Joint review of the updates to the energy plans of the South-African Department of Energy (DOE), which was released for public consultation during December 2016, namely:

Draft Integrated Energy Plan (Update: 25 November 2016) (Draft IEP 2016)

&

Draft Integrated Resource Plan for Electricity Update: Assumptions, Base Case Results and Observations, Revision 1, November 2016

Reviewer: Prof. Dawid E. Serfontein,

School of Mechanical and Nuclear Engineering, North West University, South Africa

Review commissioned by: Nuclear Industry Association of South Africa (NIASA)

This report belongs to the Nuclear Industry Association of South Africa (NIASA) and is available from its head office or website.

(Version: 31 March 2017)

Executive summary

Introduction

This is a joint review by the Nuclear Industry Association of South Africa (NIASA) of the updates to the energy plans of the South-African Department of Energy (DOE), which was released for public consultation during December 2016, namely the:

- Draft Integrated Energy Plan (Update: 25 November 2016) (Draft IEP 2016) and
- Draft Integrated Resource Plan for Electricity Update: Assumptions, Base Case Results and Observations, Revision 1, November 2016 (Draft IRP 2016 Base-Case).

Since we also reviewed the previous versions of these plans, this is a joint update of those previous reviews, which are still available on NIASA's website at the following links

- Review of IEP: http://web.vdw.co.za/niasa/Library.aspx
- Review of IRP: http://web.vdw.co.za/niasa/Library.aspx

These previous update versions of the IEP and IRP Update Report lay excellent foundations for modelling of South Africa's energy needs in that they presented a comprehensive set of data and an impressive array of test scenarios that allows the reader to assess South Africa's electricity future, regardless if his/her specific convictions about future trends. It also demonstrated and documented a sophisticated set of tools for modelling the most efficient combination of energy supply options. Unfortunately, both contained a number of unrealistic assumptions which seriously skewed their results. The most important shortcomings were:

- A too high value of the real Weighted Average Cost of Capital (WACC%) of 11.3% in the IEP, compared to the more realistic 8.3% of the IRP.
- External costs for power generation technologies that were for the most part not allocated to the respective power sources, neither in the IEP nor in the IRP.

NIASA's 2014 reviews pointed out to DOE that these flaws seriously skewed the generation mix allocations in favour of those technologies with abnormally high external costs, especially coal power, gas power, intermittent solar-PV and all imported energy types. NIASA would like to commend the DOE on the fact that most of these flaws have now been corrected, especially in the Draft IEP 2016.

Problems with the Draft IEP 2016 and Draft IRP 2016 Base-Case

Unfortunately, some flaws remained and some new ones cropped up, especially in the Draft IRP 2016 Base-Case. The result is that the Draft IEP 2016 and the Draft IRP 2016 Base-Case vary greatly in their assumptions and therefore also in their results, especially regarding the timeline for the deployment of new nuclear power plants. By definition, the IEP supplies the big integrated picture for future energy supply in South Africa, while the IRP focuses narrowly on only electricity supply. The IRP is thus supposed to be a branch that should grow directly from the main tree trunk of the IEP. It is therefore disconcerting to note such wide differences in their assumptions and results. Obviously, these differences greatly confuse the public and therefore serves to further increase the already alarming levels of polarisation and discontent within South-African society. Further they fuel conspiracy theories about corrupt energy deals, especially the theory that an illegal deal has already been made between President Zuma of South Africa and President Putin of Russia that Russia will get the tender for the supply for the envisaged 9.6 GW of new nuclear reactor capacity. These speculations on corruption regarding power supply in South Africa has led to a movement where people who can afford it intentionally defect from the South-African grid by putting up rooftop solar panel. They do this as a form of political protest, even if it costs them more to generate their own power than to use power from the grid. So, during the day when Eskom, South Africa's single state owned power utility, has surplus power capacity and can easily and profitably supply these people with power, they prefer to generate their own solar power. However, during the early morning and evening demand peaks, when the sun does not shine, they revert to grid power from Eskom. As supply is constrained during these periods, more expensive power sources, such as gas turbines, have to be employed to meet this increased demand. Due to the higher production cost, Eskom often generates power at a loss during these demand peaks. This practice of defecting from the grid when Eskom can supply power profitably, only to reconnect to the grid when Eskom generates at a loss, has already hurt Eskom's revenue substantially. Due to the continuous rapid drop in the prices of solar-PV panels, this tendency can be expected to accelerate exponentially to the point where it can financially paralyse Eskom and the local municipalities, which all depends heavily on profits of power supply. A collapse in the finances of Eskom and the municipalities can be catastrophic for the country's infrastructure development. It is therefore in the national interest fix what is wrong in the IEP and the IRP.

