therefore means increasing electricity production overall and as proportion of primary energy. A *Zero Carbon Britain* report published by the Centre for Alternative Technology envisages a 55% cut in overall energy demand by 2030 and at the same time a near doubling of electricity production.[v]

The problem is, however, that many of the renewable-energy options do not supply energy in the way that the world currently consumes it. More specifically, the most promising sources of renewable energy, ie wind and solar sources, are only intermittently available, while we have grown accustomed to consuming energy whenever we want it. This is especially true

[1] See: Greenpeace. 2011. *Advanced energy revolution: A sustainable energy outlook for South Africa*; European Climate Foundation. 2010. *Roadmap 2050*; IPCC. 2011. *Special Report Renewable Energy Sources*.
[2] *Digest of South African Energy Statistics* (2009): 2155PJ coal + 109PJ nuclear + 10PJ renewable = 2274/5536PJ (2006 figures).

for industry, which often needs energy 24/7. In simple terms: on good sites the wind blows strongly enough for wind turbines to work about 30% of the time, or sunlight is sufficient to let concentrated-solar-power (CSP) plants work 40% of the time. There is thus a great difference between maximum supply and demand and average supply and demand. In South Africa Eskom's figures indicate that it sold 224 446 GWh of electricity during the year ending 31 March 2011. If this were used at a constant rate, it would require generating capacity of 25,6 GW. Eskom, however, indicated that peak demand was 36,6 GW, almost 40% higher, and total installed capacity was 41,2 GW (to allow for a reserve margin).[vi]

To match supply with peak demand energy systems have always relied on baseload power plants that could produce energy at low cost and with great reliability and consistency. Supporting infrastructure, such as railway lines connecting coal mines directly to power plants, has been built to ensure baseload reliability. However, currently there is no supporting infrastructure to ensure continuous supply from renewable sources. The solution would be a combination of demand side management and energy storage facilitated through a 'smart grid'. The main forms of storage are pumped hydro, molten salt, hydrogen (used in conjunction with fuel cells) or other types of battery. According to the IEA, 100 GW of pumped storage capacity is already in use globally. The IEA BLUE Map Scenario – which assumes that renewables account for 45% of electricity generation by 2050 – requires storage capacity to increase to 189 GW.[vii]

Demand-levelling options – which reduce peak demand – could include automatically shutting certain appliances off when there is a high load on the grid or only switching them on where there is excess capacity. All batteries, including those of battery-powered electric vehicles, could also be used to push electricity back onto the grid, thus increasing supply in times of strain. Other technologies, such as capacitors and flywheels, can also be built into equipment to store power for short periods. Although all the technical components that would enable a smart grid are available, not much has been done to roll it out, which will require large investments. The BLUE Map Scenario estimates that the upfront cost to roll out a smart grid would be about 50% more than the requirements under a business-as-usual case, with a total global cost of US$12,3 trillion (as opposed to US$8,4 trillion) between 2010 and 2050.

Until sufficient renewable-energy capacity and the supporting storage and distribution infrastructure are installed to meet peak electricity demand, most countries needing to expand or replace their existing power-generating stock have to consider baseload options. In South Africa, where there is limited potential for hydroelectricity (a possible source of continuous renewable energy), the interim options are fossil fuel plants or nuclear energy facilities. From a sustainable development point of view both those options are far from ideal, as they involve significant social and environmental impacts and risks and are, by definition, unsustainable in the long run. One therefore has to weigh up the relative merits and concerns about different technologies in a comprehensive and objective manner. That is, however, no easy task.

There are those who are of the opinion that South Africa should stick to whatever option is the cheapest and not have any 'misguided ideas' about an obligation to contribute to combating climate change.[viii] This would imply a continued reliance on coal-fired power stations. This sentiment has, however, increasingly been countered by opposition from civil society backed by scientific evidence of the significant socioeconomic costs related to coal. The commitments made and policies adopted by the South African government have made it clear that the country must reduce its reliance on coal-fired power stations. The carbon intensity of South Africa's electricity is currently about 970 gCO_2/kWh (in 2011) compared with 743 gCO_2/kWh in China (in 2009)[ix], a fact that underlines the need to move away from an exclusive dependence on coal.

The question then becomes 'How should low-carbon electricity be produced around the world, and particularly in South Africa?' Increasingly, the technologies favoured are natural gas or nuclear power, both of which have their vocal opponents. A heated online debate between the British environmental writers George Monbiot and Jonathon Porrit last year was indicative of that. In one of the posts Porritt wrote: 'I readily acknowledge that this combination of renewables and efficiency will take some time to deliver. There will need to be some "generating bridge" to get us to that 2050 point. For me, this comes down to a straight choice between your "least worst option", namely nuclear, and my "least worst option", gas plus Carbon Capture and Storage (CCS).'[x] What complicates the debate further is that gas has come to the fore so strongly owing to breakthroughs in accessing shale gas resources and shale gas comes with additional uncertainties. The South African government has placed a moratorium on the exploration of shale gas as it investigates the perceived risks and benefits thereof.

What follows is an investigation of nuclear power and gas, in particular shale gas (with or without CCS), as meaningful contributors to an electricity 'generating bridge'. Special emphasis will be placed on the South African context.

THE POWER OF TINY THINGS: NUCLEAR ENERGY

It took a mere fifty years from the late 19th century for scientific knowledge to advance from the basic model to describe the components of atoms, via the discovery of radioactivity and Albert Einstein's famous **$e=mc^2$** equation to the first nuclear chain reaction in 1939. It was a glorious scientific achievement, as there is something almost unbelievable about the idea that splitting a microscopic atom could unleash enormous quantities of energy. The release of energy from splitting a uranium atom turns out to be two million times greater than breaking the carbon-hydrogen bond in coal, oil or wood. As beneficial as this energy could be for human development, scientists such as Einstein, Leó Szilárd and others also immediately warned of its potential destructive power.

