A review of the November 2016 Integrated Resource Plan update: The role of nuclear power

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Contents

1. Executive summary

The objective of Integrated Resource Planning, to meet consumers' electricity demands at the lowest cost to them consistent with meeting other objectives such as reliability and environmental performance is a good one. However, the way the methodology is being implemented in South Africa is a travesty of how the methodology should work. Official versions of the plan have consistently constrained the model used to determine the optimal plan, using Ministerial Determinations, by forcing it to adopt a nuclear programme of 9.6GW despite the nuclear option being more expensive than the alternatives. The contribution of other options, particularly renewables, has been heavily limited for highly questionable reasons. The model has also been run to determine the generation mix to 2050, far beyond the sensible forecasting horizon for the variables needed to run the model.

Without Ministerial Determinations, new nuclear capacity has never formed part of the least cost plan. This is in spite of the use of cost forecasts, particularly on construction cost, that are far below cost estimates from other countries. The model assumes a typical size reactor (1400MW) would cost R77bn, whereas recent international experience suggests the cost will be more than R110bn.

2. Introduction

In this paper, we look at:

- The Integrated Resource Planning (IRP) methodology;
- The assumptions and outcome of the failed 2008 nuclear Call for Proposals (CfP);
- The assumptions made on the key nuclear variables in the versions of the IRP since the first of 2010;
- The Ministerial Advisory Council on Energy's (MACE) critique of the draft 2016 IRP; and
- Eskom's Request for Information (RfI) issued in December 2016.

3. Background

In 2008, a Call for Proposals (CfP) by Eskom for 3.2-3.6GW of nuclear capacity (two or three reactors depending on their size) had to be abandoned because the government was unwilling to provide the financial guarantees that would have been necessary for the project to be financed. Despite this failure, there have been successive attempts by government to make a case for nuclear despite the deterioration in the credit rating of the South African government and Eskom, and despite the worsening of the economics of nuclear power.

In 2010, the government adopted a new method of electricity generation planning, Integrated Resource Plans (IRP), under which the cheapest way to meet consumer electricity demand would be identified subject to meeting non-financial criteria (externalities) such as reliability and sustainability. In short, it seeks to identify what the cheapest means (that is, the options to meet demand) to meet the policy goals are. Integrated Resource Planning, if properly implemented, should overcome institutional biases for particular policies and provide a supply of power that meets objectives on reliability, affordability and sustainability at the lowest cost for consumers.

This responsibility for implementing this plan lay with government so Eskom was no longer able to plan the system choosing the type and volume of power plant it would build. Government would forecast demand and choose how the required capacity was allocated for example, via a competitive tendering process. In 2016 the Electricity Regulation Act[1] was passed formalising the role of the

[1] Act 4 of 2016. Among the objects of this Act are inter alia to: 'achieve the efficient, effective, sustainable and orderly development and operation of electricity supply infrastructure in South Africa; ensure that the

Integrated Resource Plan. The first IRP was promulgated [2] by publication in the Gazette in May 2011.[3] An update in 2013 was circulated for comment but was not promulgated and the 2016 update was published in draft form in November 2016 for comment.

Nuclear power has never formed part of the least cost plan but in the promulgated 2010 IRP, a programme of 9.6GW of nuclear capacity (6-8 reactors) to be on-line by 2030 was imposed by government. The case for nuclear power was weak in the 2013 update and weaker still in the 2016 update with no nuclear capacity needed before 2037 in the least cost plan, far beyond the effective planning horizon for new generating capacity.

Government held a series of nuclear vendor workshops in 2014-15 at which the world's nuclear vendors would pitch their new technologies. Inter-Government Agreements (IGAs) with the governments of these vendors, to cooperate on nuclear power development, already existed for USA, Canada and Korea and new IGAs were signed with the Russian Federation, France and China.[4] An IGA with Japan is reported to be pending and updated IGAs with USA and Korea may be signed. Government announced its intention to hold a CfP for the 9.6GW programme on a number of occasions, most recently in September 2016 but these were never held. In October 2016, the Energy Minister, Tina Joemat-Pettersson, announced the responsibility for procuring new nuclear plant would pass back from the government to Eskom. A determination to this effect in terms of section 34 of the Electricity Regulation Act[5] was approved by the Minister on 18th October 2016.

Despite the poor economic case for nuclear power, Eskom immediately announced it expected to issue a CfP by end December for two reactors with an option for further reactors to make up the 9.6GW programme. This did not happen but Eskom did issue a Request for Information (RfI) in December to reactor vendors, essentially a non-binding request for detailed economic and technical information on the reactor design offered.

