SOUTH AFRICA'S ELECTRICITY CHOICE

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Introduction

The South African government's obsession over the past decade with nuclear power may finally come to an end with a new president and administration committed to restoring good governance and securing reliable electricity supply at least cost to support economic growth and development[1,2]. The inherent complexity of nuclear procurement, financing, and especially construction, means no new nuclear generated electricity could flow for at least a decade even with immediate procurement, and then only at prices well above other electricity options[3]. The risk that the project might collapse as unfinanceable[4,5], or through corruption, creates further uncertainty around South Africa's electricity choices.

Some South African advocates[6,7,8] assert that nuclear costs will prove affordable for five reasons:

1. vendors are eager to sell;
2. vendor financing might come at low cost and long debt tenors;
3. higher prices or subsidies are worth paying for such a "strategic input" as nuclear electricity;
4. South Africa is "ideally positioned" to help satisfy the African continent's "huge appetite for nuclear energy"; and
5. Western countries' "severe overregulation and a culture of being overly risk averse", overreacting to the ostensibly innocuous events at Chernobyl and Fukushima, caused "severe cost and schedule overruns" that South Africa, presumably with a more sensible risk perception, could avoid.

Whether capital markets would validate these assertions or view them as signs of disconnection from technical and market realities is a testable empirical question.

The country's latest two flirtations with modern nuclear power have not gone well. First, plans for a homegrown "pebble bed" modular reactor (PBMR)[9] were abandoned in 2010 after 12 years and US$1.8 billion[10] had been wasted – much of it after the project was acknowledged to be a non-starter (as Eskom presumably knew when its U.S. utility partner pulled out in 2002).

Now rarely mentioned, the PBMR found no customers or investors, but its advocates' ambition and influence live on.[11]

In 2008, perhaps slightly chastened by the unfolding PBMR episode, the government rejected as "uncompetitive and unaffordable" bids to build two light-water reactors totaling 3,2 gigawatts (GW or billion watts). The two undisclosed bids were reportedly more than twice government's expectation[12]. Despite such prices, the rejected nuclear vendors, which didn't include Russia[13], failed to thrive: Areva became insolvent and is now being bailed out for €5bn by French taxpayers[14], while Westinghouse sold its nuclear business to the now junk-rated Toshiba, and is currently in bankruptcy proceedings[15].

Despite these setbacks, the South African government's ambition mushroomed into a plan three times bigger than in 2008 – 9.6 GW of nuclear power – even though each GW will now cost more because real costs have risen by more than one-fourth[16] while the rand has lost half its value. With the national debt downgraded to junk-bond status[17], "affordability" can hardly have improved.

Electricity planning

Government's nuclear policy consistently cites as its analytic basis the *Integrated Resource Plan (IRP) for Electricity 2010 to 2030*, which was updated twice in 2010 after public consultation, promulgated 25 March 2011, and formally published 6 May 2011[18]. It called for 13% nuclear capacity and 21% solar and wind capacity in 2030. The IRP's analysis found new nuclear power not economically optimal, even at real dollar costs far below today's (though 40% above initial assumptions) and assumed to fall by a further 3%/y (they instead rose by roughly 5%/y).

The IRP nonetheless committed to 9.6 GW of nuclear power – as a matter of "policy" despite its inconsistency with the National Development Plan[19]. This "non-negotiable" nuclear policy has been enunciated consistently by President Zuma and his energy ministers from 2010[20], even as its stated rationale has steadily evaporated. That rationale was chiefly "to account for the uncertainties associated with the costs of renewables and fuels". As we'll see, South African renewable energy costs were then discovered in the marketplace and proved to be far lower than empirical nuclear costs, with the spread between them continuing to widen; renewables, just like nuclear power, displace the same fuels whose uncertain prices were of concern; and renewables meet all the other stated policy objectives as well as or better than nuclear power.

A 2013 draft IRP update[21], though somewhat flawed[22], was posted on the Department of Energy (DoE) website in November 2013[23], soliciting public comment by February 2014 for consideration “in preparing a final draft IRP 2010 Update which [was to] be submitted to Cabinet for final approval by March 2014”. That updated draft was required, said the DoE’s website, because “there have been a number of developments in the energy sector” since 2010 and “the electricity demand outlook has changed markedly.”

The 2013 draft update strengthened the previous finding that nuclear new-build lacked economic rationale. It concluded that “in 2015, even if demand is high and there is no prospect of shale-gas power plant,…if nuclear costs exceed $6 500/kW, then the [nuclear] procurement programme should be abandoned.” Specifically, the draft found new nuclear plants clearly uneconomic if they got costlier, or renewables got cheaper, or demand growth slackened. In fact, all three strongly occurred. The plan indicated new nuclear to be unneeded for 15 to 25+ years – or ever if its capital costs rose another 12%. They have since risen much higher than this, with costs in some countries exceeding $6 500/kW[24,25] while renewables cost less and (using the best U.S. data) performed one-third better[26,27] than the 2013 draft update had assumed. Two years on, the gap between nuclear and renewable costs had widened further[28,29].

However, the IRP 2013 was never finally approved and the parliamentary energy portfolio committee chair was reported at the time saying it “will never see the light of day”; indeed, it was never gazetted[30] and can thus be officially ignored.

By 2016, many of the 2013 draft update’s data had become even more antiquated and a decision was made by the DoE to produce a further IRP update, which was gazetted on 25 November 2016 for public consultation[31]. In the base (or reference) case, nuclear energy appears only from 2037, but after questions posed formally to the department by the Ministerial Advisory Council on Energy (MACE), it became clear that the modelers had placed artificial constraints on the amount of solar or wind energy that could be built in any one year. Once these constraints were removed, nuclear energy did not appear in any of the optimal least-cost scenarios[32].

The government ignored rational warnings and requested Eskom to expedite the procurement of nuclear power. However, it soon started butting up against increasingly vocal challenges from various quarters. In 2016, civil society organisations launched a court challenge to government’s continued preference for nuclear power. On 26 April 2017, the Western Cape High Court not only set aside a number of international nuclear cooperation agreements, including that with Russia, but also invalidated the ministerial determination (made in terms of section 34 of the Electricity Regulation Act) to procure nuclear electricity. The court found that the National Energy Regulator of South Africa (NERSA) had concurred with this ministerial determination (as required in law) but had done so without adequate public consultation. In effect, the ruling forced government to restart the procurement process from scratch, including producing a new update of the IRP and a new official ministerial procurement determination, but only after the concurrence of NERSA is obtained, and this only after adequate public consultation[33].

During the last quarter of 2017, the DoE asked the IRP modelers (based in Eskom) to produce another updated IRP to reflect lower actual electricity demand and the latest comparative energy prices. The DoE may have noticed the global publicity about plummeting renewable energy prices, now so low in many good sites, without subsidies, that they rival or undercut just the operating costs of many existing nuclear or fossil-fueled power stations, let alone the total cost of power from new ones[34,35].

