DOI number: 10.5027/jnrd.v2i0.07

JOURNAL OF
NATURAL RESOURCES
AND DEVELOPMENT

Energy options from the 20th Century: Comparing Conventional and Nuclear Energy from a Sustainable Standpoint

Eric Ndeh Mboumien Ngang[a,b*]

[a] Student, Masters of Environmental Management and Sustainability, University of South Australia, Australia.

[b] Founder Action Group on Governance and Environmental Management (AGGEM) Cameroon, P.O. Box 1132, Bamenda, Cameroon.

*Corresponding author: ngangeric@yahoo.com

Article history

Received 18.07.2012
Accepted 24.09.2012
Published 09.11.2012

Keywords

Conventional energy
Nuclear energy
Sustainability

Abstract

Different Energy options have been the driving force for the world economy with an evolution in types and sources. Decades ago choosing what energy option to use did not call for much debate as issues of sustainability, pressure on our environment, and our climate were not a major concern. However today, humans have to grapple with these current global challenges especially those exacerbated by our current sources of energy. The review article argues that science and sustainability thinking should be the basis for making the choice about what energy option is suitable for our era. It proposes that a more fruitful discourse should follow from a dialogue that puts in place the set of sustainability indicators and evaluating the suitability of the options for our era in that context. Focusing on two energy options; conventional and nuclear energy; the review compares them based on a set of sustainability indicators including, but not limited to, the environment, economics, ethics, expertise requirements, technical information, health, safety, uncertainty and government funding. In trying to answer the question Unsustainable conventional energy sources, is nuclear energy similar?, the review concludes that despite the demerits of nuclear energy, it is the solution to meet the world's growing energy needs and to reverse the impending threat posed by climate change if research and development efforts in the sector are accelerated.

Introduction

The discovery and use of new energy sources has been central to human's survival through the different stages leading up to the industrial and technological era. The quest for more and efficient sources was the motivation for the use of biomass (wood), through harvesting the wind to steer ships, to the use of energy from the combustion of coal, oil, gas (Nakicenovic and Grubler 2000, p. 5). The base load electricity generated from these sources has been the main energy source in driving most aspects of modern life and recently, directly used in transportation and domestic heating sector by some countries (Bodansky 2004, p. 5).

The conventional energy sources (coal, oil and gas) have progressively been the major contributors to the world´s energy base since the 18th century, with the nuclear energy and renewable sources becoming prominent in the past three decades (see figure 1). Per capita energy consumption rate is growing every year in line with the world demography -3.5 to 5.5 billion people in 1970 and 5.5 to 7 billion in 2011, with a projected 8 billion in 2025 and 9.3 by 2050 (Mohammad 2012, p.34; Hinrichsen 2012). Many authors assert that rising consumption of energy from conventional sources will further compound efforts to reduce or reverse their environmental, social and economic impacts on the globe (CDIAC 2012, ENERGYNEWS 2010; Wilson & Burgh 2008; Evans et al 2009; Ola E, and Bjorn F 2001,).

Richard C. J Somerville, of the Scripps Institute of Oceanography, University of California San Diego in the foreword to Catherine Gautiers book title Oil Water and Climate Change says "the fuel age will surely end, and it will end sooner rather than later just like the stone age which did not end because we ran out of stones" Gautier (2008, p. XVIII). The challenges posed by global warming and climate change are one of the high priority issues in most political and development arenas today. Anxiety is on the rise over global and national energy prices hitting record high. Demand is increasing, linked to rapid growth in population, urbanisation and industrialisation, and coping with the diminishing finite base load materials for energy production. If the world energy-intensive economy was to come to a halt due to non availability of fossil fuels to meet up with energy demand, there shall be dramatic consequences for human civilisation.

Many suggestions and recommendations have been made calling on action to be taken now, by considering other energy options as the world risk facing belated responses to find substitutes for existing conventional reserves especially exploration and exploitation of new field which would culminate in huge financial and environmental costs (Goodstein 2004, p. 123). However, adoption of nuclear energy, a sound option from a sustainable point of view, with a real potential to solve the world energy crisis faces numerous barriers which are not scientific or factual, with its opponents calling for its non-adoption. Figure 1 shows the gives a comparison of percentage energy consumption by energy type as of 2006.

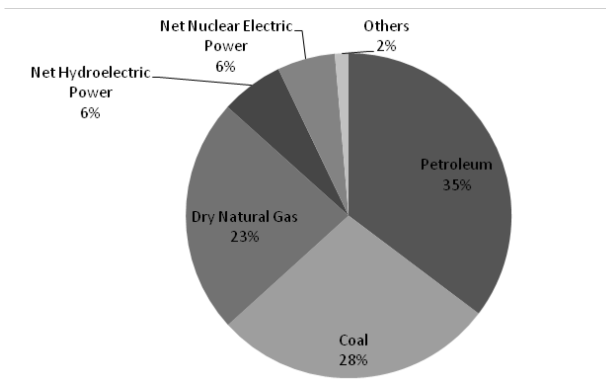

Figure 1. Global consumption by energy type as of 2006 (BP/EIA 2006)

In this review article, the concept of sustainability is used in a holistic manner, to answer the question "Unsustainable conventional energy sources, is nuclear energy similar?" In our era, it is crucial that a chosen energy options must respect some indicators linked to the three facets of sustainability - economically, socially and environmentally acceptable. Most discourses from the 90s focussed more on the physical depletion of the raw materials rather than on how the options were sustainable. It will be argued in this article that this is not a good basis for choosing a sound energy option from a sustainable perspective especially at this time when our use of conventional energy is a threat to the earth's stability.