4. Integrated resource planning methodology

Integrated resource planning methodology has its roots in the USA in the 1980's where energy regulatory bodies used it to try to ensure that investments to meet the apparent need for new generating capacity were met at the lowest cost to consumers, so-called least cost planning. The underlying philosophy was that consumers were concerned that their electricity needs be met reliably, affordably and sustainably.[6] They were not concerned how their demands were met whether it was via new large generating stations, small decentralised plants or by energy efficiency measures. In simple form, this often led to 'capacity auctions' under which the government (regional or national) would set standards of environmental performance and reliability that the options considered had to meet and then hold an 'all-sources' auction under which bids were solicited to

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interests and needs of present and future electricity customers and end users are safeguarded and met, having regard to the governance, efficiency, effectiveness and long-term sustainability of the electricity supply industry within the broader context of economic energy regulation in the Republic; promote competitiveness and customer and end user choice.' This Act defines an 'integrated resource plan' as a resource plan established by the national sphere of government to give effect to national policy

[2] GNR 400 of 6 May 2011 in Gazette Number 34263. See https://www.greengazette.co.za/documents/regulation-gazette-34263-of-06-may-2011-vol-551-no-9531_20110506-GGR-34263 (Accessed January 10, 2017)

[3] https://www.greengazette.co.za/documents/regulation-gazette-34263-of-06-may-2011-vol-551-no-9531_20110506-GGR-34263 (Accessed January 10, 2017)

[4] The agreement with USA was signed in August 1995, Canada 2007, Korea October 2010. New agreements were signed with Russian Federation September 2014, France October 2014, and China November 2014.

[5] Act 4 of 2006

[6] Some talk now about the energy 'trilemma' of trying to meet these three objectives simultaneously but in reality, energy policy has always required a trade-off of these three factors.

meet the amount of capacity needed was held. The lowest bid would be awarded a contract to sell power (or install energy efficiency measures) at the price bid. In other cases, Feed-in Tariffs were offered under which companies that could offer power at less than a specified level would be offered long-term power purchase agreements.

Integrated Resource Planning takes this process several steps further. It seeks to build a long-term investment plan for the electricity system, including demand (energy efficiency) as well as supply options[7], over several decades, in the South African case, about 35 years, that would meet consumer's needs for reliability and sustainability at the lowest price to them consistent with full cost recovery. One of the usual justifications given for this longer term approach is that it would allow capabilities for technologies that would be needed in significant amounts to be built up to ensure the need for these technologies could be met as cheaply and efficiently as possible.

In general, the IRP process would be based not on actual bids from companies but on a complex mathematical model with the assumed costs of all the possible options included and set against a long-term electricity demand forecast.

While the mathematical model is a powerful tool, a number of points need to be understood in order for the results to be interpreted. The data requirements are daunting and the model requires:

- **Detailed cost estimates for technologies for the next 35 years.** For many of the technologies, current costs are not well-established, much less those that will apply in three decades;
- **Forecasts of fuel costs for three decades forward.** Fossil fuel prices are notoriously volatile and difficult to forecast and, for example, the world oil price in 2013 was about $120/barrel while only two years later, it had fallen to $30/barrel;
- **Currency exchange rates are required.** These are also notoriously volatile and difficult to forecast, must be forecast for three decades so that inputs priced in, say, Dollars can be converted to Rand. For example, in 2012, the Rand Dollar exchange rate was less than 8 but by 2017, it had risen to about 13, and went as high as 16.84 in January 2016. Even if technology and fuel prices, which are often denominated in Dollars, could be forecast accurately, an inaccurate exchange rate assumption could produce a very inaccurate result;
- **Demand is difficult to forecast.** The 2010 IRP forecast electricity demand in 2015 would be about 300TWh, whereas the actual demand was 240TWh, an error of 25 per cent in only 5 years.

If the assumptions made are not accurate, the results of the modelling will inevitably be to suggest policies that will impose significantly higher costs on consumers than the lowest cost solution. If it is judged that accurately forecasting the variables needed over the period required simply cannot be done, use of the model cannot be justified. The South African process requires that the plan be continually updated to take account of changed perceptions of the future, but given that the first IRP has not been officially updated since it was published in 2010, there must be doubts as to how realistic this plan is. It also incorporates a number of scenarios to reflect different perceptions about the future of energy markets and technologies.

[7] The 2010 IRP states: '"Integrated Resource Plan" refers to the co-ordinated schedule for generation expansion and demand-side intervention programmes, taking into consideration multiple criteria to meet electricity demand.' It also states: '"Integrated Energy Plan" refers to the over-arching co-ordinated energy plan combining the constraints and capabilities of alternative energy carriers to meet the country's energy needs.' http://www.energy.gov.za/IRP/irp%20files/INTEGRATED_RESOURCE_PLAN_ELECTRICITY_2010_v8.pdf (Accessed January 11, 2017)

Two factors should be borne in mind when implementing the results:

- **Constraining the model.** While the standards for reliability and environmental performance that options must meet should be imposed, it is inappropriate to impose particular technology options as was done in 2010 when a nuclear programme of 9.6GW by 2030 was imposed on the model. If the government wants to prescribe the technologies, it should not hide behind the bogus objectivity of a mathematical model;
- **Implementing the results.** If the model results are to be adopted, their implementation must be under the control of a public body with no commercial interest in any particular outcome, for example, the National Energy Regulator of South Africa (NERSA) ought to be a neutral body. If the current draft is adopted and Eskom goes ahead with its plan to carry out a Request for Proposals for 9.6GW of new nuclear capacity, that would either impose huge extra costs because more capacity was built than was needed or Eskom's plant would squeeze out cheaper options offered by competing companies.