Thus, when the atomic bombs were dropped on Hiroshima and Nagasaki in 1945, most of the world came to realise the incredible power of nuclear technology. The civilian application for energy arrived about a decade later when the first nuclear power plants started to produce electricity for the power grid in Russia, the UK and then the US. By 1960 there was 1 GW of installed nuclear power, which increased to 100 GW by the late 1970s. By the end of 2010 there were 441 reactors with a generating capacity of 393 GW in operation in 30 countries around the world.[xi] Today nuclear energy provides 14% of global electricity supply and about 5% of South Africa's needs. The growth in nuclear energy capacity slowed down significantly in the mid-1980s due to a few factors. These included increased safety concerns after the Chernobyl nuclear disaster in 1986, higher-than-expected construction costs and low fossil fuel prices.

Renewed interest was shown in nuclear power after 2000 as the world was evaluating low-carbon energy options, and according to Capgemini there were 558 plants under construction or on the drawing board by 2011.[xii] Many of these plans have been shelved since the Fukushima incident in 2011 and countries such as Germany announced that they would phase out nuclear power over the next decade. Some experts are, however, concerned about the emissions impact of shutting down nuclear plants. An August 2011 report in *New Scientist* claims that Germany's decision to shut down its nuclear plants will, despite its massive investment in new renewables, create an extra 300 million tonnes of CO_2 between now and 2020 due to the increased use of fossil fuels.[xiii] In Japan, where all nuclear plants were shut down after Fukushima, CO_2 emissions increased by 2,4% in 2011 while all other developed countries reduced their emissions.

Environmental and social concerns

Using nuclear energy has always attracted vociferous opponents, especially from activist organisations. The main environmental and social concerns with nuclear power are safety, waste and proliferation. Three Mile Island (1979), Chernobyl (1986) and, more recently, Fukushima (2011) have cast dark shadows over the public attitude towards nuclear power. Although fewer direct deaths are attributable to nuclear power than to fossil fuels, the danger of exposure to radiation, which could linger for hundreds of years, invokes a particular sense of fear in people. An area in Ukraine similar in size to Luxemburg will remain a no-go area for hundreds of years because of the Chernobyl disaster. The economic costs of nuclear accidents are also much greater than those from other power sources.

Linked to safety is the issue of the management and disposal of nuclear waste. Although the volume of waste is tiny compared to that from coal-fired power stations (about 1/50th), part of the waste is highly radioactive. The conventional management protocol is to store the 3% or so highly radioactive waste material at the reactor in pools of water, where it is cooled down for about 40 years. Some of this waste can be reprocessed, which decreases the amount of high-level waste (to 0,3%) and the need to mine fresh uranium. High-level waste takes about 1 000 years to reach the radioactive level of uranium ore and currently there is no solution for safely disposing of this waste during that period. About 7% of waste is intermediate level and is mixed with concrete before storage in tanks, drums and vaults onsite. Low-level waste is typically also stored in concrete vaults until it is safe enough to go into hazardous-waste landfill sites. In the UK, which generates more than three times as much nuclear energy as South Africa, it is expected that by the time the existing reactors are shut down the country will have about 40 000 m^3 of high-level and intermediate-level waste material, equivalent to 14 Olympic-sized swimming pools. In absolute terms the volume of waste is thus small, but managing it is very complex and expensive, and improper treatment has severe consequences.[xiv]

A third concern is the ongoing threat that fissile material can be further enriched to produce nuclear weapons. Uranium that is used for nuclear power generation cannot be diverted to produce nuclear weapons without significant additional enrichment. India, Israel, North Korea and Pakistan are the only countries possessing nuclear weapons or nuclear-weapon capacity that are not parties to the Nuclear Non-proliferation Treaty. Iran is a party to the agreement, but it has been found that it does not comply with the treaty and the status of its nuclear programme remains in dispute. Along with North

Korea it regularly tops the agenda of the UN Security Council. South Africa is the only country in the world that developed nuclear weapons by itself and later dismantled them. The International Atomic Energy Agency (IAEA) was set up in 1957 to monitor nuclear safety and compliance with the Non-proliferation Treaty.

Cost and economics

Apart from environmental and safety concerns, many critics point to the high cost of nuclear plants as a reason to oppose it. The operating cost of a nuclear plant is typically very low, but the upfront construction cost is high and long lead times are required. This dynamic means that operators building nuclear power plants typically demand some type of guarantee or support from government to lower the risk of investing many billions in something that has a payoff period measured in decades. The nature and value of these guarantees or incentives are typically not transparent, giving rise to claims of government subsidies for nuclear energy and making real cost comparisons with other forms of energy problematic. As Jonathon Porritt wrote in his exchange with George Monbiot: 'Because of implicit and explicit guarantees, the private cost element of nuclear is uncertain and continues to escalate … and the public subsidy portion is generally missing entirely, so that nuclear cannot be properly compared to alternatives, nor can the potentially enormous cost to taxpayers be properly vetted.' [xv] So contentious is the issue of subsidies to the nuclear industry that opposition to such subsides was explicitly included in the coalition agreement between the Conservative and Liberal Democratic Parties in the UK.

A further economic concern with nuclear is its dependence on a non-renewable resource, uranium, of which the world has limited reserves. This means that costs could escalate significantly in the event of a uranium shortage. There are about 4,7 million tonnes of known recoverable uranium in the world, of which more than 7% is found in South Africa. A once-through 1GW nuclear power station uses 162 tonnes of uranium per year, so at current demand there is enough uranium for about 74 years. Significantly more uranium, about 22 million tonnes, is contained in phosphate deposits and could, according to David MacKay, become economic to mine if the uranium price exceeds $130 per kg.[xvi] At the end of May 2012 the price was $115 per kg.

Newer types of nuclear reactors, called fast-breeder reactors, can use uranium 60 times more efficiently than once-through reactors and as such extend the available fuel resource by many centuries. These reactors can also use the vast majority of depleted uranium 'waste' sitting in stockpiles.

Another technological option is to use reactors that feed on thorium instead of uranium. The current known thorium reserves could power 10 times the current nuclear stock for 70 years. For the purpose of evaluating nuclear power as an interim or bridging technology, there seems to be more than enough feedstock available.