The resulting new electricity demand forecasts of the modelers are almost certainly still too high, as are their assumptions of renewable energy costs. In a number of emerging economies in 2017, we have seen solar and wind auctions deliver prices that are half those registered in the last renewable energy auction in South Africa held in November 2015, after which Eskom had stalled further bids by refusing to sign PPAs [36,37,38]. And the DoE's nuclear cost assumptions seem much lower than many recent contracts, such as the Rosatom deal for up to $21bn in Egypt[39].

But even with these conservative assumptions, nuclear energy is not picked in any of these new South African modeling scenarios, other than one where artificial constraints are placed on how much solar and wind energy can be built and where additional carbon budget limits are imposed. Even in this extreme scenario, nuclear energy would only be required after 2039.

These outcomes are consistent with the IRP update undertaken by the DoE in 2016 under the direction of the Ministerial Advisory Council on Energy and with the Council for Scientific and Industrial Research's (CSIRs) model which used the same PLEXOS software and assumptions as the DoE in 2016.[40] A few years back, the National Planning Commission asked South Africa's premier university-based energy modeling group – the University of Cape Town's Energy Research Centre – to run an independent model. They too came to the same conclusion[41].

These outcomes were not welcomed by the nuclear section in the DoE and the modelers were asked to run a scenario where 9,6 GW of nuclear power stations are "hardwired" or forced into the model. Fortunately, the modelers also calculated the additional wholesale cost of electricity in this scenario – R800bn over 20 years at net present value[42].

The optimal, least-cost mix recommended by all these models includes solar and wind energy complemented by pumped storage, hydro-electricity and gas turbines or engines, on top of legacy coal fired powered stations.

South Africa's Energy Minister decided to ignore the conclusions of his modeling team and presented a revised IRP2017 to Cabinet on 6 December 2017, which still included the procurement of 9,6 GW of nuclear power but over a longer period to reflect lower electricity demand.

South Africa's Constitution requires administrative action to be lawful, reasonable, and procedurally fair. Almost certainly, civil society organisations will go back to court to challenge the rationality of the latest IRP and any actual procurements that might follow.

The IRP should be a living planning document that is regularly revised and updated as necessitated by changing circumstances. At the very least, it should be revised by the DoE every two years and should provide a rational and informed base for power procurement and investment decisions. The way in which DOE has continued to manipulate and adjust least-cost, optimal plans to incorporate nuclear power reduces stakeholder confidence that Cabinet is fully informed about the very fast-moving competitive landscape in electricity[43]. Just *within one year* (2016), levelised world costs for new onshore windpower fell by 18%, for offshore wind by 28%, and for utility-scale photovoltaics (PV) by 17%[44], while low bids fell 37% for Mexican PV and 43% for EU offshore wind[45]. Yet South Africa's Cabinet is still apparently relying on data using 2010 cost data if not earlier – myopia that would not pass muster in any private-sector boardroom.

Shifts ever more adverse to nuclear new-build have accelerated on every front. The global nuclear enterprise is slowly dying of an incurable attack of market forces[46]. Financial distress stalks vendors, with cascading insolvencies spreading in the past two years. Construction cost and delays keep rising worldwide[47]. As a Frost & Sullivan analysis found in 2014[48], whatever is driving South Africa's nuclear push, it's not economics. And as financial consultant Dirk de Vos concluded[49], "The nuclear industry can only exist when the state underwrites its cost. Countries that procure their power through democratic, transparent and market-based methods are not building new reactors."

All this rasies several questions: what could emerge from the "full, transparent and thorough"[50] cost-benefit analysis previously requested by the ANC national general council in 2015[51,52], and from the Constitutionally required transparent competition demanded by the National Union of Mineworkers[53]? What salient evidence was absent when Cabinet formally launched the nuclear procurement programme based on the gravely outdated 2010–11 analysis? What major decision factors have changed since the failed 2008 nuclear plan? We explore these questions in the context of the two most dynamic competitors – renewable generation and efficient use – then discuss policy risks.

Renewable energy

While the 2010–11 Plan was rapidly going out of date and stakeholders debated what South African renewable electricity might cost, South Africa's DoE launched a bold experiment to substitute market data for speculation[54]. By end-2017 its pioneering auctions or open-tenders had resulted in the selection of 6.3 GW of renewable energy projects of which 3.2 GW had been constructed and connected to the grid (with average lead times of 1.6 years, one-sixth nuclear power's norm)[55]. In January to June 2015 alone, that new renewable capacity saved R4bn more – in fuel and in avoided load-shedding – than it cost[56]. Despite Eskom's delay in signing contracts with winning bidders in the most recent auction[57], it may fairly be said that South Africa has been a world pioneer in the transparent competitive procurement and market development of renewable electricity, alongside such other emerging economies as Brazil, Mexico, Chile, and lately India[58], which (like China) is adding modern renewable generation faster than nuclear power did in its fastest global growth decade.

Renewable investment and price results have been impressive. South Africa's transparent auctions have already cut solar PV electricity prices by close to 80% and wind energy by nearly 50%[59], with further price drops in the latest, so-called expedited, auction for both wind and PV power to about 4.7 US¢ per kilowatt-hour (kWh). Renewable costs in South Africa are now near the lower end of world market prices[60]: unsubsidised PV and onshore wind in the world market today sell at a levelised real price at or below 3–5 US¢/kWh[61], while the latest renewable auction prices in emerging economies have fallen below 2 US¢/kWh[62]. Thus, modern renewables are up to seven-fold cheaper than new nuclear power, which sells in the world market for between 9 and 15+ US¢/kWh[63,64,65] – *e.g.*, 12.4¢ for a Turkish nuclear plant planned by Russia (repeatedly delayed[66], unable to attract private financing[67], suspended[68,69] for a time, but resumed in 2017[70]).

Renewables everywhere thrive on the fair and open competition that no new nuclear plant has achieved anywhere. Nuclear costs are murky, rising, and augmented by the long-term burdens of decommissioning the radioactive plants[71,72] and storing their wastes for millennia. In contrast, renewable energy costs are transparent and falling. Windpower and PV have no costly long-term obligations, consequential wastes, climate burdens, or risks, use virtually no water[73], and have almost no operating costs: they burn no fuel, and the wind and sun are free.