The rationale for the model is to identify the cheapest solution to meet electricity demands within the constraints on reliability and environmental issues. If the model is overridden by forcing particular options into the solution or one party is allowed to ignore the results produced, the policy will end up as a travesty of what it should do. In the past the former happened with the South African government forcing an arbitrary volume (9600MW or 6-8 reactors) of nuclear capacity into the solution. With the present exercise, Eskom's plan to issue a Request for Proposals for 9600MW of nuclear capacity will pre-empt the investment decisions that the model prescribes and will impose additional costs on consumers.

In the next section, we look at the forecasts made for some of the key nuclear variables.

5. Key assumptions related to the nuclear option

Following the Fukushima disaster of March 2011, the South African government stated it would build only designs that met the current state-of-the-art in safety terms. The draft environmental impact report of 2011 stated:

'Generation III/III+ reactors are advancements of Generation II reactors largely due to safety enhancements to the Generation II reactors. Power stations using these reactors are currently being constructed in Japan, Finland, France and China. It is this generation of PWRs that is proposed to be installed for the Nuclear-1 project.'[8]

This statement was essentially repeated in the August 2015 revision.[9]

A detailed estimate of the cost of a kWh of nuclear electricity requires forecasts of a large number of often complex variables. However, the cost of nuclear electricity is dominated, perhaps 75% or more, by fixed costs, that is costs that are incurred whether or not the plant is operated. These, in turn are dominated by the costs related to construction, in particular, the construction cost, the cost

[8] Eskom Holdings (2011) 'Eskom proposed Nuclear-1 power station and associated infrastructure' Revised draft environmental impact report, Department of Environmental Affairs Reference No: 12/12/20/944

[9] It stated: 'It is this generation of PWRs that is proposed to be installed for the Nuclear-1 project. https://projects.gibb.co.za/DesktopModules/Bring2mind/DMX/Download.aspx?Command=Core_Download&EntryId=2935&language=en-US&PortalId=3&TabId=352 (Accessed January 11, 2016)

of borrowing and the plant load factor[10]. We focus therefore on the assumptions made for these three variables.

Construction cost is typically quoted in 'overnight' costs, that is, the cost excluding the cost of finance. The cost of finance is substantial and might add 30% or more to the overnight cost. However, the cost of finance will depend on the credit-worthiness of the buyer rather than the intrinsic cost of nuclear and including finance would distort international comparisons. Construction cost is usually quoted in US$ per kW of installed capacity so that a 1600MW plant costing US$5000/kW would cost US$8bn. Quoting in US$ makes sense because reactors are bought from an international market but it does lead to further uncertainty. If the real Dollar/Rand exchange rate changes significantly this will change the Rand price even if the Dollar price is unchanged. Contracts are sometimes described as 'turnkey'.[11] This should mean that the cost paid by the utility is fixed at the time the contract is signed and any additional costs must fall on the vendor. In practice, contracts that are not fixed price are sometimes described as turnkey. Turnkey contracts are very rare because of the risk they impose on the vendor. The contract for the Olkiluoto (Finland) reactor, signed in 2004, was a turnkey contract but when costs began to over-run, the vendor, Areva, denied responsibility for these extra costs and who pays the extra costs is still being determined in the International Chamber of Commerce (ICC).

Projects are usually financed by a mix of debt (borrowing) and equity (the buyer's own cash) with a typical project financed by 70/30 debt/equity. Equity has no actual cost but because a company's funds are limited, there is an 'opportunity' cost, that is, if its cash is spent on a particular project, that cash will not be available for other projects even if the return on investment is better. The discount rate is effectively a capital rationing mechanism used by government and sets the real rate of return all adopted projects must achieve. It should be set at a level at which only projects that exceed that level can be funded and money is not available. In the IRP, the government's discount rate is effectively the cost of capital.

The load factor determines how many units of output are sold and therefore how thinly these fixed costs can be spread. For example, if with a load factor of 90%, the fixed costs are R9/kWh, if the load factor is only 60%, the fixed costs will be R13.5/kWh.

5.1 Reactor options

Fukushima has yet to have a significant impact on the reactor designs now on offer and none of the designs listed below has undergone significant changes as a result of Fukushima. It will be some time before the exact failures that occurred at Fukushima are fully identified and translated into design modifications. What has changed for some countries is the perception of how acceptable the design of existing reactors is. In some countries, for example Germany, this has resulted in early closure of existing reactors and in others, for example France, the need for extensive upgrades to existing plants.[12] Following the Fukushima disaster, the South African government confirmed it was only considering reactor designs that met the latest standards. In effect, this means designs that would meet the requirements of regulators in Europe and the USA. It also stated it was only interested in Pressurised Water Reactors (PWRs), the type installed at Koeberg and which accounts for 291 of the