Given the sensitivities around building nuclear plants, it is difficult to get an 'average' cost estimate, but various studies have attempted to put a number to it. According to the IEA, the current investment cost for building new nuclear plants in 2010 is US$3 000 to $3 700/kW. This compares with about US$2 100/kW for supercritical coal plants and US$3 500 to $5 600/kW for Solar PV. The cost for building the new Eskom Medupi coal plant is about US$2 500/kW (R20 000/kW).

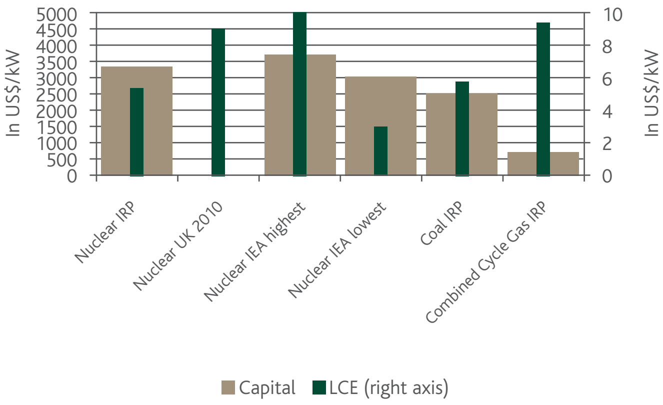
The IEA's 2010 calculation for the median levelised cost of electricity from nuclear sources is US$0,06 to $0,10/kWh in Europe, US$0,05 to $0,07/kWh in North America and US$0,03 to $0,05 in Asia Pacific.[xvii] The lower and upper boundaries assume a finance cost of 5% and 10% respectively. Given the high upfront costs, the levelised cost of nuclear is very sensitive to capital costs.

A 2002 UK government report stated that power from the country's most recently built reactor costs about US$0,09/kWh (£0,06/kWh). It estimated that by 2020 the cost would have dropped to US$0,05 to $0,06/kWh, although the antinuclear New Economics Foundation has said such costs are dramatically underestimated and could mount to twice as much.[xviii] In May 2011 the UK Committee on Climate Change published its *Renewable Energy Review*, examining options for decarbonising the UK's electricity supply by 2030. The committee concluded that nuclear technology was the most cost-effective of the low-carbon technologies.

In the Integrated Resource Plan 2010 (IRP 2010) issued by the South African Department of Energy the overnight capital cost[3] of nuclear energy is estimated at R26 575/kW. The IRP also indicates that in 2020 the levelised cost for nuclear power is between R0,43 and R0,53/kWh, whereas coal would be R0,46 and gas R0,75/kWh. The final IRP document did note, however, that several comments were received that the nuclear costs are underestimated. Although the IRP figures are towards the lower end of the IEA estimates, it seems as if they are in the right ballpark. What is less clear is the extent to which all of the published costs exclude or underestimate the full cost of dealing with waste and the public liability insurance against accidents. The UK has budgeted an amount that equates to US$0,04/kWh for cleaning up all the nuclear power sites in that country.

[3] 'Overnight capital cost' is an estimate of the cost at which a plant could be constructed assuming that the entire process from planning to completion could be accomplished in a single day.

Figure: Capital and levelised costs for nuclear energy from various studies compared with coal and gas



Current plans and forecasts

In its 2010 baseline projection the IEA forecasts the use of nuclear energy to increase from 393 GW to 610 GW by 2050. In the BLUE Map Scenario, which assumes emissions are reduced by 50% by 2050, nuclear capacity rises further to 1 200 GW. In this scenario nuclear power accounts for 24% of the electricity generated worldwide. To achieve this would require roughly 23 nuclear reactors to be constructed each year up to 2050. While this is much higher than what has materialised over the last two decades, similar or higher rates of construction were achieved from the mid-1960s to the early 1980s. At the end of 2010 67 new power reactors were under construction in 14 countries.[xix] It takes between five and seven years to build a nuclear plant, compared with about four years for coal-fired plants (five years for the first phase of Medupi), three years for gas-fired plants and two years for wind turbines. The process of planning and licensing nuclear plants take about another five years, so the growth in capacity up to 2020 will be significantly below the BLUE Map growth rates, implying much higher rates thereafter. Most of the growth in nuclear capacity is expected to occur outside of the Organisation for Economic Cooperation and Development (OECD), with China, India and Russia currently having the most ambitious plans. The actual experience of lead times and costs in these countries will probably differ from that in the OECD countries, with Chinese and South Korean experience indicating shorter lead times and lower costs. In February 2012 the US government gave the first approval for the building of a new nuclear reactor in 30 years.

South Africa has had an operating nuclear plant (Koeberg) for many years. The Koeberg plant produced about 5% of all electricity in the country last year. In the 2000s there was renewed interest in nuclear power in the country as research was conducted into pebble bed modular reactors, but after many years the financial support for the project dried up.

Still, nuclear power has been prominently included in the IRP 2010 to the tune of 9,6 GW of new capacity coming on stream by 2030. That is just below 25% of the total additional electricity capacity.

New technologies

Multiple technology developments promise to address several of the main concerns with nuclear power. Most of the new nuclear reactors being built are known collectively as Generation III and are water-cooled thermal reactors. A more advanced technology, sometimes called Generation IV, is the fast-breeder reactor. Fast-breeder reactors can in principle extract almost all of the energy contained in uranium, decreasing fuel requirements by nearly two orders of magnitude compared with traditional reactors. This means fast-breeder reactors only need to be loaded with fissile material once and from then on they can keep recycling it, extracting ever more of its energy, until a small fraction of the waste remains. These reactors can also be fuelled with 'waste' from older reactors, of which the world has a massive stockpile. GE and Hitachi have together developed a fast-breeder reactor called PRISM that uses a sodium solution instead of water to cool the reactor. According to the companies PRISM is based on technology that was demonstrated in a fast reactor in the US called the EBR II (Experimental Breeder Reactor) that operated successfully for 30 years. GE/Hitachi has proposed to build a fast-breeder reactor in the UK as a way of dealing with its tonnes of nuclear waste and only charge a rate for every tonne of nuclear waste 'disposed' of. This plant will at the same time generate 600 MW of electricity. A fast-breeder reactor has been running in Russia for 30 years and similar plants are now being built in China and India.