The following is a summary of the said differences between the Draft IEP 2016 and the Draft IRP 2016 Base-Case:

Several well-known academics and institutions recently claimed that it will be more profitable for South Africa (SA) to replace the said new nuclear capacity with a mixture of PV-solar panels, wind turbines and gas turbines. However, Eskom claimed that the wind and PV-solar power that DOE forces Eskom to buy through the REIPPPP is largely useless, as it arrives at the wrong time of day. Therefore, Eskom prefers stable base-load nuclear and coal power. Because of the following differences in their respective assumptions the Draft IEP 2016 came down more on Eskom's side of the argument with large allocations of new nuclear and coal earlier on in the program, while the Draft IRP 2016 Base-Case moved the deployment of new nuclear out to 2037:

- The Draft IEP 2016 takes Externality Costs much more seriously than the Draft IRP 2016 Base-Case:
    - Climate change cost of CO_2 emissions up from Government's announced carbon tax R150/ton CO_2 to R270/ton CO_2!
    - With 947.3 g CO2 released/kWh that equates to R0.26/kWh CO_2 damage cost, which is at the high and of international practice.
    - Coal is thus squeezed out and nuclear and renewables are brought in early.
    - **The Draft IEP 2016 thus deploys between 10 and 29 GW by 2050, depending on the scenario selected, which is quite an aggressive nuclear build program!**
- **Draft IRP 2016 Base-Case, on the other hand, allocated a zero carbon cost, but rather applies a maximum annual limit to CO_2 emissions.**
    - Coal is thus not penalised for CO_2 emissions, until the annual limit is reached in a decade or two.
    - The Levellized (LCOE) coal cost is thus artificially low at R0.89/kWh, which is cheaper than nuclear at R0.97/kWh.
    - Nuclear is thus squeezed out to 2037 and the resulting void is filled with coal, wind, solar-PV and gas power.
    - However, this is unfair as Coal CO_2 is not penalised at all, until the limit is reached!
    - **This also makes localisation of coal and nuclear construction difficult** as coal is first built at a rate that is so high that there is little time to train local artisans etc. However, just when a decent number of these local artisans have been trained, coal construction is stopped abruptly and replaced with nuclear construction. As the required skills levels for nuclear construction are much higher than for coal construction, the trained coal construction artisans then lose their jobs.

      The whole roller-coaster rides then starts again with feverish training of nuclear artisans, only to lose their jobs once the nuclear construction comes to an end…

So from a localisation perspective, it would be much better to find a compromise between the Draft IEP 2016 and Draft IRP 2016 Base-Case so that new coal and nuclear construction starts simultaneously, but proceeds at a slower pace, so that artisans that are trained on the first coal and nuclear plant can then find work on the subsequent coal and nuclear plants etc.

- Therefore, if we rightly add the R0.26/kWh CO_2 coal climate damage cost, coal's true cost moves up to R1.15, which is much more expensive than the competing options.
  - Coal would then largely be replaced by nuclear at R0.97/kWh. Therefore, nuclear should then come in well before 2037.
  - However, coal could, for strategic reasons, such as its superior ability to do load following, its shorter lead times than nuclear and the many local jobs it creates, take some capacity away from nuclear.
- Input assumptions that limited the deployment of new intermittent wind and solar-PV:
  - Draft IRP 2016 Base-Case estimated PV and wind costs are at about R0.85/kWh, which is much higher than the minimum of R0.60 in the latest round of the REIPPPP.
  - Limits on yearly capacity additions of intermittent renewables, for the sake of power grad stability, restricted new solar-PV to 1000 MW/year and new wind to 1600 MW, year.
  - This means that even if wind and PV were to become much cheaper than the competing options, they will only be deployed in only limited quantities, which will create scope for more nuclear and coal.
  - This un-transparent manner in which these limitations were announced, i.e. without proper scientific explanation and motivation, caused an outcry from the renewables community with, complete with conspiracy theories about Government corruption in support of nuclear.
  - **This lack of transparency makes NIASA's job much harder regarding explaining to the public the case for nuclear power** as a clean, green and affordable stable base-load power source.