[10] The load factor, the power produced as a percentage of the power that would have been produced had the plant operated uninterrupted at full design rating.
[11] With a turnkey contract, the utility simply has to 'turn the key' and start the reactor.
[12] The French Court of Auditors has estimated that to upgrade the 58 existing reactors in France to acceptable standards will cost at least €100bn by 2030. Platts Power in Europe 'CdC ups EDF investment forecast' February 15, 2016

450 reactors in operation worldwide in January 2017. This rules out Boiling Water Reactors (BWRs), which account for 78 reactors. However, there is only one BWR design on offer, the Hitachi-GE ABWR, which meets current requirements.[13]

The reactor vendors invited to the reactor vendor workshops in 2013/14 suggests the designs that will be considered.[14]

5.1.1 Areva EPR

The Areva EPR placed the lowest bid in the 2008 RFP and there are four reactors of this design under construction (two in China and one in Finland and in France). However, none of these is complete and all are late, between 4-13 years, and far over budget. Areva is effectively bankrupt and while there are attempts by the French government to save it, it is far from clear whether these will be successful. It is also embroiled in a quality control (QC) scandal that involves inadequate and possibly falsified QC documentation dating back 50 years. The EPR was given design clearance by the UK safety regulator in 2012.[15]

5.1.2 Toshiba/Westinghouse AP1000

The Toshiba AP1000 was the other, higher, bidder in 2008 and there are eight reactors of this design under construction (four in China and four in the USA). However, none of the reactors is complete and all are at least three years late and far over budget. The Toshiba nuclear division is in severe financial difficulties and has been heavily fined for overstating its profits between 2008 and 2014. It is not clear whether it can survive in its present form. The reactor design was given design clearance by the US safety regulator in 2011 and is under review by the UK regulator with completion expected in 2017.

5.1.3 Rosatom AES-2006

The Rosatom AES-2006 was seen as the front-running technology when the South African government was in charge of reactor procurement. Rosatom claims more than 30 export orders for reactors of this design on which construction has yet to start. There are six reactors of this design actually under construction, four in Russia and two in Belarus. The first reactor of this design was declared to be in commercial operation on December 31, 2016. All the reactors in Russia are at least four years late. The two in Belarus were claimed to be on time at the start of 2016, but the reactor vessel for one of the reactors was dropped while it was being manoeuvred and Belarus is requiring that it be replaced. This will delay completion but it is not known yet by how long. The design has not been fully reviewed by a European regulator yet but the Finnish and Hungarian regulators are looking at the design.

5.1.4 SPI CAP1400

The State Power Investment Corporation (SPI)[16] of China is offering the CAP1400, which is essentially a scaled up version of the Toshiba AP1000, although SPI claim the design is their own intellectual property. By January 2017, despite numerous announcements that construction was due to start on the first unit in China, construction of the first unit had yet to start. There were reports in 2014 that

[13] Toshiba also offers the ABWR design but it has no prospective sales

[14] The Canadian vendor, AECL participated in these workshops but since they do not offer a PWR design, they are not considered further.

[15] The US and UK regulators carry out a comprehensive, 'generic', design review before construction is allowed to start. This process typically takes five years or more. The French and Finnish regulators review the design details as they arise in construction. It is not clear what the regulatory processes are in China and Russia but it is apparent that it does not involve a lengthy generic design review before construction starts.

[16] Formerly the State Nuclear Power Technology Corporation

Turkey had committed to buy two AP1000s followed by two CAP1400s from SPI but that deal appears to be in doubt now.

5.1.5 KEPCO APR1400

The Korean KEPCO is offering the APR1400, originally a US design that received US regulatory approval in 1997 but was never built. KEPCO has licensed the design and there is one APR1400 in commercial operation in Korea (since December 2016) with three more under construction there. There are also four reactors of this design under construction in the UAE. The plants in Korea were delayed because in 2012, the QC documentation for parts had been found to be falsified and these parts had to be replaced. The plants in UAE are claimed to be on schedule. KEPCO acknowledges that the design under construction does not meet European or US standards as it lacks a 'core-catcher' and is not built to withstand an aircraft impact. Adding these features is likely to substantially increase the cost. The design is being upgraded for the European and US market although it has no customers in either market. It was submitted to the US regulator in 2014 but it is not clear how much progress has been made while plans to submit the design to the UK regulator appear to be a year or more away.

5.1.6 CNNC and CGN Hualong One

Two other Chinese vendors, China General Nuclear (CGN) and China National Nuclear Corporation (CNNC) offer their own versions of the Hualong One design. Both companies have two reactors of their Hualong One design under construction in China, the earliest since May 2015. There were plans to submit the design to the UK regulator in 2016 but by January 2017, this had not happened. The Chinese vendors have not competed directly with each other in export markets so it is not clear whether CNNC and CGN would compete in South Africa given that SPI already has a foothold.

5.1.7 Summary

None of the designs that might be ordered for South Africa is yet proven in operation. Experience with the designs with significant construction, EPR, AP1000, AES-2006 and APR1400 is poor with long delays and cost over-runs typical. Only the EPR and the AP1000 designs have been fully evaluated by US or European regulators although the dire financial state of the vendors, Areva and Toshiba, suggests these may not be viable options. The other designs are probably at least five years from completion of safety reviews.