As mentioned previously, another nuclear technology option is to use thorium instead of uranium to fuel the reactor. A 1 GW thorium plant would only require six tonnes of thorium per year, resulting in much less waste that would contain no uranium or plutonium, so the proliferation risk is eliminated. Several reactors have used thorium as an additive (several of these are in operation in India). An alternative nuclear reactor based on thorium, the 'energy amplifier', has been proposed by Nobel laureate Carlo Rubbia and his colleagues and this system would cut fuel consumption by a factor of 6.

Fast-breeder reactors, using either uranium or thorium, still have some way to go to convince regulators and financiers of their commercial viability. Those that have been operated have suffered from cost overruns and have had lower operational reliability than traditional reactors. Another alternative technology, proposed by TerraPower, is a travelling-wave reactor.

TerraPower is a project that developed out of Intellectual Ventures and has been publicly and financially supported by Bill Gates, as it could potentially overcome all shortcomings of Generation III and fast-breeder reactors. Even if the technology performs as promised, it will take about two decades before a travelling-wave reactor can be up and running. The majority of reactors commissioned in the next decade will therefore likely be based on Generation III technology.

THE BOON OR BANE THAT IS SHALE GAS

US businessman George Mitchell was an early admirer of the design and ecology work of Buckminster Fuller and in the 1970s he helped sponsor the work of Dennis Meadows, whose *Limits to Growth* study was a global wake-up call on the finite nature of energy resources and raw materials amidst an ever-growing population. Subsequently Mitchell has sponsored and donated money for several initiatives focusing on sustainable development, including the US Academies of Science's efforts in Sustainability Science.[xx] Yet, perhaps ironically, George Mitchell's best known legacy may be the development in the 1980s and 1990s of horizontal-drilling technology for natural gas. This technique, combined with hydraulic fracturing, makes it possible economically to extract gas from shale formations. This has radically changed the US gas industry and has the potential to transform the entire global energy picture.

The appeal of the current natural-gas boom is that it can potentially address the geopolitical risk in traditional oil and gas markets, it may offer a climate benefit over coal and it is relatively cheap – especially because it is compatible with existing infrastructure. Natural gas can in principle be used in all four major areas of energy demand: for heating in the residential sector, as feedstock in industry, to produce electricity and as compressed natural gas (CNG) or gas-to-liquid (GTL) fuel in transport.

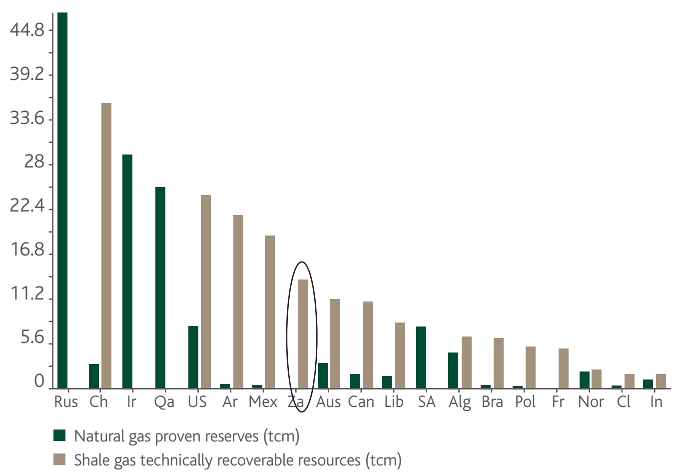
Despite George Mitchell's avowed commitment to sustainability, the exploration of shale gas has met significant, even violent, resistance from social and environmental groups. From Pennsylvania to Transylvania (Romania) and including the UK, France, South Africa, Australia and Bulgaria, there has been public protest against hydraulic fracturing or 'fracking'. In response some governments have banned it, others have placed a moratorium on further developments and many more are critically reviewing its merits and possible impacts.

Based on the possibilities presented by shale gas, the IEA produced a study entitled *Are we entering a Golden Age of Gas?* Faced with all the environmental concerns that have been expressed about shale gas, it has since published the *Golden Rules for a Golden Age of Gas*. According to a recent report in the *Financial Times*, the debate is currently locked in stalemate, with opponents taking an almost 'religious' stance against fracking, while gas companies deploy economic arguments to 'shut up' opponents. The proponents argue that shale gas can enhance global energy security and reduce CO_2 emissions by replacing coal over time. The opponents contest that the extraction of shale gas comes with great environmental risks, that its climate benefits are rather small and that is dependent on CCS technology that itself brings many challenges.

Energy security

Proven reserves of conventional natural gas at the end of 2008 totalled more than 180 trillion cubic metres (tcm) globally. Over half of these reserves was located in just three countries – Russia, Iran and Qatar. Proven reserves, however, are technically defined as those that are economically recoverable given current market conditions, therefore they represent only a portion of total resources in the ground; potential recoverable resources are estimated at more than 800 tcm. Unconventional gas, including shale, accounts for about 50% of this total. Of this total resource base about 40% is in the Eastern Europe/Eurasia and the Middle East, while almost 170 tcm can be found in OECD countries. The worldwide cumulative production of all natural gas up to the end of 2010 has been less than 100 tcm.[xxi]

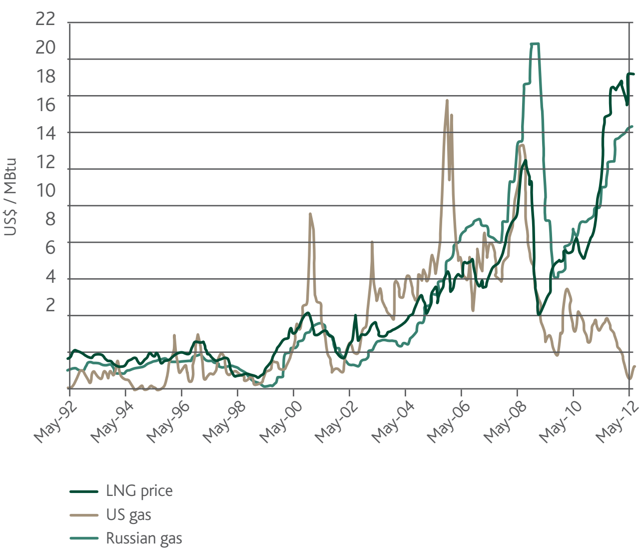
Figure: Conventional natural gas reserves and shale gas resources
Source: Financial Times



Total demand for natural gas in 2009 was 3,1 tcm (just less than 40% of that used in the electricity generation sector) and it provided about 21% of global primary energy. The proven gas reserves are thus equal to about 60 years of production at current rates, but the recoverable resources are equal to more than 200 years of current production. The World Energy Outlook (WEO) New Policies Scenario forecasts gas demand to increase to 4,8 tcm by 2035, but even under such a growth trajectory there would be ample gas resources way beyond 2050. Shale now supplies about a quarter of US natural-gas production and by 2035 half of US natural gas is expected to come from this source.