This renewable revolution is global[74]. From Chile and Mexico to India and the Middle East, renewables sweep unsubsidised auctions. Worldwide, they dominate new capacity[75], and are expected by Bloomberg New Energy Finance (based on the world's most detailed transaction-tracking and market analytics) to capture 72% of global power generation investment to 2040 as levelised costs plummet by another 66% for PV, 47% for onshore wind, and 71% for inshore wind[76]. Even the conservative International Energy Agency forecasters, who had raised by one-third their solar growth forecasts (already 19 times those they made in 2000), expected renewables' lower cost to drive *35-fold* greater global capacity additions in 2017 to 2040 from renewables than from nuclear power[77]. There is no reason to expect SA relative prices to drive the opposite conclusion. Consistent with these expectations, 2016 new capital commitments worldwide were eight to 23 times larger for modern renewables than for nuclear power[78], and of 162 nations' Paris pledges (INDCs), only five proposed climate mitigation by expanding nuclear power, *vs.* 111 with renewable plans or targets.

China has generated more windpower than nuclear electricity since 2012. In 2013, it added more PV than the U.S. had added cumulatively since developing it in 1954; in 2014 it invested nine times more in renewables than nuclear; in 2015 it added 46 GW of wind and solar power (more than South Africa's 2010 total generating capacity); and in 2016, it built three football pitches' solar installations per hour, including 11.3 GW of solar capacity in the month of June alone. China is building two-fifths of the world's new nuclear reactors (albeit with rising delays, costs[79], and economic doubts[80]), but invested ninefold more in renewables in 2014, and in 2015, boosted its 2020 wind-and-PV target to 450 GW while its nuclear efforts lagged[81]. By then the immediate past Chairman of China's State Grid was predicting [82] that in 2050, global electricity will come from 14% hydro, 73% other renewables (six times their current market share), 7% gas, 3% coal, and just 3% nuclear (less than one-third its current market share).

India has quadrupled its renewables target. It is planning 100 GW of solar power (now cheaper than coal power) by 2022[83] and can electrify households cheaper and faster from decentralized solar power than from the grid. In the past few years, India's windpower, like China's, has out-produced its nuclear stations[84,85].

Over 3bn people now get more non-hydro renewable than nuclear electricity, in three of the world's four top economies (China, Germany, Japan) and in Brazil, India, Mexico, Holland, Spain, and the United Kingdom[86]. From 2000 to 2016, windpower added 11 times nuclear's added capacity and PV seven times[87]. Measured in increases of generated output, wind outpaced nuclear 29-fold, and PV 10-fold. In each year from 2010 to 2015, nuclear power added fewer than 6 GW, virtually all financed by conscripted capital, while modern renewables added over 80 GW and got more than a quarter-trillion dollars' voluntary private investment.

This revolution has come to Africa. African heads of state now back the continent-wide African Renewable Energy Initiative, which plans – emphasizing small-scale "virtual power stations" – to develop at least 10 GW of new renewable capacity by 2020 and at least 300 GW by 2030, "potentially making the continent's electricity supply the cleanest in the world." This $500+bn effort, led by such nations as Kenya and Rwanda, is backed by the African Development Bank, World Bank, and private investors[88]. With the lowest-cost African solar microgrids now costing half the average, and the best designs (validated elsewhere) able to cut Africa's lowest cost by another half[89], Africa's solar revolution is rapidly accelerating. There is no corresponding evidence that the African continent's "huge appetite for nuclear energy" claimed by nuclear advocates and referenced at the start of this paper is financeable or indeed more than rhetorical.

Social and economic benefits of renewable energy in South Africa

Importantly, most of South Africa's R193bn in renewable projects were financed by banks and private investors, including R53bn from abroad[90]. It's not hard to see why: a solar plant built in sunny South Africa pays for itself twice as fast as one in Italy[91]. And while big renewable projects are very fast, small-scale renewable projects, such as solar power for a home or a village, can be up and running within *weeks*.

The International Renewable Energy Agency (IRENA) found that worldwide, doubling renewables' energy share by 2030 (to 36%) could raise global GDP up to 1.1%, improve welfare up to 3.7%, and support over 24 million renewable-energy jobs[92]. These benefits are fractal, demonstrated by renewable initiatives' already bringing important economic benefits to South Africans[93].

A unique feature of South Africa's renewable energy IPP programme has been its promotion of social and economic benefits. Bids were evaluated on a 70:30 split between price and a basket of economic development (ED) criteria divided among seven broad categories: job creation, local content, management control, preferential procurement, enterprise development, and socio-economic development. Table 1 shows the weighting given to each of these categories as well as threshold levels that had to be reached for bids to be compliant and target levels to increase bid scores[94].

Table 1: Economic Development Criteria Thresholds, Targets and Achievements in the REIPPPPP

Element (Weighting)	Description	Threshold	Target	Achieved (BW1-3)
JOB CREATION (25%)	RSA Based employees who are citizens	50%	80%	90% (Construction) 95% (Operations
	RSA Based employees who are Black people	30%	50%	80% (Construction); 82% (Operations)
	Skilled employees who are Black people	18%	30%	66% (Construction); 77% (Operations)
	RSA based employees who are citizens and from local communities	12%	20%	51% (Construction); 67% (Operations)
	RSA based citizens employees per MW of Contracted capacity	N/A	N/A	N/A
LOCAL CONTENT (25%)	Value of local content spending	40% – 45%*	65%	50% (R 37 billion)
OWNERSHIP (15%)	Shareholding by Black People in the Seller	12%	30%	31 %
	Shareholding by Local Communities in the Seller	2.5%	5%	11%
	Shareholding by Black people in the Construction Contractor	8%	20%	18%
	Shareholding by Black people in the Operations Contractor	8%	20%	19%
MANAGEMENT CONTROL (5%)	Black people in Top Management	-	40%	61%
PREFERENTIAL PROCUREMENT (10%)	BBBEE[1] Procurement**	-	60%	88%
	QSE[2] & SME[3] Procurement**	-	10%	33%
	Women Owned Vendor Procurement**	-	5%	3% (Construction); 4% (Operation)
ENTERPRISE DEVELOPMENT (5%)	Enterprise Development Contributions***	-	0.6%	(No percentage provided) R 115,2 million
SOCIO ECONOMIC DEVELOPMENT (15%)	Socio-Economic Development Contributions***	1%	1.5%	1.2% (R357 million)

**Depending on technology. 45% for solar PV, 40% for all other technologies.*
***As percentage of total procurement spend.*
****As a percentage of Revenue*

1 As per the Government Gazette No. 36928 General Notice 1019 to the Broad-Based Black Economic Empowerment Act (53/2003) on the issue of Codes of Good Practice. The fundamental objective of the Act is to advance economic transformation and enhance the economic participation of black people in the South African economy. Companies are scored on a BBBEE scorecard and assigned a corresponding BBBEE level. The elements that make up this score are: preferential procurement (20%); ownership (20%); enterprise development (15%); skills development (15%); employment equity (15%); management (10%); and socio-economic development (5%).