6. South Africa's policy on nuclear power

6.1 The 2008 CfP

In 2006, the South African government forecast that a new unit could be on-line between 2010 and 2012.[17] By mid-2007, Eskom was targeting construction of 20,000 MW on new nuclear capacity by 2025, although completion of the first unit had slipped to 2014.[18] It expected a construction cost of US$2,500/kW. In January 2008, Eskom received two bids in reply to its call for tenders from November of the previous year for 3200-3600 MW of new nuclear capacity in the near term and up to 20,000MW by 2025. One bid was from Areva for two European Pressurised water Reactors, EPRs (plus 10 more for the long-term) and the other from Westinghouse for the three AP1000s (plus 17 more in the long term).[19] Both claimed their bids were "turnkey", but whether they were really turnkey in the fixed price sense or whether they were simply for the whole plant is not clear. It was

[17] Sunday Times (South Africa), "SA Going Nuclear", June 24, 2006.
[18] Nucleonics Week, "Cabinet Mulls Policy as Eskom Launches Consultation on New Plant", June 7, 2007.
[19] Nucleonics Week, "Eskom Gets Bids for Two EPRS, Three AP1000s, Bigger 'Fleet' ". February 7, 2008.

later reported that the bids were for around US$6,000/kW – more than double the expected price.[20] It was therefore no surprise when Eskom abandoned the tender in December 2008 on the grounds that the magnitude of the investment was too much for it to handle.[21] Engineering News reported that the issue was the credit rating of Eskom:[22] '.. ratings agency Standard & Poor's said on Thursday that South Africa's National Treasury needed to extend "unconditional, timely guarantees" across all Eskom's debt stock if it hoped to sustain the utility's current BBB+ investment-grade credit rating.'

While this experience is now nearly a decade old, it does illustrate some persistent features in South African nuclear power policy: electricity demand growth and hence the need for new (nuclear) capacity is persistently over-estimated; the cost of nuclear plants is persistently under-estimated; and the speed with which a nuclear programme can be implemented is over-estimated. These features were also apparent in South Africa's pursuit of Pebble Bed Modular Reactor technology from 1998-2010.[23] Nevertheless, the 2008 RfP did provide a strong benchmark of the current market price of nuclear power plants. Eskom's then credit rating was investment grade, albeit not strong enough to allow the nuclear order to go ahead, but by 2017, its rating had fallen five notches to BB-, 'non-investment grade speculative' commonly known as junk.[24]

6.2 The 2010/11 IRP

One of the most noteworthy of the recommendations of the 2010 IRP was that 9600MW of new nuclear capacity would be needed by 2030. However, as discussed above, this was not a result from the model, it was imposed on the model by the government. It is not clear what the model would have prescribed if this imposition had been made and how much cheaper the solution would have been without new nuclear. The Energy Minister, Dipuo Peters said in May 2011: '[The] first megawatts must kick in by 2023 so that the lights stay on.'[25]

A draft version of the IRP from October 2010[26] was based on a peak demand in 2030 of 67.8GW for the base case. This led to a requirement of about 39.5GW of new generating capacity of which 9.6GW would be nuclear with the first reactor coming on-line in 2023. As this was 13 years away then, it was said that there was no need for a decision until 2011. It was assumed that the maximum build rate was one unit completed every 18 months. The assumed construction cost, like the costs for most technologies, was provided by US consultants, the Electric Power Research Institute (EPRI) and was R26575/kW based on the EPRI estimate of US$3600/kW. It is hard to understand why, in the absence of any evidence that the 2008 costs were unreliable or that costs had fallen, the government would assume a construction cost which was only 60% of the winning bid from the RfP of only two years before. For other technologies, such as solar and regional hydro, gas and coal options, an EPRI assumption was not used. The discount rate was the government rate of 8%, the load factor 92% and the Dollar/Rand exchange rate of R7.40=US$1. The load factor assumption was also hard to understand given that the lifetime load factor of the Koeberg reactors was then only 69% and by 2016 no more than a handful of the approximately 400 reactors in operation worldwide had achieved lifetime load factors of 92%.

[20] Nucleonics Week, "Big Cost Hikes Make Vendors Wary of Releasing Reactor Cost Estimates", September 11, 2008.
[21] Nucleonics Week, "Eskom Cancels Tender for Initial Reactors", December 11, 2008.
[22] Engineering News, "Eskom Terminates Nuclear 1 Procurement Process, but SA Still Committed to Nuclear", December 5, 2008
[23] S Thomas (2011) 'The Pebble Bed Modular Reactor: An obituary' Energy Policy, 39, 2431–2440
[24] http://www.eskom.co.za/news/Pages/Marr22.aspx (Accessed March 23, 2017)
[25] Mail & Guardian 'SA needs to start nuclear bidding next year' May 19, 2011
[26] http://www.energy.gov.za/IRP/irp%20files/INTEGRATED_RESOURCE_PLAN_ELECTRICITY_2010_v8.pdf (Accessed January 6, 2016)

A revised version was published in March 2011 and this was the version that was promulgated in May 2011.[27] The programme of 9.6GW of new nuclear capacity was imposed on the model with the justification of: 'reduced risk exposure to future fuel and renewable costs'. The revised report did acknowledge that the assumed nuclear construction cost was too low and increased it by 40% to US$5000/kW. However, this still left it at 83% of the actual bid cost of 2-3 years earlier. The other assumptions, for example on load factor and discount rate were unchanged. The 'Revised Balanced Scenario' had the same maximum demand for 2030 as the first draft but foresaw a need for 41.4GW of new capacity by 2030.