The boom in US shale gas, up from just two percent of the total in 2000, has cut gas prices to record lows, reduced energy imports and set the country on a path to energy self-sufficiency. What this has done, though, is create a great disparity in the global gas market. For most of the last two decades gas prices in the US and in Europe and the prices of liquefied natural gas (LNG) in Asia have moved broadly in lock step, the latter typically being a few dollars higher. Over the last three years the US gas prices have diverged significantly, though. At the end of May 2012 the gas price in the US was US$3,14 per million British thermal units (MBtus),[4] whereas European prices were US$16,35 and LNG prices in Japan US$19,18. This massive price differential persists because there is still limited gas export capacity in the world and virtually none in the US.

Figure: Prices of natural gas in the US and Europe (piped from Russia) and LNG imported into Japan (all in US$/MBtu) | **Data:** IMF



South Africa has only tiny proven reserves of natural gas, off the coast of the southern Cape, which is used by PetroSA to produce diesel through its GTL plant just outside Mossel Bay. The country produced about 3,3 billion cubic meters (bcm) and consumed about twice that amount in 2008. Over the last decade Sasol has built a pipeline to import natural gas from neighbouring Mozambique. New finds that were recently made off the Mozambican coast are expected to total as much as 2,8 tcm. Compared to the tiny amount of conventional gas, the US Energy Information Agency (EIA) has estimated that South Africa could have shale resources approaching 13,6 tcm (or 485 trillion cubic feet), about 1,7% of the world total. The Petroleum Agency of South Africa estimates the reserve to be only 10% of that figure – still a significant amount. A recent Econometrix study, commissioned by Shell South Africa, worked on two test scenarios of gas resources totalling 0,56 tcm and 1,4 tcm (about 4% and 10% of reserves) respectively.

Environmental concerns

Writer Tom Wilber recently wrote at the Dot Earth blog on the New York Times website about shale gas: 'We are aware of the benefits as spelled out by industry proponents – cheap fuel, energy independence, jobs, an alternative to dirty coal. Now we need a complete and honest discussion about the impacts of shale gas development on environment and health.' [xxii] The biggest environmental concerns related to shale gas are around surface water and ground water pollution, fugitive emissions, the infrastructure required for drilling and the possibility of earthquakes.

Surface water

Huge ponds or tanks are required to deal with all the flowback water associated with the fracking process. A single well requires 9 to 29 million litres of water and up to 180 000 to 580 000 litres of chemicals. Anywhere between 15% and 80% of the injected water is brought back to the surface, and this water contains the chemicals and often elevated concentrations of heavy metals and naturally occurring radioactive materials. Most of this water is produced in the first few months of production and, as it is toxic, must be recycled or processed at waste water treatment facilities, or disposed of through reinjection. Pollution risks are therefore similar to those of other hazardous waste water facilities.

Ground water

The biggest environmental concern related to shale gas is the contamination of ground water due to the structural failure in the cement casings of the wells. When this happens, the fracking chemicals as well as the methane (natural gas essentially consists of methane molecules) itself can pollute ground water. University of Free State researcher Prof Gerrit van

[4] One billion cubic metres (bcm) are equal to 35 700 000 MBtu; $3,14 per MBtu is thus equal to $112 098 000 per bcm. One MBtu is also equal to about 293 kWh.

Tonder recently wrote: 'There is no doubt that the fracking well casings will fail, sooner or later. There is proof of this. That is why I say that contamination is absolutely inevitable and it will be one of the biggest water pollution disasters in the world. South Africa is so short of water. We cannot risk this.' [xxiii] Furthermore, environmentalists suggest that there also remains the possibility of cracks in the shale formation caused by fracking operations to connect with numerous natural faults in the local geology to allow gas and fracking fluid to make its way up the various rock formations and find their way to the aquifer over a prolonged period of time.[xxiv]

According to the *Financial Times*, there is so far little evidence that fracking automatically causes such damage – but more than enough to suggest poorly constructed wells are a threat and that a clear need exists for more research to establish the practice's impact more precisely. A review by Massachusetts Institute for Technology researchers concluded last year: 'With over 20,000 shale wells drilled in the last 10 years, the environmental record of shale gas development has for the most part been a good one – but it is important to recognise the inherent risks and the damage that can be caused by just one poor operation.' [xxv] Prof Bill Chameides, dean of the School of Environment at Duke University, writes: 'There are those (who) say that there is no credible documentation that drilling and fracking have contaminated people's well water. They're either intentionally or unknowingly sticking their heads in the sand. I have a hard time believing that all the water problems I heard about during my visit were either coincidence with nothing to do with drilling or were made up by people trying to make a fraudulent buck. It's clear to me that at least sometimes drilling in Pennsylvania has caused water contamination with disastrous results for families and communities.' [xxvi]

Fugitive emissions

Gas contains about 40% less carbon than coal for every unit of energy, but given the typically higher efficiencies of gas-fired over coal-fired turbines, electricity from gas produces less than half of the CO_2 emissions per kWh associated with coal power. However, a concern with shale gas is that methane could escape during the drilling process. Methane is a much more potent greenhouse gas than CO_2 and if significant amounts of the gas escape, then the climate benefit can be cancelled out and even reversed. A study by Howarth et al from Cornell University that found the lifecycle emissions of shale gas to be higher than coal has been vigorously disputed by the industry. A separate study released by the US Environmental Protection Agency (EPA) calculated that the lifecycle CO_2-equivalent emissions from unconventional gas are 22% higher than the emissions when only considering enduse. ProPublica reviewed the EPA emissions report and concluded that natural gas may be at best only 25% cleaner than coal.[xxvii]