2 Qualifying Small Enterprises.

3 Small and Medium Enterprises

Table 2: REIPPPP Job Creation Commitments for Auctions 1 – 4 (1 job = 1 job year)

Jobs during Construction			Jobs during Operations			Total Jobs		
SA Citizens	Black Citizens	Local Communities	SA Citizens	Black Citizens	Local Communities	SA Citizens	Black Citizens	Local Communities
33,799	24,746	13,328	75,644	59,818	44,362	109,444	84,564	57,690

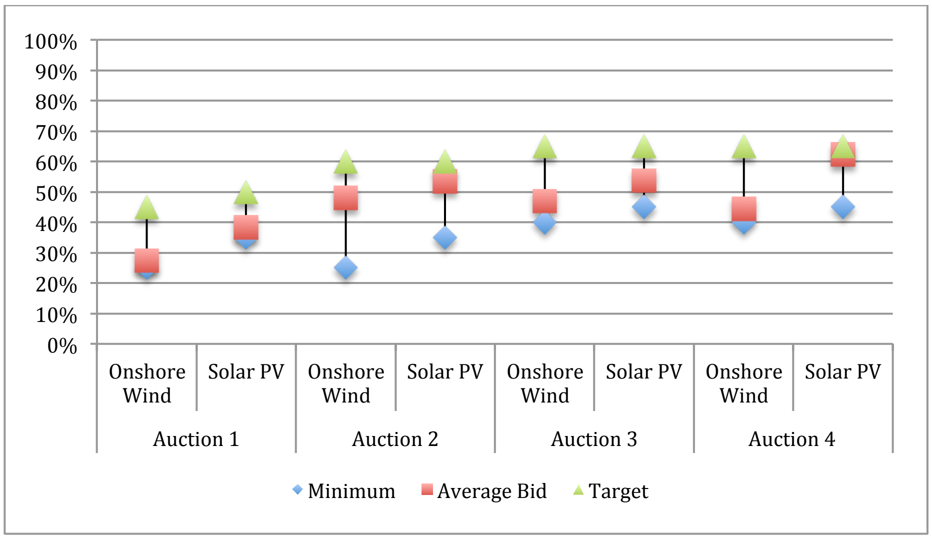
Source: Authors' calculations from DOE Project IPP data

Successful bidders are required to report on each of these commitments on a quarterly basis, and a specific provision in the Government Support Agreement between the bidders and the DoE allows for fines or the cancelling of the Power Purchase Agreement if a project underperforms on these commitments. According to reports from the DoE's IPP Office, completed projects have been meeting or exceeding their economic development commitments for all the above categories[95].

Job creation accounts for 25% of the ED points available and comprises five sub-elements, as elucidated in Table 2. A total of 32,532 job years have been created through the programme to date for South African citizens, with construction phase employment being significantly higher than planned. The 57 projects that have successfully completed construction and moved into operation planned to deliver 20,689 job years during the construction phase, but achieved 29,046 job years. The number of people from local communities employed during construction was more than double that stated in project bids, and the number of black South African citizens employed during construction also exceeded the planned numbers by 83%[96]. While the majority of jobs created appear to be unskilled[97], the share of skilled black citizens as a percentage of skilled employees also appears to show significant results, for both construction (67%) and operations (77%), substantially exceeding both the threshold (18%) and target (30%) for this element.

Equipment local content requirements also account for 25% of the total ED score, with the objective of creating jobs through increased local manufacturing. This criterion, assessed by the value of local content expenditure in relation to all expenditure for the construction of the project, has undergone several changes as the renewable energy auctions progressed. A stricter definition of what constituted 'local content' was enforced in the second auction, with further refinements to the definition and required disclosures in the third auction. Local content thresholds and targets were also increased for almost all technologies across the subsequent renewable energy auctions – and consistently exceeded (Figure 1). While there have been questions raised about the manner in which some of these requirements have been met and the actual long-term impacts of these commitments[98], the programme's local content requirements have led several technology and component manufacturers to establish local manufacturing facilities. Current local content commitments by IPPs amount to R67,1 billion, equivalent to about 45% of total equipment value. Actual local content expenditure of projects that have started and completed construction exceeds this level and is now about 50% of total project value[99].

Figure 1: Local Content Tracking - Actual % vs. targets (active projects)[100]



The South African renewable energy auctions also aim to direct development to previously marginalised and disadvantaged groups and communities. Black South Africans own, on average, 31% of projects that have reached financial close (the threshold requirement was 30%). Black local communities further own on average 11% of the equity of projects (the target was 5%). An average of 18% shareholding by black people in construction (EPC) contractors has been achieved – against a threshold level of 8% and a target of 20%. The shareholding of black South Africans in O&M companies is 19% for the 56 projects in operation, against a threshold level of 8% and a target of 20%[101].

Targets for enterprise development and procurement from designated groups were also exceeded. Winning bidders were further required to invest a minimum of 1% of revenue in socio-economic development projects amongst local communities. Bidders have committed 2,2% of all project revenue in five broad categories: education and skills development (40%); social welfare (22%); health care (4%); general administration (10%); and enterprise development (24%)[102].

Some problems and challenges have emerged around these investments in local community projects including: coordination and alignment with other energy projects in the area, as well as broader government development strategies; the lack of experience and capacity of energy projects in community upliftment initiatives; and the ability of recipient communities to absorb these contributions. Furthermore, the equity dividend benefits that might accrue to local communities will only be fully realised after the loans that financed local equity have been serviced[103].

Reliability of renewable energy

A regular critique of renewable energy made by proponents of nuclear power is that it is unreliable – the wind does not always blow and the sun does not always shine[104]. However, the objective function of the computer model – PLEXOS – used to prepare South Africa's IRPs is a least-cost, optimal generation mix that meets a *specified security of supply* each hour of the day throughout the year. The latest IRP2017 modeled by Eskom also records that there is sufficient "dispatchable power" to fully cover peak demand.

The IRP 2017 incorporates concentrated solar power plants procured in the first three renewable energy auctions. While this power source is still regarded as expensive in South Africa, global developments indicate that it is becoming increasingly competitive. Night-time solar power from stored solar heat – similar to the 9.3 hours of thermal storage in South Africa's new Bokpoort solar plant in the Northern Cape[105] – sells in Chile[106] for 9.7 US¢/kWh, one-half above the day-time solar price (6.5¢) but one-third below the EU nuclear price (~13–15+¢)[107,108].

But even without bulk electrical or thermal storage, wind and PV's accurately forecastable variability can readily be managed by approximately several proven methods that are generally profitable in their own right[109]. This is not just a theoretical possibility but well proven in practice. In 2014, four EU countries not rich in hydropower, met about half their electricity needs from renewables (Spain 46%[110], Scotland 50%[111], Denmark 59%[112], Portugal 64%[113]) without increasing bulk storage or decreasing reliability. They run their grids as a conductor leads an orchestra: no instrument plays all the time, but the ensemble continuously produces beautiful music. Similarly, renewables met 33% of Italy's 2014 electricity needs, 27% of Germany's, 22% of Ireland's, 20% of France's, and 19% of Britain's. Most of these renewable fractions continued their upward progress in 2015 and 2016[114], generally accompanied by *increasing* reliability of grid supply[115] and by moderating or decreasing wholesale electricity prices (often overlooked by those who focus on high *retail* prices in a few countries, notably Denmark and Germany, where longstanding policy heavily taxes household electricity).