The first part of the article will define sustainable development and identify some sustainability indicators which will be used throughout the paper. The second part will compare conventional energy and nuclear energy based on the set of indicators and ascertains that nuclear energy has the potential address our current and future energy challenge and looks at the prospects of development of the sector. The review ends with a conclusion including some proposals to make nuclear energy a realistic option within the confines of time to save the planet from the predicted climate catastrophe.

The meaning of sustainability development and its relevance to the energy sector

There is a greater will than ever before to handle the balance between human's quest for more energy (electricity) and lessening the social, environmental and economic impacts this causes on the Earth. This need for balance is the basis for sustainability. The notion of 'sustainability' was first used in 1972 in the publication The Limits to Growth (Goldie et al 2005 p. 2; Davidson 2011, p. 7). Attempts have been made in the last three decades to define sustainability in a comprehensive way. The most revered is the definition contained in 'The Brundtland Report'; which merges the notion of 'sustainability' and 'development' and defines it as "development that meets the needs of the present without compromising the ability of future generations to meet their needs" (WCED 1987, p. 43). Many scholars have criticised this definition as a political economic ideology and that it obscures the connections between the three facets of sustainability (Davidson 2011, p. 7; Goldie et al 2005, p. 3). They claim that it fails to recognise the stress on the finite natural resources in meeting the 'needs'; while spelling affluence for everyone now and in the future.

This ethically grounded concept, whose meaning is not fully understood, lacks standardised approaches, methods, and indicators for its assessment. Thus the full consequences on the planet on which human existence depends as a result of not paying closer attention to the assessment component of sustainability are not fully known or elaborated (Davidson 2011, p. 10; Stamford 2010, p. 6037; Goldie et al 2005 p. 13). Sustainability thinking, one that takes into account the environment, social, and economic impacts of human actions today, includes choosing what energy option to depend on. This is particularly relevant now as our present energy options are contributing to global environment, social, and economic instability. Different authors have proposed varied indicators and parameters for sustainability assessment for different energy options, hinged to the three sustainability facets throughout energy life cycles. For example, Evans et al (2009, p.3) although have not done a comparative analysis of different energy options, proposes 8 sustainability parameters to assess renewable, nuclear and fossil fuel electricity generated technologies. On the other hand, Stamford (2010, pp. 6039-6042) proposes 41 sustainability indicators under the three sustainability facets, applicable to the nuclear power life cycle stages. These authors and many others agree that although harmonised and standardised approaches for assessing and comparing sustainable energy options do not exist, they propose that any approach adopted must incorporate economic, environmental and social indicators and not only a consideration of base load availability, energy security, and climate change issues (Stamford 2010, p. 6037; Ola, E, and Bjorn, F 2001, 521-523, Nakicenovic and Grubler 2000, p. 11, Makhijani 1996, pp 14-15).

Some authors have presented a rather controversial point of view when looking at nuclear energy and fossil fuel energy from a sustainable standpoint. For example Jaccard (2005, p. 8-11) says a closer look at the energy sources makes it difficult to stick to a classification that separate nuclear and conventional energy. Rather he sees both as the same given that the originate from the activities of solar conversion, and thus need to be seen as having the same impact on the environment with the only difference being the type of technology use to generate energy from the similar base load materials that are both finite (nuclear by fission and fossil fuels by combustion). However the same author presents an interesting definition to sustainability within the context of energy by saying it needs to be looked at as a system – as the combined processes of acquiring and using energy in a given society or economy and spells out two conditions for an energy system to be considered sustainable. These include;

- It must have the prospect to endure indefinitely with respect to the type and level of energy services it provides (lighting, space conditioning, washing, drying, cooking, communication, education, information, driving industrial process and other sectors of the economy, and with a potential meet the world rising demands.
- The cumulative impact of the processes of the energy production and use (extraction, transformation, transportation and consumption) must be negligible on people and ecosystems. Any extraordinary risk it poses must be significantly unlikely, with the systems likely to recover within minimum time with the support of minimal rehabilitation efforts.

In this review article, indicators including; cost which is often cross-cutting from construction through commissioning and decommissioning, availability of raw material, waste generation and management, safety, risk perception and risk reality, terrorist attack and proliferation, actual and potential occurrence of accidents, emergency response and technology, also cross-cutting indicators are used to compare the two energy options.

Conventional energy sources: sustainability considerations

Conventional energy sources, also referred as fossil fuels, include coal, oil, natural gas, oil shales, and tar sand. Coal, oil, and natural gas are considered less expensive to produce and constitute the global energy mainstay today (Kaufman and Cleveland 2008, p. 420). Figure 2 shows the global level of fossil fuel production as at 2009. Their mining, extraction, transportation, and combustion for energy generation have unfavourable social, environmental and economic impacts (Grover 1980, p.45).