Drilling impact

Compared with conventional gas, the distance between drilling wells for shale gas is much smaller (two to four times), meaning there is a greater concentration of wells in a specific area. Additionally, the decline rate of shale gas wells is much higher than in conventional drilling, so a single well has a shorter life expectancy. Conventional gas wells typically decline by 25% to 40% in their first year of production, whereas for shale gas the decline rate is much higher, typically between 63% and 85% in year one. The physical infrastructure requirements and movement of equipment and trucks are therefore greater for shale than for conventional gas, but possibly smaller than for some forms of coal mining.[xxviii]

Earthquakes

Recently opponents to fracking have seized on the findings of an independent report in the UK, namely that it was 'highly probable' that a recent tremor felt in Blackpool, Lancashire, was indeed caused by hydraulic fracturing. Even more recently it has even been claimed that an earthquake in Ohio measuring 5.6 on the Richter scale was also linked to fracking activity and the return of waste water in particular. It is unlikely, however, that seismic events caused by fracking will be of sufficient magnitude to cause structural damage on the surface, but structural damage to drilling wells could and have been caused.[xxix]

Golden rules

In 2012 the IEA launched its *Golden Rules for a Golden Age of Gas*, outlining best-practice principles that should be applied to minimise the environmental impact from shale gas production.

The golden rules are:

- Measure, disclose and engage – establish baselines for key environmental indicators prior to commencing and measure and disclose operational data.
- Watch where you drill – choose sites to minimise impacts on local communities and the ecology.
- Isolate wells and prevent leaks.
- Treat water responsibly – reuse or recycle water where possible and minimise the use of chemicals.
- Eliminate venting, minimise flaring and other emissions.

- Be ready to think big – seek opportunities for coordinated development to reduce environmental impacts.
- Ensure a consistently high level of environmental performance – pursue continuous improvement of regulation and operating practices.

The report estimates that applying the golden rules would add about 7% to the cost of developing a typical shale gas well. For larger projects with multiple wells the additional investment might be offset by lower operating cost and capturing more gas.[xxx]

Economics

The surge in shale gas production in the US has significantly changed the economics of natural gas in that country and can possibly change the global market dynamics. Over the last four years the price of gas has fallen by 75% in the US while staying broadly flat in Europe. This drop in price has made many electricity producers in the US switch from coal to gas for financial reasons. Current US prices are, however, not sustainable, as they are below the breakeven cost for unconventional gas. An analyst from Bernstein Research in New York believes that the full cost of finding, developing and operating shale gas wells, and paying an average return on capital to investors, requires a spot gas price of around US$7 to $8/MBtu.[xxxi] The IEA Golden Rules report indicated the breakeven point for shale gas in the US at $5 to $7/MBtu. In Europe the expected breakeven point is US$5 to $10/MBtu. This compares with the breakeven point of less than US$2/MBtu for conventional gas in Russia and Qatar.

The price of gas is a very important determinant in the feasibility of gas-fired power stations. A 50% change in the gas price could impact the levelised cost of electricity by more than 30%, while a similar variation in coal price only impacts cost by 10%.[xxxii] In 2010 the investment cost to build a natural-gas combined-cycle plant was about $900/kW and it was expected to drop to $750/kW in 2050. The 2011 WEO calculated an average levelised cost of electricity from gas turbines at about US$0,075/kWh in the OECD countries,[5] slightly higher than that of coal-fired power stations. This is based on a coal price (per tonne) that is between six and 10 times higher than the gas (per MBtu) price. In 2010 Eskom spent on average about US$25 per tonne of coal,[xxxiii] implying that, if the same economics were to hold for South Africa, a gas price that is competitive with coal should be in the region of $2,50 to $4,20/MBtu. Above that, the cost to produce electricity from gas-fired power stations will be higher than that of coal.

The IRP 2010 estimated the levelised cost of electricity in 2020 from a combined-cycle gas turbine as R0,75/kWh, of which about 80% is made up of the fuel cost. This compares with a cost of R0,43 to R0,53/kWh for nuclear power and R0,46/kWh for coal. The IRP plans for the building of 2,4 GW of combined-cycle gas turbines by 2030.

Carbon capture and storage

Renewable energy and nuclear energy are both considered near-zero-emission sources of electricity. The mining of uranium is not a zero-emission process, but it is likely in the same order as the operational emissions from drilling gas, excluding fugitive emissions from gas that escapes, and can therefore be ignored for the purpose of this analysis. Burning natural gas to generate electricity does, however, release emissions of about 370g CO_2/kWh (about half that of coal-fired plants in OECD countries, but 60% less than the Eskom average). Based on preliminary scientific evidence, it appears the emissions of shale gas are higher than conventional gas due to the amount of fugitive emissions. To compare gas with nuclear energy as competing 'bridging technologies' towards a zero-carbon electricity sector it is thus necessary to consider what it will take to eliminate virtually all the emissions from gas. With CCS it is estimated that the emissions from gas-fired power generation can be reduced to as low as 55g CO_2/kWh, which is low enough to make a fair comparison with other near-zero carbon energy technologies.[xxxiv]

CCS – the practice of capturing CO_2 emissions, concentrating them and then burying them in some deep, underground reservoir – has been applied commercially in the oil and gas industry for several decades, but is still an emerging technology in the power sector, where it has not yet been demonstrated on a large scale. Current estimates of the cost and performance are therefore based on small-scale plants and eventual experience could differ significantly. The IEA BLUE Map Scenario sees CCS contributing 19% cumulatively to emission reductions up to 2050. This requires 79 Gt to be captured from the power sector. Despite all the promise of CCS, several concerns remain.