South African wind and solar tend to work best at different times, together making contributions to morning and evening peak loads[116]. The government wants nuclear power lest "variable" renewables prove unreliable, but modern experience abroad has resolved this problem: in 2015, the ultra-reliable former East German utility 50Hertz was 46% powered by wind and PV, and its CEO said 60 to 70% would be feasible without added storage. On the contrary, it is nuclear power whose rather inflexible output, traditionally blended with varying output from coal and gas plants, complicates integration with the renewables now rapidly replacing those polluting and erratically priced fossil fuels[117,118,119,120,121,122].

It might be argued that the South African grid is isolated – certainly more so than, say, that of Denmark, whose strong links to the Nordic and German grids have let its wind power produce up to 140% of total national demand, and on one autumn day in 2015, to turn off all the country's central power plants[123]. But such grids as Ireland's and Portugal's are only lightly interconnected with neighboring countries, and in 2016, 63%-renewable Portugal was a net electricity exporter to Spain. Moreover, Germany (32% renewably powered in 2016, and 82% for several days in May 2017) and Denmark (62% renewably powered including 42% windpower in 2015, and 100% on many days each year) both have electricity grids roughly tenfold more reliable than those of the United States[124], which in 2016 met 16% of its net electricity needs with renewables, or 9% without hydropower, or 7% from wind and PV.

South Africa's heavy industry potentially offers a dispatchable resource – cogenerating industrial heat and power together – which is far more efficient and economical than producing them separately, and could advantageously use emerging regional supplies of natural gas. South Africa plans to strengthen interconnections to neighbors' hydroelectric and other electricity resources. And in not infrequent circumstances, mines can often provide economically advantageous demand response by adjusting major loads like milling and beneficiation to match grid needs: ore and product are far cheaper to store than electricity. By the same logic, some metallurgical industries abroad can make more profit by selling demand response than selling metal.

It clearly makes sense to invest in the lowest-cost power generation sources – solar and wind – and it is now clear that increasing the share of these variable renewable energy resources can be done without prejudicing system reliability provided sufficient flexible and demand-side resources are also contracted. The IRP models show that this combination still offers the lowest system cost.

A recent engineering study "confirms that the South African power system will be sufficiently flexible to handle very large amounts of wind and PV generation … to cope with increased flexibility requirements resulting from the installation of 4.2 GW of wind generation and up to 12.8 GW of PV by 2020, and 11 GW of wind and 27.5 GW of PV by 2030; flexibility requirements can be handled by existing and planned power plants at moderate additional costs[125]."

It is only a matter of time before debunked notions lately introduced by the coal-and-nuclear-centric U.S. Administration (to general ridicule in the electricity community) enter the SA debate[126]. In reality, nuclear and coal-fired power stations have few of the magical properties claimed for them by their U.S advocates[127], and in particular, have little effect – or statistically, a somewhat negative effect[128] –on grid resilience[129]. However, as is abundantly clear from the French example[130,131,132], nuclear plants' relative inflexibility[133] makes their massive installation a serious impediment to operating a grid to take proper advantage of renewable energy's many attributes, including resilience (such as the ability to keep providing local power despite transmission faults that disconnect remote central stations).

One further aspect of reliability bears mention: the global nuclear industry continues to suffer major risks of project failure or abandonment, akin to "dry holes" in oil exploration. A new analysis indicates[134]

> Of 259 U.S. nuclear units ordered in 1955-2016, 128 (49%) were abandoned before startup and 34 (13%) prematurely closed later. Of the 97 units (37%) operating at mid-2017, 49 are uneconomic to run; 35 have suffered 45 year-plus safety-related outages; and just 28 units (11%), some slated for closure, remain economically viable and have not yet suffered a year-plus outage. Globally, too, serious delays and operational challenges abound. Such disappointing performance shrinks nuclear plants' expected carbon savings and burdens them with often-overlooked abandonment costs. Such large gaps between promise and performance are almost unheard-of with modern renewables.

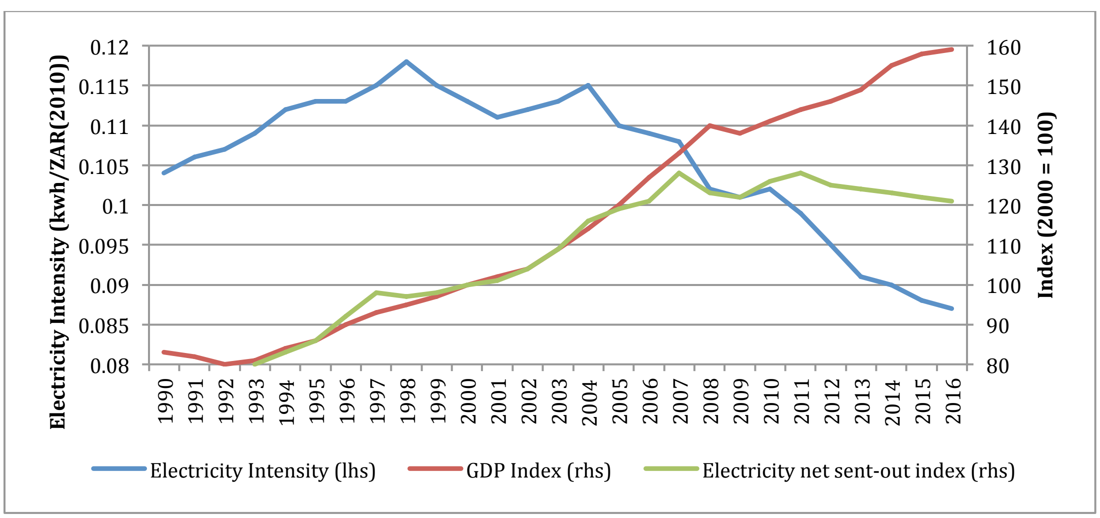
Nuclear construction and operational problems also occur in South Africa, where objective conditions make them arguably more likely and far riskier to the national economy. Renewable projects' smaller unit size and shorter lead times help mitigate that risk.

Energy efficiency and electricity demand

Even at old costs – low nuclear, high renewables – government's ignored IRP 2013, 2016, and 2017 updates found nuclear new-build unjustified if electricity demand grew slowly. In fact, as Eskom more than quadrupled its nominal electricity price and nearly tripled its real price over the past decade from levels originally among the lowest in the world[135], not just growth but absolute annual national usage of electricity in 2017 has *fallen* to below 2007 levels[136 137]. Total electricity sales dropped even in the thriving City of Cape Town[138]. Week-on-week Eskom demand in MW has also dropped[139].