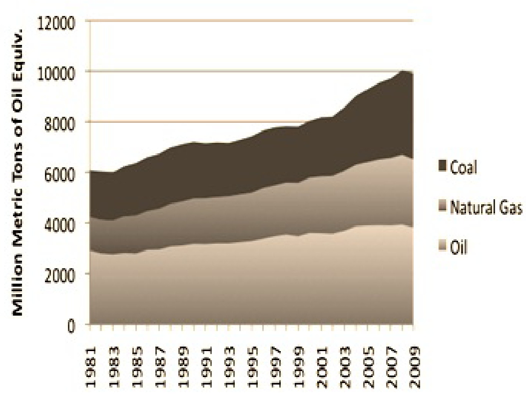

Figure 2. Global fossil production (BP 2009)

Coal

Coal was the first fossil fuel to be used and its usage rapidly grew with technological innovations in the steam engines in the 17th and 18th Centuries. It was also the main energy source for the first century of the Industrial Revolution (Kaufman and Cleveland 2008, p. 421; Vaclav 2003, p. 20). Underground and surface strip mining of coal has many impacts including top soil removal, toxic releases, deforestation, water contamination, cancer clusters in downstream communities with its combustion generating 43% (12.5Gt) of global CO2 in 2009 (IEA 2011, p 8; Wiegman 2009, p. 123; National Academy of Science 2009, p.408). The mortality rate of coal workers is higher (for example in the US, 1,000 miners die each year) and although coal contains low levels of naturally occurring radioactive isotopes (Uranium and Thorium), the burning substantial amounts of coal release potentially dangerous amounts than nuclear power (Wiegman 2009, p. 123).With respect to the cost indicator, it is asserted that coal is not an asset that can be tapped in a rush as it takes close to 10 years to open a new coal mine, at least 10 years put forward mining process innovation, a generation to innovate coal usage and another to retrofit or scrap out-dated plants or replace with technological innovations (Grover 1980, p. 83).The author says this demerits associated with the use of coal is often given a politico-environmentalists undertone in debates on sustainable energy options.

Oil

Oil, another fossil fuel, was predominantly used in the second Century of the Industrial Revolution due to its increase accessibility, ease to exploit, transport and use with a higher energy density than coal, requiring less storage space (Kaufman and Cleveland 2008 p. 421; Vaclav 2003, p. 18). Oil exploration and extraction disturbs wildlife breeding grounds, coastal and arctic ecologies, it is a messy process that degrades the land, especially river estuaries and forest ecologies. Oil transport often results in huge spills that contaminate coastlines and refineries emit carcinogens such as benzene with on-site burning and combustion in other energy processes. Oil generated 37% (10.6%) of CO2 in 2009 (IEA 2011, p. 8; Wiegman 2009, p.123)

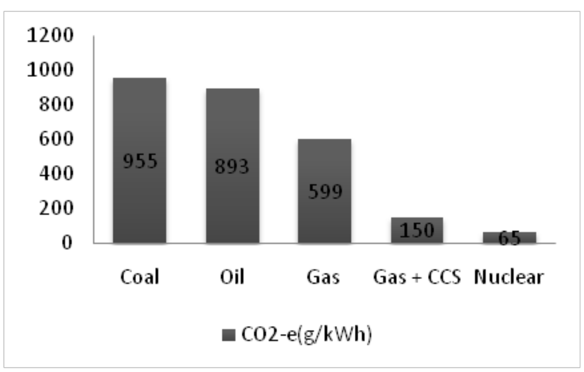

Figure 3. Comparative emissions by energy type (Adapted from ENERGYNEWS 2010 p. 69)

Natural Gas

On the other hand, the use of natural gas became predominant in the last half of the 20th Century. It generated 20% (5.8Gt) of global CO2 in 2009 (IEA 2011, p. 8). Its natural tendency to flow spontaneously to the surface, ease in transportation via pipelines, compressibility, ease to store, with a high energy potential, and less polluting offered advantages over coal and oil. Natural gas in different forms is used in the transport sector, and extensively used in domestic heating. It has been revered as the most reliable and environmentally friendly of the fossil fuels. It has low sulphur content, pollutants can easily be stripped off before gas is channelled through pipelines, and its combustion releases the lowest amount of CO2 per unit of energy compared to the other conventional sources (Energynews 2010, p.69; Bodnasky 2004, p. 7; US EIA 2004; Vaclav 2003, p. 20). See figure 3 and 4 compares global emissions from conventional energy sources and nuclear energy which shows the marked contribution made by net amount from the conventional sources which is projected to increase through 2030 (Figure 5).

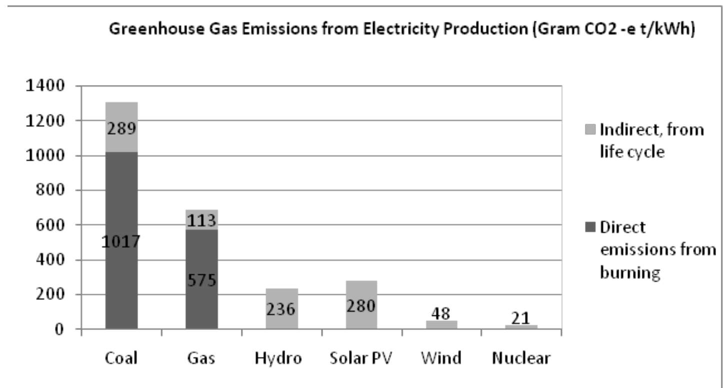

Figure 4. Greenhouse gas emissions from electricity production using different sources (IAEA 2000)

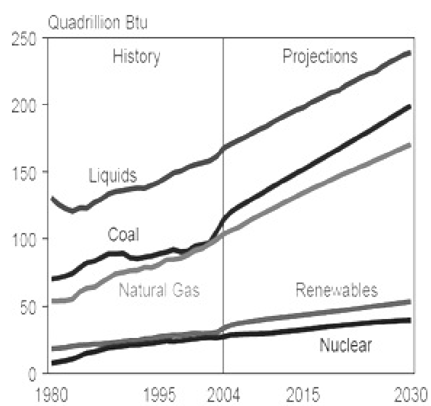

Figure 5. World Marketed Energy use by Fuel type, 1980-2030 (US Energy Information Administration –EIA)