The first big issue is the energy penalty involved in CCS. For a gas plant it is about eight percentage points or 15% overall and for coal it is about ten percentage points or 25% overall. This means the practical efficiency of a gas plant decreases from about 56% to 48% and a coal plant from 41% to 31%.[xxxv] Secondly, the capital cost of a CCS-equipped plant is significantly higher – about 82% for gas-fired plants and 74% for coal-fired plants. The combination of these two factors means that the levelised cost of electricity increases by 33% for gas – from US$0,075 to US$0,100/kWh.[6]

[5] Their estimates for gas prices are $10,4 in Europe and $6,7/MBtu in the US (real terms).
[6] The cost of CO_2 emissions avoided works out at US$80/t$CO_2$.

Finally, there is concern about what it would require for CCS to play a significant role in reducing emissions. Prof Vaclav Smil from the University of Manitoba commented in *Nature*: 'To sequester just 25% of CO_2 emitted in 2005 by large stationary sources of the gas … we would have to create a system whose annual throughput (by volume) would be slightly more than twice that of the world's crude-oil industry, an undertaking that would take many decades to accomplish.' The IEA remarks that more than 30 Mt of CO_2 is transported in pipelines in the US every year. To meet its own projections of CCS in the power sector about 100 times that quantity would need to be transported globally by 2050.

George Monbiot expresses his concerns about assumptions regarding CCS: 'The likelihood is that, if we press for gas with CCS, we'll get gas without CCS. As the difficulties with CCS mount up, investors will flee. But the gas plants will still be built and the public won't perceive a great deal of difference between gas with or without abatement.' [xxxvi]

South Africa has developed a Carbon Capture and Storage Atlas for the geological storage of CO_2 in the country. The Atlas highlights, at a theoretical level, that South Africa has about 150 Gt of storage capacity. The largest storage volume, representing about 98% of the total storage potential, is situated along the coast of South Africa, in the capacity of saline formations in the Outeniqua, Orange and Durban or Zululand basins.[xxxvii] Depending on the location of new power plants, there could be a significant logistics cost involved in storing the carbon offshore. Current plans foresee a first commercial CCS project in SA operating by 2025. [xxxviii]

AVOIDING DANGEROUS CLIMATE CHANGE

The primary goal of the United Nations Framework Convention on Climate Change (UNFCCC) is to avoid dangerous climate change. What exactly constitutes 'dangerous' was not defined until COP15 in Copenhagen in 2009. There the parties adopted the goal of keeping the increase in global temperature, over the long-term preindustrial average, to below 2 °C. Many scientists believe that 2 °C warming is already dangerous, but this threshold was reaffirmed in Cancun in 2010 and Durban in 2011.

The Fourth Assessment Report from the IPCC (2007) stated that a reduction in emissions of between 50% and 85% from 2000 levels by 2050 is probably **not** enough to keep the increase in temperature below 2 °C. This means, on a per capita basis, that the cut from current levels must be greater than 71% to 91%. For all practical purposes, therefore, emissions may have to be reduced to zero by 2050.

Another way of approaching emission reductions is in terms of a carbon budget. To limit the probability of exceeding 2 °C to 50% scientists have calculated that the world can emit only 1 440 Gt of CO_2 between 2000 and 2049. [xxxix] Between 2000 and 2009 we have already emitted about 264 Gt, so there remains just 1 176 Gt of the budget. Given the current emission levels of about 31 Gt per year (energy only, excluding land use change) on an upward trajectory, it is unlikely that emissions will decrease significantly in the next decade, thus requiring aggressive reductions in the following decades, to near-zero emissions by 2050. To avoid 'dangerous' climate change we therefore have a fixed amount of carbon that we can emit in the next 40 years and have to get to near zero by mid-century.

This provides a useful framework when assessing our energy options going forward. It makes clear that we absolutely cannot continue to increase carbon emissions and that the earlier we start reducing emissions, the more time it buys us for complete decarbonisation. But, no matter how the sums are done, eventually we have to phase out all forms of CO_2 emissions. Shell in its *Blueprints* scenario acknowledges that achieving 2 °C will require a near-zero energy sector by 2050.[xl] There are experts who believe that a 50% probability of breaching the 2 °C threshold is unacceptably high and some who believe that we cannot avoid staying below 2 °C anymore. Given the rapidly escalating impacts of warming beyond 2 °C, this should serve as a reason to increase efforts rather than relaxing. Aiming for 2 °C, just missing it or stabilising at 2,2 °C, for example, is a much better outcome than arriving at 3 °C.

It goes without saying that the world needs energy and at the same time needs to reduce its CO_2 emissions drastically. South Africa faces the same challenge. We therefore need low-carbon energy, but it must match the demands of consumption, particularly for industry. Despite the promise and attraction of renewable energy, there still appears to be a need for some baseload power that can provide a 'generating bridge' over the next few decades. Coal-fired power stations emit the most carbon and therefore do not fit the bill, which leaves gas and nuclear energy as the two most likely contenders.

The South African Climate Change Response White Paper (2011) also incorporates a budgeting approach in dealing with emission mitigation in the country. According to this, the indicative greenhouse gas budget (for all greenhouse gases, not just CO_2) from 2010 to 2049 is between 15,5 and 22,5 Gt CO_2-equivalent.

Historically just more than 75% of South Africa's greenhouse gas emissions were CO_2, so the corresponding carbon budget would be between 11,9 and 17,2 Gt CO_2. In assessing future energy options for South Africa this carbon budget provides an important analytical lens. What could the impact of gas be in terms of the country's carbon budget?

Using the scenarios of 0,56 tcm and 1,4 tcm gas reserves as per the Econometrix study, burning all of it in South Africa will emit 1,13 Gt and 2,82 Gt CO_2 respectively. If all of this were used in gas-fired power stations, then it can in the 30 years between 2020 and 2049 produce the equivalent of either 16,7% or 41,7% of the country's electricity demand, should demand stay at the current level. Given that gas-fired power stations emit about 50% of the CO_2 of coal-fired power stations, the corresponding reduction in emissions would be 1,13 Gt and 2,82 Gt CO_2. (This calculation excludes the possible fugitive emissions from shale gas.) This is a rather significant mitigation impact, but unlike renewable or nuclear energy, gas can never be a carbon-free source of power, unless gas-fired power stations are equipped with CCS. If the world's energy system has to be close to zero by 2050, then it is essential that gas-fired power stations that operate then are equipped with CCS. To the extent that South Africa wants to increase electricity usage from current levels, in line with global expectations, it might be necessary that all additional generating capacity, beyond the existing fleet, is carbon neutral, thus moving the CCS requirement for gas forward.

