Putting nuclear power into perspective

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South Africa has on a number of occasions announced its intention to include nuclear power generation in its future power generation mix. The world's attention was captured when another announcement about South Africa's intention to explore nuclear possibilities was made within days of the Fukushima Daichii nuclear disaster on 11 March 2011. Subsequently, there were a number of similar confirmations of South Africa's nuclear endeavours.

Typically, every announcement stirs opposition to nuclear power and the media is usually flooded with statistics that claim that nuclear power has one or other flaw that is intentionally hidden from the public. These statistics span a wide variety of specialist fields, from economics, safety and sustainability, to weapons proliferation and waste. After some time, the panic subsides until the next announcement is made. Before branding nuclear power as a viable option, one has to objectively examine the main issues that are normally raised. These are safety, economics and waste.

Safety

In terms of nuclear power's safety, experts often wonder how it can be measured objectively. It seems that the most obvious way is to determine how many lives were lost on average per unit of energy produced by a particular power generation technology. In this assessment, however, the entire chain – from exploration for energy resources up to the final disposal of the waste – for each of the alternative energy sources has to be compared.

It is also important to realise that some of the stages in the chain might not be applicable to some of the power technologies considered. Conca (2012) compared the worldwide fatalities per year for each unit of energy produced per power-producing technology. The results of this study are summarised in Table 1.

It should be obvious from Table 1 that the nuclear energy production, even with the inclusion of the confirmed fatalities, as well as suggested latent fatalities that may eventually result from the accidents at Chernobyl and Fukushima Daichii, is undoubtedly the safest of the various technologies considered.

Economics

If one does an economic analysis of the production of energy through a number of energy production technologies, a common metric for comparison is necessary.

Table 1: Fatalities per power-producing technology

Power technology	Fatalities per year per terawatt-hour (TWh) produced
Coal (world average)	161
Coal (China)	278
Coal (USA)	15
Oil	36
Gas	4
Wind	0.15
Hydro (world)	0.10
Hydro (world)*	1.40
Nuclear#	0.09

** The figure includes the 170 000 deaths of the Banqiao Reservoir Dam in China in 1975.*

 # The figure includes all fatalities and suggested latent fatalities that may eventually result from the accidents at Chernobyl in 1986 and Fukushima Daichii in March 2011.

Firstly, a common monetary baseline needs to be established. Internationally, the dollar is regarded as a well-recognised base for comparative purposes. Secondly, although there are a number of ways to do a financial analysis of a plant, one of the indicators developed and mostly used for comparing different systems is the levelised cost of energy (LCOE). This represents the ratio of total assumed financial lifetime expenses to the total kilowatt-hours of energy delivered at the connecting points to the grid during this lifetime. A number of factors are used in the calculation of the LCOE:

- **The capital cost of the power-generating technology:** This cost is expressed as a cost of the entire installation as if it was erected from one day to another. It is the so-called "overnight capital cost".
- **The fixed operational and maintenance expenditures in each year**
- **The variable operational expenditures in each year:** This factor includes the cost of the fuel.
- **The net electricity generated in a year:** This is a factor that includes the availability of the power expressed as a fraction of the total time available in a year for the production of power.
- **The cost for the funding that is provided for the construction of the generating plant:** This cost also implies the discount rate used in discounted cash flow analysis to determine the present value of future cash flows. This discount rate is normally calculated for a certain period over which capital cost is to be recovered and is a weighted average between debt and equity capital, called the weighted average cost of capital (WACC).
- **The availability of various country-specific incentives such as tax credits**

A selection of the results of an analysis of the average levelised cost for electricity-generating plants done in the USA for plants entering service in 2019 (US Department of Energy, 2014) is reported in Table 2.

The WACC for the study was taken as 6.5% and a common basis of 30 years was used as the cost recovery period for all the power generation technologies considered. This WACC of 6.5% consisted of two components. The first was 3.5%, which is the discount rate to analyse similar programmes in the UK (HM Treasury, 2003). The second component is a three-percentage point increase to evaluate investments in greenhouse gas-intensive technologies.

The capacity factors used for the conventional coal and advanced nuclear plants are in agreement with figures generally quoted for these two technologies worldwide. The factors for wind and solar power are both somewhat higher than those quoted for stations around the world. The introduction of wind and solar power in a network should also be analysed with caution, because of the fluctuating nature of its generating capacity, which may require reliable backup sources that will supply reliable power on demand. This will influence the cost analysis and should be included if more detailed analyses are carried out for these generating technologies.