This drop is attributable to the fact that customers who can are buying efficiency. Because saved kWh and kW are just as valuable to Eskom as generated ones, Eskom bought back over 2.5 GW of "negawatts" (saved watts) from 2008 to 2013[140] – 90% cheaper than Medupi coal capacity, let alone the coal it burns. Far more efficiency remains unanalysed and unbought: for example, the Rocky Mountain Institute's 2004 collaboration with South African engineers found that a vast South African mine could save 43% of its energy, repaying the investment in three years at Eskom's very low tariff then prevailing. Those who assert that SA's efficiency potential is nearly at theoretical limits[141] are badly out of touch with both theory[142] and modern practice[143,144,145]. South Africa's electricity intensity – the number of kWh per unit of GSP output – reached a peak in 1998 and has now fallen for nearly two decades, yet it can profitably fall very much further.

Figure 2: South Africa's GDP growth, electricity intensity and electricity consumption



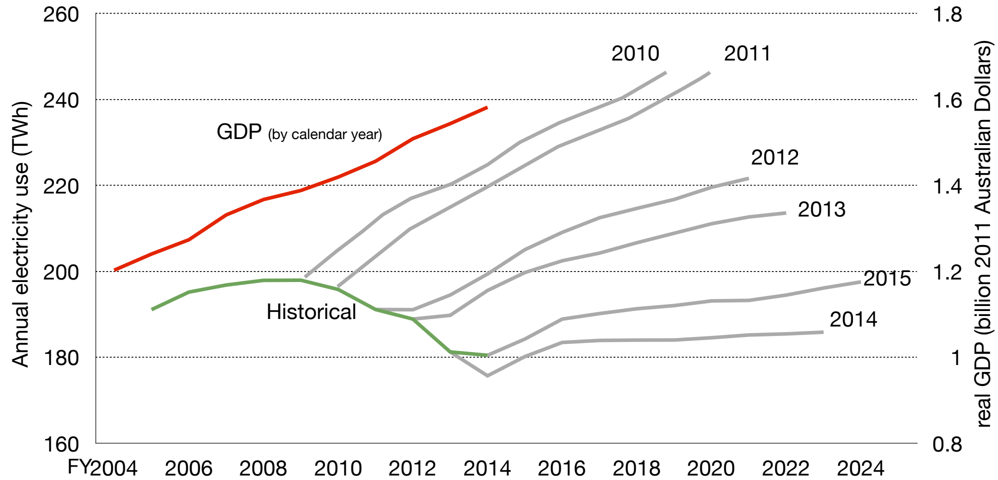
South Africa's energy[146] and electricity intensities are among the world's highest not only because of its heavy industry (attracted by policy and by historically very low energy prices), but also because commendable recent efficiency efforts barely scratch the surface of the profitable potential in all sectors. This is illustrated by the most detailed and rigorous published analyses for both a developed and a developing country's 2050 potential:

- The United States[147] could run a 2050 economy 2.6-fold bigger than that of 2010 using no oil, coal, or nuclear energy and one-third less natural gas, with tripled efficiency (roughly quadrupled for electricity) and quintupled renewables, at a net-present-value private internal cost (i.e. valuing all externalities at zero) $5tn lower than business-as-usual, emitting 82–86% less fossil carbon than in 2000, using no new inventions, needing no Acts of Congress (as the needed policy changes can be done administratively or subnationally), but led by business for profit – a trajectory on track in the marketplace since 2010.
- China[148] could increase its real GDP 7-fold by 2050, in accordance with official targets, using scarcely more primary energy than in 2010 and getting most of it from non-fossil sources with 13-fold higher carbon productivity than in 2010, hence using four-fifths less coal, emitting two-fifths less carbon, and costing $3.4tn less in net present value than business-as-usual.

Meanwhile, Eskom's hemorrhage continues. Electricity sales in its 2017/8 financial year are expected to be 14% lower than projected in its original MYPD3 tariff application[149]. For the coming year, it applied to the National Energy Regulator of South Africa for a 19.9% tariff increase—in part to compensate for lost sales, but was awarded only 5.2%[150]. Despite a R23bn state bailout in 2015[151], which came after a state R60bn subordinated loan – subsequently converted into equity – and state guarantees of R350bn for its debt[152], it still can't cover its costs and can't escape a junk rating even after years of above-inflation tariff increases[153]. It will need R60 to 80bn per year in additional finance over the next five years to complete its capex programme[154], so further price rises seem inevitable. To keep raising prices without strongly adjusting the demand forecast for observed and likely longer-term price elasticity risks severe overshoot – as SA, to its great cost, experienced in a previous burst of central-station construction[155].

Indeed, Eskom may *already* have triggered the sort of "death spiral" already seen in another commodity-dependent economy, Australia where costlier electricity, falling demand, rising prices, then defection to PV (over 6.5 GW now installed, often on roofs) plus efficiency, flexible loads, and local storage, combined to cut grid sales further. In 2014, Australian electricity demand was expected to rise 20% in ten years. Instead it fell 9% in six years despite robust GDP growth.

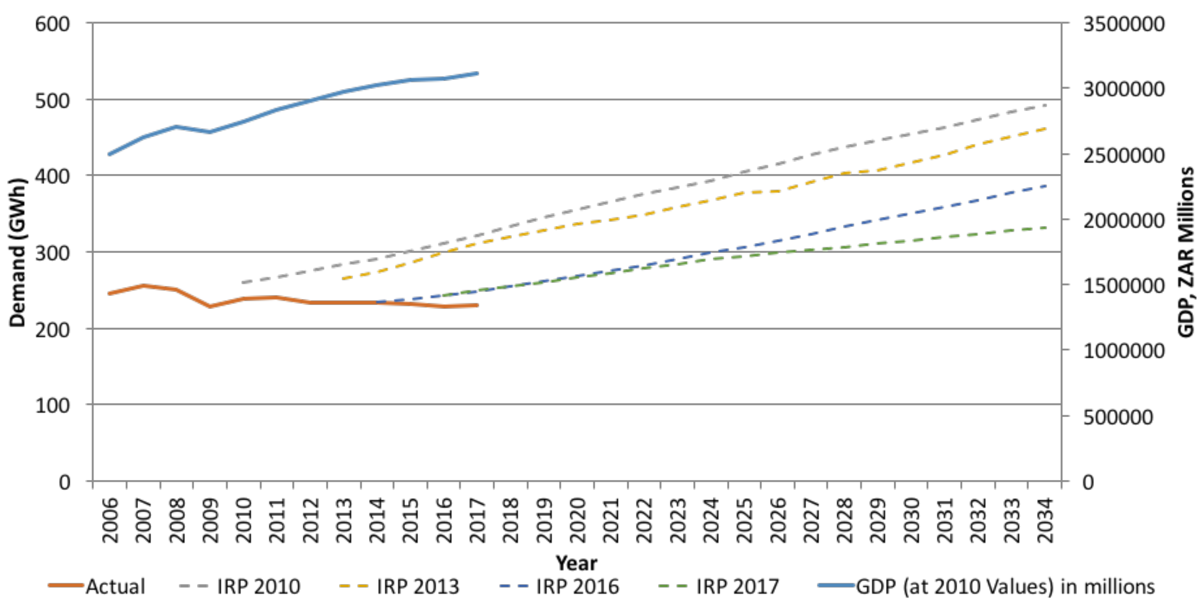
Figure 3: Australian actual vs. forecase electricity demand by financial year