South Africa has to decide whether to proceed with the exploration and possible production of shale gas. The IEA's golden rules provide some valuable guidelines for minimising the environmental impacts of shale gas production, but it is silent on how the gas is used. From the perspective of meeting climate change goals and getting the most energy services from the limited carbon budget, the enduse is a critical factor. Should local shale gas producers export the gas as LNG, it would contribute neither to local energy provision nor to lowering the carbon intensity of the country (apart from possibly increasing it through fugitive methane emissions). If the gas is used for gas to liquids (GTL), similar to PetroSA, to replace imported crude oil, then there is a big balance-of-payments benefit for the country, but no emissions benefit. GTL has the same lifecycle emissions as fuels derived from crude oil. Given that 80% of those emissions are at the tailpipe and not at the refinery/ plant, the majority of them can never be captured. Using gas as liquid fuel could therefore never form part of a zero-carbon economy.

EITHER, NEITHER OR BOTH?

In one of his responses to Jonathon Porritt George Monbiot wrote: 'So the only question which divides us is how this low-carbon electricity should be produced. I don't much care about which technology is used, as long as the other impacts are as small as possible, and greenhouse gas emissions are reduced quickly and efficiently. None of our options is easy and painless.' [xli]

There are indeed different forms of 'pain' involved with both nuclear energy and gas as part of a low-carbon energy mix. With nuclear energy there is the risk of radiation caused by an accident at a nuclear plant or during the waste disposal process. There is also the risk that nuclear power production could serve as a pretence for producing nuclear weapons. Furthermore, building nuclear plants is very complex, typically takes many years and requires significant upfront capital outlays. Any delays, cost overruns or safety problems can quickly turn the economics from a very competitive source of electricity to an expensive one. Newer, better nuclear technologies are in development, but will most likely not be rolled out in the next 20 years and can therefore not really be considered in terms of a 'generating bridge'.

Nuclear energy does, however, produce near-zero carbon electricity. When recently asked by *Yale Environment 360* if the world community can prevent serious climate change without using nuclear power, Fatih Birol, the chief economist of the IEA, said 'Absolutely not.' [xlii] In similar vein, David MacKay commented: 'I think it's already so difficult to reach the 2050 targets, even with nuclear, that assuming that nuclear is off the table just makes the whole pressure of keeping the lights on and taking climate change action even harder.' [xliii]

Producing electricity from natural gas is generally accepted by most people, as it is a much cleaner process than burning coal and only emits about half of the CO_2. Conventional gas reserves are, however, very concentrated in the world, and fairly limited, making it a difficult and/or very expensive option in many countries. Shale gas reserves are, however, available in many more parts of the world, changing the economics and geopolitics of gas. But there are numerous environmental concerns and strong social opposition to shale gas and it might have a smaller-than-expected CO_2 advantage over coal. As the demand for zero-carbon energy increases, gas-fired power plants will have to be equipped with CCS in order to be viable.

CCS does, however, have its own drawbacks, particularly as it imposes a significant energy penalty (due to loss of efficiency) and drives up cost by up to 80%. The large-scale rollout of CCS for power plants is still unproven and the supporting infrastructure will take decades to roll out, subtracting from its potential role as a 'generating bridge'.

Many experts do, however, see gas as crucial. On the eve of the recent Rio+20 conference Kendeh Yumkella, cochair of the UN's Sustainable Energy for All Initiative, came out in support of shale gas: 'Natural gas, including non-traditional shale gas, should play a major role in cutting greenhouse gases, protecting forests and improving the health and living standards of the world's poor. Without it, the UN's Sustainable Energy for All Initiative will have difficulty meeting goals of ensuring universal energy access, doubling the world's share of renewable energy and doubling the rate of improvement in energy efficiency by 2030.' [xliv] As a challenge to Josh Fox, the maker of the film *Gasland* and vocal shale gas opponent, Andrew Revkin, wrote: 'You lay out — for the Northeast, the United States, or the planet — a real-world energy plan (how many wind turbines or PV panels, how to store that power for when it's needed, etc.) that *doesn't* include a substantial role for natural gas and I'll cross it off my list.' [xlv]

It is no easy task to find a balance between energy supply needs, energy cost, climate change concerns and minimal environmental impacts. Outlining possible energy pathways has conventionally been the domain of economists modelling the costs and social benefits of different technological options based on information supplied by engineers. In other words, it has been a rational, numbers-based exercise that seeks the most efficient outcomes. But that stereotype has perhaps never been quite accurate. Not only does energy economics always involve a dimension of political choice, but also, to use George Monbiot's words: 'You think you're discussing technologies, you quickly discover that you're discussing belief systems. The battle among environmentalists over how or whether our future energy is supplied is a cipher for something much bigger: who we are, who we want to be, how we want society to evolve. We choose our technology – or absence of technology – according to a set of deep beliefs; beliefs which in some cases remain unexamined.' [xlvi]

As this analysis has attempted to show, with a few important exceptions, there are good sources of data and fairly reliable estimates of cost and performance relating to most energy pathways open to South Africa at this point. What has perhaps been missing from much of the public discourse has been a framing logic that can help with the assessment of political priorities and the 'belief systems' Monbiot refers to. It can be argued that the idea of a global budget for the carbon that can safely be emitted in the coming decades – and the country-scale budgets that flow from that – provides decisionmakers in all spheres with that framing logic. The carbon budget approach already contains in it carefully considered judgements, based on decades of scientific research, about the costs and benefits of reducing emissions compared with the socioeconomic risks and impacts of climate change.

Applying the logic of the carbon budget to different energy pathways can throw light on their different characteristics in ways that conventional cost-benefit analyses cannot.

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