Debates on the finite nature of conventional energy sources

The conventional energy sources represent a unique and finite source of organic chemicals. Views are diverse on how long these resources will last as it will depend on two not easily predicted factors including discovery of new oil, coal and gas fields and world consumption which is projected to rise by 1.8% annually during the period leading up to 2030 (US Department of Energy, cited in Kaufman and Cleveland 2008, p. 436). Some authors including conservation geologists hold a strong belief in the finite nature of conventional energy sources. They estimate that at present consumption rate oil reserves will be depleted in 40 years?, gas in 65 years if no interruptions of supplies from the Middle East and Russia, and coal to last for the next 155 years. They further predict a consumption peak by 2035, triggering the collapse of the entire oil dependent system by the end of the 21st Century with CO2 emissions reaching 35.4Gt from 28.9Gt in 2009 (IEA2011, p. 8; WEO 2011, p. 102; Iwaro&Mwasha 2010, p. 705-708; Stamford 2010, p. 504; Pradeep 2009, pp. 1-5; Gautier, 2008, p.5; Garnaut 2008, p. 33; IPCC 2007; Eerkens 2006, p. 2, Bodansky 2004, p. 7; in Vaclav, 2003, p. 187; Evans et al 2009, p.2). Some schools of thought present a rather contrary view about the finite nature of conventional energy sources saying they have a robust future with no peak or any envisaged end (Vaclav 2003, p. 181). Whatever the arguments about the timelines when these resources will continue to serve humans, it is clear that these resources are finite and will be exhausted at some point, thus a need to look at other options like nuclear power.

Nuclear energy generation from a sustainability standpoint

Production of nuclear energy and early dynamics in the sector

Uranium which is the input for nuclear energy generation is believed to have been formed some 6.6 billion years ago (Kaufman and Cleveland 2008, p. 444). Natural Uranium occurs in most rocks, soils as well as rivers, and seawater. Uranium has two isotopes 238U and 235U. Only 235U undergoes fission to produce large quantity of energy in the form of heat which is used to produce steam that turns turbines to generate electricity with a small mass wastage. Canada, Australia, Kazakhstan and Russia top the list with identified Uranium resources in the world with a total amount of 47.6% at a cost of $130/kg (Harvey and Dany 2010, p. 384; Wilson and Burgh 2008, p. 143-144). Governments of countries like Australia do not support nuclear power generation but support expansion of Uranium mining to feed external demand (ENERGY NEWS 2011, pp. 102-103, Kelton 2011, p. 12; Evans et al 2009, p.12).

It is claimed that the US generated the first electricity from nuclear sources in the 1960s. By 2008; nuclear power was contributing approximately 16% of world's electricity (Kaufman and Cleveland 2003, p. 445). During this period, the suggested number of reactors of various kinds and sizes ranged between 32 and 1200 with approximately 442 large commercial reactors working, with France, Slovakia, Lithuania, Sweden, Belgium, Ukraine, and the USA being the major users (ENERGYNEWS 2010, p. 68; Pradeep 2009, p. 37; Wiegman 2009, p.109; Kaufman and Cleveland 2008, p. 445; Wilson and Burgh 2008, p. 118). With a growing demand for energy the International Atomic Energy Agency projects a growth in nuclear generation through 2030 (Pradeep 2009, p. 104).

Like most industrial and chemical process, the nuclear sector is witnessing a couple of challenges including public concerns around issues of handling its waste, security, safety, and economic competitiveness from other energy sources (Wiegman 2009, p. 109). Nuclear power accidents including the Three Mile (1979), the Chernobyl (1986) and the Fukushima (2011) have fuelled more doubts about the future of nuclear power in energy generation from the 70s till today (ENERGYNEWS 2011, p. 103; Kaufman and Cleveland 2008, p. 446). Views about the use of nuclear energy as sustainable energy option vary, with some emotional and politically driven rather than scientific and factual. (Wiegman 2009, p. 252; Grover 1980, p. 14). Despite these controversies, many nations are accepting nuclear power as a hope for meeting their energy demands. For example; an 11% to 34% rise in nuclear derived electricity was projected OECD Countries from 1978 to 2000 (Grover 1980 p. 95). It is however prudent to examine the soundness of nuclear energy using a sustainability approach that compares its merits and demerits with the conventional sources to support its reliability for our era.

Economic consideration of nuclear energy generations

Cost indicator

Many opponents of nuclear energy claim that the rising cost of constructing and commissioning nuclear power stations is the most significant barrier to the growth of the sector (Harvey &Dany 2010, p. 389; Wiegman 2009, p. 125; Eerkens 2006, p. 38;). These opponents have claimed that it takes approximately 10 years to construct a plant and the projected cost for a new 1-gigawatt generation nuclear plant rose from $4000/KW of generating power to between $5,000 and $7,000 from the 1980s with difficulty to acquire insurance to invest in the sector. Contrarily, other authors argue that nuclear power generation is cheaper compared with generating energy conventional sources (Brook 2011, pp. 39-40; Eerkens 2006, p12; Grover 1980, pp. 80-82). For example, Grover (1980, p, 82) asserts that a few lorry loads of enriched uranium will feed a 1,000MW power station with one or two truckloads yearly. For the same power capacity, it would need 2 ¼ million tonnes per year of coal with continuous use of 38,000 rail truckloads.