6.3 The 2013 IRP

The 2013 revision[28] was not promulgated. There were major changes from the promulgated version. There was a modification to the methodology with the use of decision trees to identify key decisions that need to be taken if a given technology path is chosen. Decision trees appear to have been retained for the 2016 update. The forecasts now went out to 2050. Demand forecasts were somewhat lower as a result of low demand growth since 2010 with peak demand in 2030 forecast at 60.5GW and in 2050 80.2GW. There continued to be a 'Ministerial Determination' that 9.6GW of nuclear would be included although the first unit would not be completed until 2025 and the last in 2035. By 2050, only a further 3.2GW of nuclear was envisaged. While there was some discussion about the uncertainties of nuclear capital costs, the assumption, from 2011, updated to cover inflation was retained at US$5800/kW (in 2012 money), far below the real prices bid in 2008. The assumptions on discount rate and load factor were unchanged and the exchange rate was R8.01=US$1. Nevertheless, the plan did state that:

'No new nuclear base-load capacity is required until after 2025 (and for lower demand not until at earliest 2035) and that there are alternative options, such as regional hydro, that can fulfil the requirement and allow further exploration of the shale gas potential before prematurely committing to a technology that may be redundant if the electricity demand expectations do not materialise.'

6.4 The 2016 IRP

A draft version of a revised IRP was released for consultation in November 2016 with major changes in the underlying assumptions.[29] The exchange rate was R11.55=US$1, the required discount rate had been slightly increased by the South African Treasury to 8.2%. Demand forecasts for 2030 had fallen again with peak demand expected to be 57.3GW but forecast demand for 2050 was higher at 85.8GW.

However, there were major changes in the nuclear assumptions. The assumptions for the conventional technologies (coal, oil and gas) were provided by EPRI but the assumptions for nuclear were provided by the Department of Energy (DoE). The report stated:

'A hybrid cost is used for Nuclear based on the study commissioned by the DoE Nuclear Branch. The DoE report looks at costs in Asia which are generally less than those from the West which are in the EPRI report.'

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[27] http://www.energy.gov.za/IRP/irp%20files/IRP2010_2030_Final_Report_20110325.pdf (Accessed January 6, 2016)

[28] http://www.doe-irp.co.za/content/IRP2010_updatea.pdf (Accessed January 6, 2016)

[29] http://www.energy.gov.za/IRP/2016/Draft-IRP-2016-Assumptions-Base-Case-and-Observations-Revision1.pdf (Accessed January 6, 2016) and http://www.energy.gov.za/IRP/irp-presentaions/IRP-Update-Presentation-22-Nov-2016.pdf (Accessed January 6, 2016)

The assumed nuclear construction cost is R55260/kW or US$4785/kW, nearly 20% less than the 2013 assumption without taking account of inflation. The assumed load factor is unchanged[30] but the assumed reactor size is 1400MW instead of 1600MW. Despite the large reduction in forecast construction costs, without the Ministerial Determination, the first nuclear plant to enter the least cost plan is not till 2037 when one reactor is called for, then a second in 2039, with an additional 13 reactors required between 2041 and 2050. A presentation by the DoE shows that, unsurprisingly, if renewables are constrained and there is a 'carbon budget', effectively limiting the alternatives to nuclear, the first reactor is needed earlier, in 2026, and 25.8GW of nuclear (19 reactors) is needed by 2050.

No Ministerial Determinations were included in the draft Base Case, although it seems likely that some will be imposed in the final case and these may include a nuclear programme forcing nuclear capacity into the plan before 2037.

6.5 The MACE critique of the 2016 IRP

In 2014, the South African Energy Minister set up a Ministerial Advisory Council on Energy (MACE) composed of a wide range of interests including academics, civil society, labour and engineering expertise. As its name makes clear, it is purely an advisory body with no powers. In September 2016, in response to concerns expressed by its members, the Minister of Energy appointed a Working Group of four members of MACE to look at these concerns.[31]

Its main finding was:

'A least cost IRP model, free of any artificial constraints and before any policy adjustments does not include any new nuclear power generators. The optimal least cost mix is one of solar PV, wind and flexible power generators (with relatively low utilisation).'