    Therefore, NIASA urgently calls on DOE to replace the current culture shocking the public by pulling new unexpected and unannounced policies out of the hat at the last moment, with transparent, openly published, scientific studies that clarifies such issues beforehand, so that different grouping in civil society, on different sides of the current proversus anti-nuclear debate, can work together in a spirit of trust and lack of suspicion of pro-nuclear Government corruption.

Conclusions and recommendations

1. Corrections to the Draft IEP 2016

- It has been shown that the Draft IEP 2016 allocated most external costs well, except for the global warming cost of methane leakage during shale gas mining and the other external costs of all imported energies that were not allocated at all.
  NIASA therefore recommends that these external costs should be allocated according to the principles described in this study.

2. Corrections to the Draft IRP 2016 Base-Case

- As has been described above, the external cost allocation of the Draft IRP 2016 Base-Case was substantially inferior to that of the Draft IEP 2016. The main problem was the failure to allocate any carbon cost to coal emissions, but to replace this measure only with a limit to the maximum annual emissions.
- Identical to the Draft IEP 2016, the global warming cost of methane leakage during shale gas mining and the other external costs of all imported energies that were not allocated at all.
  NIASA therefore recommends that these external costs should be allocated identically to our recommendation for the Draft IEP 2016.

3. Expected results of proposed corrections

Since it was shown that it was the above-mentioned flaws in the Draft IRP 2016 Base-Case that resulted in the first new nuclear being moved out from about 2015 to 2037, in is to be expected that corrected these flaws in the input assumptions should lead to new nuclear moving back to approximately its original place in the timeline i.e. 2025

4. Recommendations for further study

As has been pointed out above it is disconcerting to see that the assumptions and thus the results for the Draft IEP 2016 and Draft IRP 2016 Base-Case vary so greatly, especially because both reports were generated by the same entity, namely the DOE. It is furthermore not the first time that this happened as we previously pointed out similarly large differences between the 2014 versions of these two documents. **This suggest the groups that produce these documents are perhaps overworked and underfunded.**

4.1 Motivation for greatly increasing funding for study groups to resolve outstanding issues in the IEP and IRP

- Being underfunded is a major challenge that globally hampers good research. However, **when the magnitude of the national interest is considered, underfunding should not be allowed.**

  The total cost of the planned 9.6 GW of new nuclear capacity alone was estimated in our previous review to be about 650 Billion Rand (in 2012 Rands). Thorough study and planning normally lead to great cost reduction, mostly much more than 5%. If however we were to make the conservative estimate that we can shave only 5% off of this cost by detailed study and analyses, that would amount to a saving of 32.5 Billion Rand. Bearing in mind that the nuclear fleet is comprises only a fraction of the total new-build cost, it can safely be assumed that such detailed studies can shave R50 Billion of the total project cost.

  If one further assumes that you are making very good money if you make 10 Rand for every one Rand you spend, South Africa could safely afford to spend R 5 Billion Rand on optimising the IEP an d IRP through intense study.
- If we compare that to current funding of research for the project, **we are currently probably underspending on research by a factor 100 to a factor 1000!** It is for instance well known that the cost of the recent study commissioned by the DOE to determine the likely cost of new nuclear power plants was funded to the tune of only a few hundred thousand Rands.
- Furthermore, only a handful of such studies were commissioned.
- **Therefore, NIASA recommends that the number of such studies be expanded, as necessary to improve the accuracy of the IEP and IRP.**
- **Also, the funding of such studies also be greatly increased** and that the number of people working in such teams should be greatly expanded and that top international consultants be added to their ranks**, so that very high quality studies can be delivered in a short time.**
- **NIASA would like to emphasise that its intention with recommending such detailed studies is not to delay the implementation of the IEP and the IRP, but rather to accelerate it: The 2014 versions of the IEP and IRP could not be implemented because they contained serious flaws, as was pointed out by NIASA and many others. If such high quality detailed studies had been**