By comparing the costs of nuclear and coal-fired power stations in Table 2, it is evident that the higher levelised capital cost and fixed operations and maintenance (O&M) cost of nuclear plants are virtually offset by its lesser expensive variable O&M cost, which includes the cost of fuel. In addition, if the analysis for nuclear plants is performed for the longer operating lifetime and therefore cost recovery period of 60 years, for which the new advanced nuclear stations are designed, an even more favourable levelised cost figure will result for nuclear power plants. Application of the WACC of 6.5% that is adjusted for the greenhouse gas-emitting technologies also disadvantages the levelised cost of electricity for nuclear plants. However, even with this artificially inflated WACC and the shorter cost recovery period of 30 years, the levelised cost of electricity still compares favourably with the cost of coal plants.

Waste

The issue of nuclear waste production has been debated for decades. Without exception, the arguments against nuclear power

→ *Table 2: Estimated levelised cost of new-generation resources in 2019*

Plant type	US average levelised cost for plants entering service in 2019 ($/MWh)				
	Capacity factor (percentage)	Levelised capital cost	Fixed O&M cost	Variable O&M cost (including fuel cost)	Total system levelised cost
Coal (conventional)	85	60.0	4.2	30.3	95.6
Gas (conventional combined cycle)	87	14.3	1.7	49.1	66.3
Wind	35	64.1	13	0.0	80.3
Hydro	53	72.0	4.1	6.4	84.5
Solar PV	25	114.5	11.4	0.0	130.0
Nuclear (advanced)	90	71.4	11.8	11.8	96.1

The Koeberg nuclear power plant in South Africa.

highlight the long half-lives of the specific isotopes produced in the reactor as the main issue of concern.

Radioactivity is the release of energy from the excited nuclei of elements that were exposed to neutrons in the core of a nuclear reactor. The release rate of this energy is inversely proportional to the half-life of the radioactive material. The shorter the half-life, the higher the energy release rate, and vice versa for long half-life radioactive nuclides. If the energy released in the decay reactions is the same for both the short half-life and long half-life radionuclides, it will be easy to understand that the energy release rate (power) of a short half-life decay reaction is more than that of the long half-life decay reaction. The radiological damage potential of the short half-life radionuclides is therefore higher than that of the long half-life radionuclides.

Since the very long half-life fission product activity has combined effective half-lives of billions of years and the short half-life fission products have combined effective half-lives of hundreds of years, one can see that the comparative radiological damage potential of the long half-life nuclides for the same energy per decay reaction can be less than a millionth of that of the short half-life nuclides.

Furthermore, nuclear energy is very concentrated because a lot of energy can be extracted from a small amount of fuel. As a result, the waste formed is also very concentrated. For example, if 1 g of nuclear material is totally consumed in nuclear reactions, it is equivalent to the consumption of 3 000 tons of excellent-quality coal. The volume of waste created by the consumption of the two types of material to generate power is then this ratio multiplied by the inverse ratio of their densities. The fissile material in current-day reactors is mostly uranium dioxide with a density of 10.7 g/cm^3, and it stays mechanically and chemically intact during its operational lifetime. Coal ash has a density of approximately 1.2 g/cm^3. With these values, it is easy to deduct that the volume ratio of the waste produced by coal compared to that produced by nuclear fission is approximately 2.7 x 10^7 for the same energy produced. In a nuclear power plant, waste is essentially managed by making sure, through mechanical and chemical means, that it is not released into the environment. Due to the large volumes, the waste handling of coal-fired power plants cannot be treated in the same way and the waste is essentially released into the environment around the power plants.

Conclusion

As of May 2014, 30 countries worldwide have been operating 435 nuclear reactors for electricity generation, and 72 new nuclear plants are under construction in 15 countries.

These countries have realised the rationality of utilising nuclear power. Let us believe that South Africa will also be unbiased and consider the foregoing arguments when it decides how to expand its power-generating capacity in the future.

References

Conca, J. 2012. How deadly is your kilowatt? We rank the killer energy sources. *Energy*. [Online]. Available at http://www.forbes.com/sites/jamesconca/2012/06/10/energys-deathprint-a-price-always-paid/. Accessed: 25 August 2014.

US Department of Energy. 2014. Levelized cost of new generation resources. *Annual Energy Outlook 2014*. US Energy Information Administration.

HM Treasury. 2003. *The Green Book appraisal and evaluation in Central Government*. [Online]. Available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/220541/green_book_complete.pdf.