It had three recommendations (see Appendix). The first essentially said that the IRP should not be constrained, in particular, the limits on the use of solar PV and wind should be removed. The second said that the solar PV and wind costs used in the 2016 IRP were too high and costs that reflected actual experience should be used. It noted that even though these costs appeared to have been over-estimated, nuclear still did not form a part of the least cost solution. The third stated that where policy adjustments were imposed by the government, the additional cost of these adjustments compared to the least cost. None of MACE's members contested these recommendations. The Working Group concluded:

'If the above recommendations are applied to the IRP process, it will result in a methodology that is consistent, will allow the energy planners to achieve the most efficient price path and will lead to an outcome that MACE as a whole will be able to endorse and defend in the public participation phase of the IRP to current and future electricity consumers in South Africa.'

6.6 The 2016 CfI

On 7th September 2016 the Minister of Energy announced to Parliament that the Department of Energy would release its request for proposals for nuclear power on September 30, which would "test the market".[32]This act and the subsequent proposal by Eskom to launch a call for proposals for

[30] Table 7 of the plan shows the nuclear load factor as 90% while the presentation shows it as 92%.
[31] http://www.sapvia.co.za/wp-content/uploads/2016/12/311016-MACE-WG-note-on-IRP-2016-FINAL.pdf (Accessed January 18, 2017)
[32] http://www.fin24.com/Economy/controversial-nuclear-programme-to-launch-at-month-end-20160908 (Accessed January 18, 2017)

nuclear plants makes a mockery of the IRP process. If Eskom goes ahead and orders two new reactors, this will pre-empt other cheaper generation options.

Despite this, the government initially approved the decision to launch a CfP. It stated: 'We fully support Eskom in this regard. Eskom has also indicated that regardless of the nuclear commissioning date, the RFP provides an opportunity to get an indication of costs from the market that will help inform the nuclear power costs for the country in the future.'[33] A CfP seems an extraordinarily expensive and time-consuming way to discover costs.

In November, the Energy Minister issued a statement 'clarifying' the situation.[34] It denied press reports that the government had decided 'to delay nuclear until 2037'. It stated the 'base case' presented was a 'starting point' and talked of at least 12 scenarios that would be investigated. In particular it stressed a 'carbon budget' scenario that limited the amount of carbon dioxide that could be emitted. The contribution of renewables was also limited because of 'network constraints'. Inevitably this left the model with no other option than to pursue a nuclear programme as soon as possible with the first reactor needed on line in 2026. The strong implication is that the Ministerial Determination for 9.6GW of nuclear by 2035 will remain.

In the event, Eskom did not go ahead with a CfP, choosing instead to launch a Request for Information (RfI).[35] No explanation has been given by Eskom as to why it did not proceed with the CfP, nor has the government commented on this change.

7. Nuclear costs

While the 2016 draft IRP used costs for nuclear generated by the DoE, EPRI did provide their own estimates and these were published by the South African government.[36] EPRI only considered the EPR and the AP1000, the technologies that competed and were found to be too expensive in 2008. It estimated that the cost in 2015 money of the AP1000 would be R60,000/kW (US$5200/kW) and for the EPR R80,000/kW (US$7000/kW). No explanation is given as to why EPRI's estimates were not used nor are the assumptions and methodologies used by the DoE in coming to their estimates given.

The report merely states: 'A hybrid cost is used for Nuclear based on the study commissioned by the DoE Nuclear Branch. The DoE report looks at costs in Asia which are generally less than those from the West which are in the EPRI report.' Without further details on the nuclear study, it is difficult to examine this forecast, although it appears that the assumption is that South Africa will be able to obtain 'Asian' costs rather than 'Western' costs. Only two reactors that might be considered to meet current standards have been completed in Asia, one in Russia and one in Korea (as argued above, this design would need significant upgrades to meet European standards) and costs for these were not available. The cost of earlier reactor designs is not relevant to the costs of new designs even if South Africa was able to achieve 'Asian' rather than 'European' costs.

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[33] http://www.energy.gov.za/IRP/2016/Planning-for-Power-in-South-Africa-by-Minister-of-Energy.pdf (Accessed January 6, 2016)

[34] http://www.iol.co.za/business-report/opinion/planning-for-power-in-sa-2094579 and http://us-cdn.creamermedia.co.za/assets/articles/attachments/64509_media_release_-_nnbp__re_request_for_proposals_-_minister_of_energy.pdf (Accessed January 11, 2017)

[35] http://cdn.24.co.za/files/Cms/General/d/4819/8cf2aab25c44473cb035c8606cbf264e.pdf (Accessed January 6, 2016)

[36] http://www.energy.gov.za/IRP/2016/IRP-AnnexureA-EPRI-Report-Power-Generation-Technology-Data-for-IRP-of-SA.pdf (Accessed January 6, 2016)

If we focus on Asian countries that have completed at least three PWRs of about 700MW or more from 2000 onwards, there are only two countries. China has completed 33 and Korea 9.[37] However, reliable data on Chinese costs are not available and only one of these 42 reactors (an APR1400) uses a design that might be described as Generation III/III+ and might therefore be considered for South Africa, albeit the completed reactor uses a design that would need substantial upgrading for it to be acceptable in Europe or the USA. Outside Asia, only Russia (six reactors) has completed more than three large PWRs since 2000, but as with China, no useful cost information is available. Only one of the reactors uses a design that might qualify as Generation III/III+.