Due to Technological innovations, nuclear power generation cost demonstrates an advantage over coal-fired electricity generation with respect to the lifetime output. For example, a light-water nuclear plant uses about 6% of its lifetime output while a coal-fired plant use 6.7-7.8% depending whether it burns surface or deep-mined coal. Doing a comparative cost analysis, there is a comparative cost advantage of 20% for nuclear energy compared to conventional sources (Grover 2003, p. 101). For example, the US nuclear sector in 1977 saved the country an equivalent of 120 million tonnes of coal, 2.6 trillion cubic feet of natural gas, or 425 trillion barrels of oil, all worth $5.9 billion. While in Britain in 1979, costs including capital costs, nuclear processing and decommissioning charges were announced as follows; nuclear 0.76pence/KWH, coal 1.23pence/KWH, oil 1.42pence/KWH.

Construction and commissioning cost indicators

Technological innovations in the nuclear power sector have had an influence on the cost factor. For example the Integral Fast Reactor (IFR) and other Generation IV reactors are less complex and competitive with any other type of power generation at a cost of US$1200/KW (ENERGYNEWS 2011, pp. 39-40).These reactors are capable of using spent fuels, weapon heads which are abundant in countries like Russia and thus not necessitating the mining of uranium in the next 1,000 years. There is strong international collaboration to build a new generation of reactors which efficiently use reactor fuel through recycling with affordable high decommissioning robotic technologies (Wilson and Burgh 2008, pp.127-128)

Environmental and Social considerations (Nuclear reactor safety and waste handling)

Waste Generation and management indicator

A. CO2 Emissions indicator

In an era where all decisions are guided by scientific evidence of the impact on the globe, which is currently under threat from carbon emissions, nuclear energy generation is the most sound option as it contributes a negligible amount to the global carbon emissions (see table 1). It is estimated that avoided emissions will hit 150 million tonnes per year by 2020 and 2.4 billion tonnes per year by 2050 if nuclear power is maximally deployed (National Academy of Science 2009, p. 114). In addition it does not produce of SO2, NOx and this is not mentioned in current debates about nuclear energy's soundness (Vaclav 2003, p. 313).

B. Radioactive waste (nuclear plant construction waste and spent fuels)

Comparing amount of waste generated from the 1000MW plant example cited above, Grover (1980, p. 182) says about a cubic metre of waste is generated by the nuclear plant while coal waste would require about 12,000 railway trucks to remove it. The author strongly affirms his position in support of nuclear energy saying despite the emotional talks; it is safe, clean, and more environmentally desirable. As a sign of conservation he believes, fast breeder reactors which make use of the readily available uranium (with less than 3% residual waste for burial with negligible possibility for leaching into nature) should be used. Comparing the final risk to the environment, research, and the technological requirements for storing nuclear waste and geosequestering of CO2 into coal seams and saline aquifers, the nuclear option is the cheapest option (Rothwel and Graber 2010 p. 176-177, EnergyNews 2002, p. 396-398, AEN2002, P. 23).

Natural radioactive decay to a stable state of plutonium has been reported to occur in the Earth's crust. The example of in Oklo Gabon in West Africa, which demonstrates a successful isolation of radioactive wastes from the biosphere without contaminations has been repeatedly cited (Nersesian 2007, p. 282; Glover 1980, p. 168). This is prompting more research in geological disposal.

Plants Safety indicator

Many are tempted to believe a reactor could blow up like an atomic bomb. However this is not the case as there is not enough fission and material is not arranged in a reactor in such a way as to cause an explosion (Kaufman and Cleveland 2008, p. 458-459, Eerkens 2006, p. 20). The authors assert that present day systems are regulated with backups to ensure minimised risk of radiation exposure to people and the environment. For example, the US nuclear plants use a number of physical barriers to prevent the escape of radioactive materials, including the ceramic pellet around fuel rods made of heat, radiation, corrosion resistant zirconium alloy, all placed in a thick reinforced containment unit. In addition it is asserted that the low radioactivity measured around nuclear plants and fuel facilities are equivalent to natural radioactivity from the Earth, food, and water (ENERGYNEWS 2009 p. 39; Wilson and Burgh 2008, pp. 118-119). However it is difficult to say how safe nuclear reactors are as there is uncertainty associated with the likelihood of mechanical or computer malfunctions, or the likelihood of human error in plant operations.

Technological Safety and emergency response indicator

Accidents such as the Three Mile Island in 1979 and Chernobyl in 1986 have caused massive changes in the design of reactors. These include emergency response planning, reactor operator training, human factors, engineering, and radiation protection (Wilson and Burgh 2008, p. 117; Eerkens 2006, pp. 6-7; Bodansky 2004, p.20; Clover 2003, p. 167; Vaclav 2003, pp. 311, 315). These changes have all enhanced safety of new plants and operations of existing plants and thus do not deter advances in nuclear. Bartzis (1995, p. 138) argues that other severe accidents have occurred in the chemical industry causing loss of lives and massive evacuations like the Seveso Accident of 1976 in Italy with the release of TCDD (2,3,7,8 tetrachlorodibenzoparadioxin) which is one of the most poisonous substances. He further asserts that computerised emergency response systems, for example the RODOS System at European Community level, have been built to handle nuclear emergencies, realised with the participation of 18 national laboratories. One key aspect of the decision support system is its potential to generate automatically all information essential to decision making to ensure safety including source term, dispersion, disposition, doses, health effects, economic effects and counter measure scenarios.