Inspiration: M. Liebreich, keynote, Bloomberg New Energy Finance summit, April 2015. GDP data: International Monetary Fund, World Economic Outlook database, http://www.imf.org/external/pubs/ft/weo/2015/02/weodata/download.aspx Historical and forecast electricity use: Australian Energy Market Operator, National Electricity Forecasting Report 2010–2015, http://www.aemo.com.au/AEMO%20Home/Electricity/Planning/Forecasting

Australia's rising prices, plummeting demand, and burgeoning renewables signal a market-led transformation of the coal-based, central-plant, big-grid model. A similar trend is now being observed in South Africa of falling demand and progressively lower electricity forecasts, although these are probably still too optimistic.

Figure 4: South African actual vs. forecast electricity demand by financial year



We believe South Africa's exceptional endowments – in wind and sun, energy efficiency potential, and human resources and resourcefulness – are every bit as good as Australia's. A further advantage of these resources is that they can contribute to electrification of remote areas. Decentralised power generation in every isolated corner of the nation is the pathway to "energy democracy" – investing in power for people and places lacking it, not just adding more for people who already have it. Choosing the best buys first can bring power to three million unelectrified South African households faster and cheaper from the sun than from the grid. It would also complement, and foster robust competition with, the ~100-MW renewable blocks planned by the DoE and even contemplated by Eskom[156].

In summary, new nuclear power – with its costs rising, sales shrinking, 2016 global output 7% below 2006's, retirements of old plant about to outpace new additions[157], and renewables and efficiency decisively beating it in the global marketplace – lacks a business case for South Africa, whichever country provides the technology. There is no rational basis for policy to discriminate against efficiency and renewables, which all avoid the same fuels and emissions and can provide the same electrical services with equal or better reliability at far lower cost and policy risk than nuclear power. But there is special cause for concern about South Africa's proposed nuclear deal, particularly with Russia, as we explore next.

Procurement and financial risks

South African officials have made a wide range of statements in the past few years about whether government intends a "fair, transparent, and competitive procurement process", or a process with that form but not its substance (as vendors may expect), or an opaque direct negotiation between the South African government and another government, most likely that of the Russian Federation[158]. During a series of private Presidential meetings over the past seven years[159,160,161,162,163,164,165,166,167,168,169,170], these two countries concluded an unusually strong and specific nuclear agreement[171]. It gave Russia a veto over SA's nuclear cooperation with any other country, enabled Russia to withhold any data it wishes from public scrutiny, exempted Russia from any accident liability, and promised Russia favourable tax and financial treatment. While denying favoritism, South Africa did not appear to have offered similar terms to any other potential partner. Though the decision of the Western Cape High Court in April 2017 set aside this agreement, officials have continued to imply that a nuclear deal with the Russians is likely[172].

The Government Gazette notice released by the Department of Energy on 21 December 2015, which confirmed Cabinet's decision to move ahead with the 9.6 GW nuclear procurement programme, suggested the possibility of creating special-purpose vehicles[173] or other structures that might try to evade the letter or spirit of the Constitutional §217(1)) and statutory (Public Sector Finance Management Act) requirements for "fair, equitable, transparent, competitive, and cost-effective" procurement. The South African Courts are sensitive to any appearance of sham competition. For example, in June 2017, the High Court interdicted Eskom from continuing with a controversial R4bn tender to replace its Duvha power station's damaged boiler, citing tender irregularities[174].

An instructive international example worth considering here is that of Britain's Hinkley Point C nuclear project. Several lawsuits, including one from Austria, a non nuclear nation, against alleged illegal state aid to sponsor the project, now poses a major risk to its financing. Its sponsors have not yet found that financing[175] despite a £10bn loan guarantee and a state-guaranteed 35-year inflation-indexed twice-market-price power purchase agreement backed by the then-AAA-rated UK government, which also indemnifies the owners against all political, policy, and legal risks. Any one of the parties can veto that £20+bn project: the European Court of Justice, the 65/35% co-owners (EDF and CGN), the French and Chinese governments that own most of those two enterprises, the British government, and the private capital market.

South African policymakers are doubtless keenly aware of the legal and political risks of any seemingly untransparent or unfair nuclear procurement process. But they may be less aware of fatal flaws in its *economic and financial* logic, as we discuss next. The risk to the fiscus is amplified by the perception of capital markets, which, regardless of deal structure, would view the nuclear project as a "large public debt increase" carrying "substantial fiscal risks" for South Africa's economy[176]. Perhaps this helps explain why the phrase used repeatedly since the February 2016 State of the Nation address[177] is that South Africa will "only procure nuclear on a scale and pace that our country can afford." So what affordability issues might not yet have gained sufficient policy attention?

Unless Treasury issued the loan guarantee it refused in 2008[178], South Africa's nuclear supplier would demand of government a long-term power purchase contract[179,180]. (Since SA is now junk-rated, a prudent vendor or investor would probably demand both guarantees at a minimum.) Even with such power purchase contracts, financiers may not like the counterparty risk, as the current British example makes clear. They would see that much of South Africa's current electricity shortage is due to serious delays in its mega-coal plants, and that their cost overruns (~4x at Medupi[181]) could foretell problems with SA nuclear construction too.

Russia's favoured Build-Own-Operate model[182] – the most logical of three reported options[183] – locks in increasingly uncompetitive fixed (or escalating) electricity prices for decades. Customers with increasingly potent options of their own[184,185,186,187] could escape high prices by leaving the grid – like Australians and Hawai'ians buying rooftop solar and even batteries, which major vendors like SolarCity now bundle in convenient packages. But if government repayments then stumbled for lack of Eskom revenue, Russia could simply shut off the power as Gazprom shut off Europe's gas, or as Russia put its Turkish nuclear project in limbo when the two countries got in a spat. Utter dependency on Russia[188] for electricity – as well as for nuclear safety and, the agreement implies, fuel – raises serious questions of South African national sovereignty and independence.