Forecast construction costs have never been a good indicator of actual costs with outturn costs much the best indicator. While no outturn costs are available for any of the current designs, some information on actual costs for the plants under construction in the USA, France and Finland is available. In the USA, both the Vogtle and Summer projects each for two AP1000s are about three years late and 30 per cent over budget at about US$7000/kW. The Flamanville (France) project, who may not be completed because of flaws in the reactor vessel, is six years late 3.2 times over budget ($7000/kW) and the Olkiluoto (Finland) project is nine year late and nearly three times over budget (US$5700/kW). Olkiluoto construction was started in 2005 and Flamanville in 2008 so if inflation is taken account, the costs will be significantly higher in current money.

There is little evidence from calls for tenders in the past decade with only three going ahead, including the one in South Africa. The lowest bid for Canada in 2008 was also about US$6000/kW (the EPR) and like South Africa, it was too high for the tender to proceed. A tender for four reactors in UAE was won by KEPCO in 2008 with the APR1400 for US$3600/kW nearly half the price of the next lowest bid (by the EPR). How far this low cost bid reflected real costs (it was Korea's first attempt to export reactors) and how it reflects the lack of safety features required for Europe, how is not clear. The then CEO of AREVA, Anne Lauvergeon, "likened the APR1400 to 'a car without seat belts and airbags because the South Korean design, unlike AREVA's EPR, doesn't have a double aircraft-crash-proof containment or a core catcher".[38]

The most recent nuclear order with reliable price information is the UK's order for two EPRs at a cost of £18bn or US$7000/kW, albeit construction is not expected to start before 2019.

Overall, if we bring all these prices up to today's money, the DoE's estimate of less than US$5000/kW is clearly far below current prices.

8. Conclusions

The idea underlying Integrated Resource Planning, that consumers electricity demands should be met as cheaply as possible consistent with other non-financial objectives, such as reliability and environmental targets, is sensible. However, the exercise becomes pointless if the government is going to prescribe the means (the supply options) to meet the ends, the policy goals. The way in which it is being implemented in South Africa is a travesty of the methodology. The MACE Working Group had similar concerns. It asked that the cost of government policy adjustments be explicitly identified so the public can judge whether the extra expenditure is worthwhile.

Extending the forecast period to 35 years far over-stretches the capability to forecast the variables. Some variables, especially nuclear construction costs, are not well known now, much less in 35 years' time. Others, such as world fossil fuel prices and currency exchange rates cannot be forecast

[37] Japan has completed four reactors but three are BWRs, India has completed 11 but 9 of these are heavy water reactors and Pakistan has completed 3 but these are 300MW reactors

[38] Nucleonics Week, "No core catcher, double containment for UAE reactors, South Koreans say", 22 April 2010

with tolerable accuracy more than a year or two ahead. The imposition of 'Ministerial Determinations' with little justification, which force the model to choose certain options regardless of cost, weakens the credibility of the results. The actions of Eskom going ahead with attempts to procure nuclear capacity before the IRP has been discussed and adopted pre-empts the results of the IRP.

It is difficult to avoid the conclusion that the South African government with the assistance of Eskom, is determined to try to force through a nuclear programme regardless of costs. It is doing this through Ministerial Determinations and by giving hopelessly unrealistic forecasts of nuclear costs and by over-stating future demand. MACE also believes that the cost of some of the alternatives to nuclear power, solar PV and wind were being over-stated. Even with nuclear construction cost forecasts that are about half the level of realistic estimates and with overestimates solar PV and wind, the model did not find nuclear power was part of the least cost solution until beyond 2040 unless the alternatives, renewables and fossil fuels, were so heavily constrained as to not be able to make a contribution.

Appendix Recommendations by MACE

Recommendation 1

Consistent with the approach used in IRP 2010, the scenario that forms the **Base Case must be least cost and free of any policy adjustments**. The Working Group therefore recommends that the annual new-build limits imposed on solar PV and wind are removed and this unconstrained scenario (presented in **Table 2 in this document**) forms the **Base Case for the IRP 2016**.

Recommendation 2

The input costs assumed for solar PV and wind in the IRP 2016 are significantly higher (in real terms) than what was assumed in the IRP 2010, despite the fact that tariffs actually achieved in the Renewable Energy IPP Procurement Programme (REIPPPP) are lower than what IRP 2010 had assumed. This apparently is a result of technical mistakes made when converting average tariffs achieved in Bid Window 4 of the REIPPPP into model input costs, combined with a reduced cost reduction potential for solar PV compared to IRP 2010. It is therefore recommended to **adjust the currently assumed costs of both solar PV and wind downwards** to correctly reflect South African actual tariffs as well as anticipated cost reductions as per IRP 2010 in the case of solar PV.1

Recommendation 3

Any policy-adjustment to or the imposing of a constraint on the least-cost unconstrained Base Case will increase the total cost of the power system and therefore the average tariff to the consumer. The Working Group recommends that the **cost differences between the least-cost unconstrained Base Case and each alternative scenarios be reported** so that a value for money case can be assessed by all stakeholders when a certain policy decision or a constraint is proposed.