"Risk perception" against "Risk Reality" indicators

There is a need for a clear separation between "risk perception" and "risk reality" (Squassoni 2007). Comparing the probability of occurrence of accidents, number of actual accident related deaths from coal, oil and natural gas sectors show that nuclear energy is by far the safest. The nuclear energy industry like any other chemical industry including the conventional industry occasionally experiences malfunction or other disturbances that leads to accidents. However, some authors argue that the accidents from the nuclear sector are less frequent, equivalent in magnitude or less severe compared to the others. This indication is hardly mentioned in discourse of the risks associated with the different energy options. This would be very crucial to change government and public's perception of risk with respect to nuclear energy. Jaccard (2005, p.111) indicates that although many technical studies demonstrating the low human and ecological risk associated with nuclear power, it has not reduced fears of the technology even amongst the educated of the public. Thus there is a continuous mistrust of nuclear power even though there is abundant information of the low probabilities of major accidents occurring. This further compounds efforts to site nuclear plants and expand the sector, as no one wants it in their backyard. Table 1 shows comparative figures of accidents in the energy sector between 1969 and 2000.

Table 1. Accidents in the energy sector between 1969 and 2000

Energy type	Number of accidents	Direct fatalities	Direct fatalities per GWe/year
Coal	1221	25107	0.87
Oil	397	20283	0.43
Natural Gas	125	1978	0.09
Luquified natural gas	105	3921	3.53
Hydro	11	29938	4.26
Nuclear reactor	2	56	0.11

Terrorist attacks and proliferation indicators

Other safety threats mentioned by authors include the use by terrorist of fissile material stolen from civilian nuclear fuel cycle to produce explosives. Some authors and experts have refuted the propagation of information about the danger of plutonium as there is more awareness and many binding international treaties to guard against proliferation. It is also claimed that recent breeder, Integral Fast Reactor technologies and small to medium size reactors (SMRs) refine and reuse the nuclear waste tails resulting in a near destruction of the plutonium (Brook et al. 2012; ENERGYNEWS 2011, pp. 39-40; Wiegman 2009, p. 124; Wilson and Burgh 2008, p. 119; Glover 1980, p. 81). Thus it minimises the amount of plutonium that can be proliferated. This international awareness is helping to change the perception on the nuclear energy sabotage by terrorists. In addition, there are other chemical and industrial processes that could pose a similar and even greater threat to global environment, social and economic safety and stability in the event of terrorist attack.

Prospects for growth of the nuclear sector

After the Chernobyl accident, some authors assert that it did not deter further pursuit of nuclear energy as an option. For example, Nersersian (2009, p. 286) cites the Generation IV International Forum that took place in 2000, which saw the major nuclear energy producing nations (USA, EU, Argentina, Brazil, France, Japan, Korea, South Africa, Switzerland and the UK) working on obtaining a standardised design for various types of nuclear reactors to expedite licensing and reduce capital costs and construction time. The forum revealed innovations cost effectives solutions for energy production in the sector such as the Pebble-bed Modular Reactor (PBMR) invented in South Africa. Forums such as these have continued to promote research and development, demystify the sector and contribute to change public perception given that its support is vital for the advancement of the sector.

The Fukushima Daichii accident that occurred in early March 2011 resulted in 3 deaths and costly impacts on the environment in the vicinity of the accident and beyond casted further doubts on the growth of this sector. Although nuclear energy still remains a key part of the global energy dynamics, this recent accident in the sector has impacted on nuclear projects and policies with renewed public criticism despites it being viewed by many as a key solution to the energy challenge of our era. In the midst of these contentions, a recent report by a joint secretariat of OECD Nuclear Energy Agency and the International Atomic Energy Agency (OECD-NEA/IAEA) outlines positive growth prospects for nuclear through 2035 (IAEA, 2012). The report projects an increase in world nuclear electricity generating capacity from 44% to 99% (375GWe net at the end of 2010 to between 504 GWe net in low demand case and 746 GWe net in high demand case). With respect to the base load material, the same report indicates that the potential is there to meet demand beyond 2035 and that if cutting edge technology is deployed and expansion of production to new countries happen this defined uranium base would be extended to thousands of years. The report further indicates that countries including India, the Republic of Korea, China, and the Russian Federation have shown strongest expansion of the sector.

Many experts hold different views on the barriers around nuclear energy to become main energy source replacing our fossil fuel based economy. Wang Haibin, Strategist Analyst at China Energy Fund committee identifies different human responses in developing countries to the perceived risks and benefits of nuclear energy when considered as an option with the potential to slow global warming. He categorises people into risks groups and benefits groups. He says the benefit group being the most poor and vulnerable will accept nuclear energy as bringing significant benefits, reducing the negative impacts of climate change on them. On the other hand the risk group are capable of adjusting to climate change because they are wealthier and thus will see greater risk in nuclear energy than do the poor. He states that conflict often arises as areas for the location of nuclear facilities often coincide with prosperous areas where the risk group often prefer to stay (especially along coastal areas due to high water need of the facilities). An example is the location of the Fukushima plant case which give much incentive for and the interest of the risk group to adopt a not-in-my-back yard comportment towards locating nuclear plants. For example in China, potential sites will be the rich and pristine coast of the Yangtze Delta, Pearl River Delta and the Bohai Bay Area full of businesses and often owned by the risk groups (Haibin 2012).