Despite a troubling domestic record on cost, delays, quality, and transparency[189,190], and the same human-resource challenges that afflict Western vendors[191], Russia claims cheaper nuclear power abroad (5–6 US¢/kWh "in most countries" but three times that, 12.35 US¢/kWh, in Turkey[192]). The expected dollar cost of a Russian 2.4 GW plant on offer to Bangladesh has nearly trebled in six years[193]. The rand exchange rate continues to slide due to anemic growth, high debt, weak commodity prices, an insolvent utility, opacity, and corruption. The rouble's fall has largely been offset by the rand's, and of course goods bought in roubles are made in Russia, creating no jobs in South Africa.

There's a much bigger issue. The lower the world oil price, the more precarious Russia's finances become[194], with insolvency looming in the next couple of years if low prices and sanctions persist. Already, Russia has gone in dollar terms from the world's #6 economy to #15, just below Mexico[195]; in 2015 alone, real wages fell 10%, and by May 2016, average monthly salaries were below China's and only slightly above India's[196]. Domestic political pressures are building as ability to buy them off dwindles.

So is Russia a credible and reliable financial partner? Its ~$72bn National Wealth Fund is under pressure[197]; by early 2015 it was already overextended by $24bn pledged to finance nuclear exports to four countries[198]. (Those included the Hungarian Paks nuclear deal[199], whose low-interest loan commitment helped crash Russia's state foreign-trade bank needing an $18bn bailout[200].) About another $64bn would be needed to fulfill other offers already extended[201]. And even that couldn't go far if more than a handful of deals were like the proposed Bangladeshi

Rooppur plant mentioned above – 90% financed ($12bn) at 2.55%/y interest with a 10-year grace period, then 18-year repayment[202].

Rosatom, the self-regulated[203] state nuclear enterprise, is led by a former Prime Minister reporting to President Putin and exempted from all normal state controls. Independent experts agree that Rosatom (or any other state entity) would be lucky to build half the 30 additional nuclear projects it's trying to sell for $300bn to a dozen more countries including South Africa[204]. Russia's interest rate in early 2016 was twice (and in an earlier spike, over three times) what any conceivably coal-competitive nuclear project would require. The Russian state's capacity to absorb the spread is quickly vanishing. Russia's domestic reactor starts halved in 2015[205,206]; all state nuclear subsidies are to halt in 2016[207]; yet without those subsidies, "Rosatom wouldn't complete a single project anywhere"[208].

Russia needs huge amounts of outside capital to finance its nuclear commitments. But Western capital is now blocked by sanctions for aggression in Ukraine. The low-interest bank financing that Russia promised South Africa[209] does not exist, even in the state-owned Russian banks Rosatom could engage on paper[210]. As nuclear-industry economist Steve Kidd notes[211], "Since vendors cannot bear the substantial costs of nuclear projects on their own, they are going to have to seek outside equity investors, many of whom are the same people who have repeatedly turned down nuclear in the past." In mid-2016, he added[212]: "Rosatom is pretty good at announcing 100 billion euros of orders in 25 countries, but not an awful lot of these are firm contracts, they are just bits of paper".

Affordable capital from banks and private investors is especially unavailable in this case because Russia and its nuclear builder Atomenergoprom are junk-rated, judged even riskier than junk-rated Eskom – whose credit rating has fallen six notches since 2007[213]. South Africa, in junk territory itself and likely to slip even further the longer markets think government plans to proceed with a nuclear deal, has similar credit ratings to Turkey[214], whose Russian nuclear deal private investors have already rejected. This stands in striking contrast to foreign private investors' proven eagerness to finance South Africa's low-risk renewables[215].

Russia – its oil and gas exports cheapened and unwelcome, its prestige dented, Western partners fleeing, Ukraine adventure thwarted, Turkey sporadically alienated[216,217,218]; and its economy and $360bn foreign reserves shrinking – now seeks nuclear deals less for doubtful economic advantage (especially on a risk-adjusted basis) than for domestic political reassurance[219] and geopolitical leverage[220] [221]. The bear is hungry not cuddly.

Conclusions

One of the global nuclear industry's most outspoken advocates, Steve Kidd, criticizes the industry's "myths…that financing is a substantial barrier to nuclear build [and] that many developing countries are now set to develop active nuclear programmes."[222] Finance, he notes, "is not so much an input into a nuclear project as an output." He adds that:

> "…there is no unique financing mechanism that the relevant institutions can come up with to rescue a nuclear project that has questionable returns or too high a degree of risk for investors. This is the real problem: nuclear projects have largely become too expensive and risky to offer lenders the degree of assurance they require.…Even with government incentives such as loan guarantees, fixed electricity prices and certain power offtake, nuclear projects today struggle to make economic sense, at least in the developed world. There are lots of different ways of generating electricity and the cost and schedule overruns at the latest projects are a warning to potential investors. They cannot be expected to put in either equity or loan finance if the prospective returns are inferior to those of other projects.…[O]n current trends very few of [the developing countries that have expressed a wish to establish nuclear power programmes]…are likely to do so and for the same reasons that nuclear power has stalled in…most of the rest of the world.…The fundamental problem is that nuclear in these countries suffers from the same public acceptance and economic problems as elsewhere."

As we have seen, that generic concern comes to a sharp focus in this specific case. Not just Russian but *any* nuclear new-build is a poor choice for South Africa. It cannot compete with efficiency and renewables, by every relevant measure: cost, timeliness, financing, jobs, economic development, environmental and safety risk, independence, security, abundance of eternally free local energy sources, and the social good of "energy democracy." These goals support and are advanced by the agenda of "an electricity sector that will deliver, transparently, competitively, reliably and sustainably, the electric services that will power economic growth and improve the welfare of all our people"[223,224].

It has come to this: ever more sales-starved nuclear vendors, seeking ever less solvent customers, now offer a risky project the seller can't finance to a customer who can't pay[225] – a customer with no need, enchanted by the same nuclear devotees whose broken promises already cost the nation dearly, and with no apparent accountability.

South Africans deserve, and politics or markets will ultimately deliver, reliable and affordable electrical services – enough, for all, for ever. At issue is how much money, time, and opportunity for national advancement will be lost before South Africa finally abandons the folly of procuring new nuclear power plants.

Biographies of Authors

Physicist Amory Lovins is widely considered one of the world's leading energy experts. A former Oxford don, honorary U.S architect, Swedish engineering academician, advisor to business and government leaders for 44 years in over 65 countries including South Africa, he has won many of the world's top energy and environment awards, received 12 honorary doctorates, taught at 10 universities, and written 31 books and over 625 papers. Time *named him one of the world's 100 most influential people;* Foreign Policy*, one of the 100 top global thinkers.*

Anton Eberhard was inspired to undertake his PhD in the field of energy and development in 1979 after reading Amory Lovins's seminal publications on renewable energy and energy efficiency. He has recently been elected to the rank of Emeritus Professor and Senior Scholar at the University of Cape Town after 35 years of research, teaching and policy advocacy in energy and sustainable development in Africa.

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