Wiegman (2009, p. 252) says scientific facts should be the basis for making choices about energy options for this century and beyond. He argues that the debate around the nuclear option as a future energy choice has seen proponents or opponents accept or denying it without any scientific basis. From a sustainable standpoint, many authors assert that the merits of nuclear energy outweighs its demerits and merits of conventional energy sources and is the solution energy challenges (Harvey 2010, p. 387; Bodansky 2004, p.22). However, a major advancement with the use of nuclear energy as a main source of energy generation is not expected prior to 2050, a timescale these authors say is longer than expected for quickly curbing CO2 emissions from conventional sources.

Despite the uncertainties surrounding the future and impacts of conventional energy sources on the earth, many enthusiasts in countries like Denmark and Australia have discourage the pursuance of nuclear energy as a sound option from a sustainable standpoint. Rather they favour more exploitation and use of conventional energy sources and investments in ponderous alternative energy sources (seawaves, tidal power, windmills, geothermal) which are more capital and material intensive and fall short of their energy generating potentials. Some institutions have equally voice their support for renewable energy as a climate benign solution to meet the growing global energy needs especially for developing countries. For example the 2001 report of the Global Environmental Facility states;

> *A transition to renewable is inevitable, not because fossil fuel supplies will run out - large reserves of oil, coal and gas remain in the world - but because cost and risks of using these supplies will continue to increase relative to renewable energy.*

It is worth mention that some authors have completely denied both the conventional energy and nuclear energy options as unfit for our era. For example, Jaccard (2005, p.2) asserts that nuclear energy and fossil fuels failed to stand the test of time with respect to financial performance as the cost of nuclear power added up higher than envisage often excluding the high cost for insurance liabilities, upfront subsidies, decommissioning and cost of permanent storage of radioactive waste. Also oil, the dominant fossil fuel has experienced a volatile price as a result of depleted resources and the geopolitical instability for example the oil price shocks of 1970s and early 1980s and the increase in price following the 1991 Gulf War and 2003 Iraq War. Contrary to other authors who cite renewable energy as incurring ponderous costs, Jaccard (2005, p.3) claims that although the initial cost for renewable energy might sometimes be very high, its cost of operation is eventually stable and predictable, reflecting the continuous and free energy from the sun and other natural forces.

Conclusion

The discourse on energy options that will help reverse the impending environmental, economic and social instability of the planet needs to be informed by a clear sustainability framework and indicators. It is clear from the essay that nuclear power generation incurs a significant competitive capital cost which is often deferred in some cases by government subsidies. On the other hand, its opponents who strongly support the burning of fossil fuels, fail to see carbon cost associated with the life cycle cost for conventional fuels. This cost if added results in a cost which is significantly higher than that of nuclear energy. Ongoing research and technological advances show that solutions to the safety, security, issues of waste, and construction time exist. These can be effectively harmonised and for sharing across the board in the nuclear sector which is unlikely with carbon handling from conventional energy. Thus its soundness is not doubted.

However it will require more years to agree on standards, harmonise operations and skills for wide sharing aimed at a sustainable nuclear energy sector. In addition, it will require a quick change of some present systems and adapting sectors' operations which rely heavily on natural gas and oil. For example the transport systems, other production equipment and systems, and home heating systems to electrical. The examples of other countries like Australia and Japan that have advanced with the use of electric vehicles, electrified public transport systems, battery powered systems and electric domestic heating will be very useful. The timescale to expect a significant contribution of nuclear energy at a level which replaces the conventional energy sources as an option with less carbon emissions is difficult to estimate. The wise decision now would be to speed up this technologies and applications of this less capital, material intensive and sound option to handle the economic, social and environmental urgencies of our era.

References

Australian Government Department of Resources, Energy and Tourism 2011, 'Energy in Australia 2011', ENERGYNEWS, vol. 29, no. 4.

Bartzis, J, 1995, 'Environmental Monitoring and Simulation', in Avouris N and Page B (eds), Environmental informatics: methodology and applications of environmental information processing. Kluwer Academic Publishers, pp. 138-150.

Bodansky, D 2004, Nuclear energy: principles, practices and perceptions, Spinger, New York.

BP 2006, Global consumption by energy type as of 2006, British Petroleum, London.

Brook, B 2011, 'Advanced Nuclear Power Systems for Long-term Energy and Climate Security', ENERGYNEWS, vol. 29, no. 2, pp. 39-40.

Brook, B, Blees, T, and Hannum, W 2012, Nuclear Waste: Use fast reactors to burn plutonium, Nature, 486, pp.167-168.

Bulletin of Atomic Scientists (2012), The nuclear approach to climate risk, http://www.thebulletin.org/web-edition/roundtables/the-nuclear-approach-to-climate-risk, accessed 4/08/2012.

CDIAC 2012, Carbon dioxide Information Analysis Centre – http:/cdiac.ornl.gov, accessed 12/08/2012

Davidson, k 2011, 'Can we measure sustainability?' in Roetman P &Daniels C (eds), Creating Sustainable communities in a changing world. Crawford House Publishing, Adelaide, pp. 5-11.

Dittmar, M 2012, 'Nuclear energy: Status and future limitations',Energy, vol. 37, no. 1, pp. 35 – 40.

Eerkens, J 2006,The nuclear Imperatives, Springer, Dordrecht.

Evans, A, Strezov V, & Tim, E 2009, Comparing the sustainability parameters of renewable, nuclear and fossil fuel electricity generation technologies, http://www.worldenergy.org/documents/congresspapers/272.pdf, accessed 20/04/2012,

Faeth, P 2012, 'Energy Security and Water', Environment, vol. 54, no. 1 pp. 4-6.

Garnaut, R 2008, the Garnaut Climate Change Review; Final Report, Cambridge University Press, Melbourne

Gautier, C 2008, Oil, Water and Climate: An introduction, Cambridge University Press, Cambridge.

GEF 2001, Renewable Energy: GEF partners with Business for a Better Future, 3, Washington DC,

Geodesic 2002, Australian Energy News, Issue 24, June, p. 23.

Goldie, J, Douglas B, &Furnass, B 2005,In Search of Sustainability, CSIRO.

Goodstein, D 2004, Out of Gas: the End of the Age of oil, Norton, New York.

Gover, J 1980, The struggle for power: the real issue behind the uranium argument, E. J. Dwyer Pty Ltd, NSW.

Haibin, W 2012, The nuclear approach to climate risk: To each technology, its proper time and place, Bulletin of the Atomic Scientist, http://thebulletin.org/web-edition/roundtables/the-nuclear-approach-to-climate-risk, accessed 15/08/2012

Harvey, L 2010, Energy and the New Reality: Carbon-free energy supply, Earthscan Ltd, London.

Hinrichsen, D 2012, Commentary: 20 years on - and time runs desperately short, http://www.peopleandplanet.net/?lid=30401&section=33&topic=27, accessed 19/08/2012

IAEA 2012, Global Uranium Supply Ensured for Long Term, http://www.iaea.org/newscenter/pressreleases/2012/prn201219.html, accessed 04/08/2012

IEA2011, 'World Energy Outlook (WEO) 2011', ENERGYNEWS, vol. 29, no. 4, p. 102

IEA 2011, CO2Emissions from Fuel Combustion, http://www.iea.org/co2highlights/co2highlights.pdf, accessed 19/04/2012.

IAEA 2000, Comparative Carbon Dioxide Emissions from Power Generation, http://www.worldnuclear.org/education/comparativeco2.html, accessed 17/08/2012

IPCC 2007, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007, Cambridge University Press, Cambridge Fourth Assessment Report: Climate Change 2007

Iwaro, J, &Mwasha, A 2010, 'Towards energy sustainability in the world: the implications of energy subsidy for developing countries', International Journal of Energy and Environment, Vol.1, Issue 4 pp. 705-715.

Jaccard, M 2005, Sustainable Fossil Fuels: The unusual suspect in the quest for clean and enduring energy, CUP, Cambridge.

Kelton, G 2012, 'Premier confident mine will go ahead', Advertiser 17, April 2012, p. 12.

Makhijani, A 1996, comparison of fossil fuels and nuclear energy, Energy and society, Energy and Society, pp. 14-16

Meaton, C 2010, 'The elephant in the energy room', ENERGYNEWS, vol. 28, no. 3, pp. 68-69.

Muhammad, I 2012, Visualising Global Shift in Energy Demand and Supply, International Journal of Energy Economics and Policy, Vol. 2, No.3, p134-146.

Murray, L 2009, The History of nuclear energy, viewed 18/04/2012DOI: 10.1016/B978-0-12-370547-1.00015-8.

Nakicenovic, N. And Grübler, A. (2000) 'Energy and the protection of the atmosphere', International Journal of Global Energy Issues, Vol. 13, Nos. 1–3, pp.4–57.

NAS 2009, America's Energy Future: Technology and Transformation, National Academies Press, Washington.

Nersesian, R 2007, Energy for the 21st Century: a comparative guide to conventional and alternative sources, M.E. Sharpe, London.

Ola, E, and Bjorn, F 2001, 'An approach to sustainability assessment of energy', in Semedi S (ed), Building sustainable energy systems: Swedish Experience, Bulls Tryckeriaktiebolag, Halstad, pp. 503-530.

Pradeep, S 2009, Energy and Climate Change: issues of sustainable development , The Associate Publishers, AmbalaCantt, India.

Rothwell, G,& Graber, R 2010,'The role of nuclear power in climate change', in Sioshansi F (ed) Generating electricity in a carbon-constrained world, Academy Press, pp. 175-206, DOI: 10.1016/B978-1-85617-655-2.00020-1.

Selena, Ng 2009, 'Global Nuclear Power and Opportunities for Australia', ENERGYNEWS, vol. 27, no. 2, pp. 27-28.

Squassoni, S 2007, Risks and Realities: The "New Nuclear Energy Revival, http://www.armscontrol.org/act/2007_05/squassoni, viewed 17/08/2012

Stamford, L 2011, 'Sustainability indicators for the assessment of nuclear power' Energy, vol. 36, no. 10, pp. 6037-6057, viewed 17 April 2012, DOI: 101016/j.energy.2011.08.011.

US Energy Information Administration 2004, Projections: Energy for the analysis of global energy markets in 2007, International Energy Annual, May-July 2006.

Vacla, S 2003, at the Crossroads; global perspectives and uncertainties, The MIT Press, London.

WCED Report 1987, http://www.un-documents.net/our-common-future.pdf, accessed 01/08/2012

WEO 2011, Cost of delaying action on climate change, http://www.iea.org/publications/worldenergyoutlook/publications/weo-2011/, accessed 17/08/2012

Wiegman, D, 2009, Climate change: what we know and what to do about it, Island Press, California.

Wilson, J, and Burgh, G 2008, Energising our future: Rational choices for the 21st Century, John Wiley & Sons, New Jersey.