performed prior to 2014, we could have implemented the 2014 versions immediately. By the same logic, the 2016 Drafts also cannot be implemented due to the flaws they contain. So studies must be accelerated in order to prevent any further delays.

4.2. Recommended study topics for the DOE

- A detailed study to determine the full external costs for the proposed large LNG imports**, which will then reveal the full external cost of Solar-PV and wind power, which can be expected to be substantially higher than currently portrayed in the Draft IRP 2016 Base-Case. The** global warming **cost** of methane leakage **during shale gas mining should feature prominent in this study.**
- **It is recommended that a** full detailed study into the issue of grid stability **in the face of high penetrations of intermittent renewables.**
- **The** potential of massively rolling out time-of-use smart meters to households, coupled to aggressive time-of-use price incentives **aimed at shifting demand towards supply so that power can be supplied in the cheapest and most profitable possible way**
- An independent high power research team should be created to duplicate and verify the very important research published by Dr. Tobias Bischof-Niemz of CSIR Energy Research**: "Wind, solar can supply bulk of South Africa's power at least cost". Emphasis should be placed on all the aspects that were neglected in the CSIR study, as was pointed out above.**
- **The highest priority should be given to overhauling the REIPPPP**, in order to bring its policies in line with that of the IRP. The following should be emphasised:
    - **The flaw of deploying intermittent REIPPPP wind and solar-PV, before the required gas back-up to stabilise their intermittent outputs, should be stopped immediately. The REIPPPP is on this point totally out of line with the IEP and IRP: The IEP and IRP modelling rolls out gas back-up power together with intermittent wind and solar-PV, so that the gas can stabilise the grid. There is a problem with the REIPPPP, namely that it might take approximately five years to construct the infrastructure for LNG imports. This means that in the next five year the intermittent renewables on our grid will come without the stabilising effect of affordable gas power and, therefore, these renewables will be largely useless to our economy and will also destabilise our grid.**

- **Since wind power and solar-PV power are now the cheapest readily available power types on the South Africa grid, these should now be viewed as fully matured technologies. Therefore all subsidies should be removed from these** and they should simply compete with all the other technologies on a level playing field, especially regarding time-of day mitching between supply and demand. After all, the CSIR claim to have proven that wind, solar-PV and gas are now cheaper than any other combination of power sources. By definition, this should mean that they are now the senior kids on the block and that they thus can by no means anymore demand subsidies!
- The **subsidies in the REIPPPP should this be moved to problems that has not yet been solved**, such as energy storage and fuel cell technology.
- **The huge mistake of using REIPPPP subsidies to subsidise production, instead of research should never be repeated.** There is a valid adage in the R&D community that says that for every one Rand you spend on research, you will spend 10 Rand on demonstration of the technology and 100 Rand on actual production. In reverse, this statement means that **if you spend 100 Rand to subsidise on Production of immature technologies, only one rand of that will eventually trickle down to research**. **So if you had spent the full hundred Rand on research in the first place, you would have increased you research impact a hundred fold.**
- Furthermore, **if you spent your subsidies on production of technologies that are not yet economically viable, your money simply drains away in the sand and you in the end have almost nothing to show for it,** as is presently the case with the Billions of Rand that South Africa annually waste on paying for the extremely expensive wind and solar power contracts from Bid Windows 1, 2 and 3 of the REIPPP.
- However, **if you were to spend the same amount of money on investment in research** (as oppose to expenses in construction) **you could have acquired a top research company or hundreds of important patents or you could have sent hundreds of scientist and engineers overseas** to collaborate and be trained on the relevant research projects. In short, **if you invest in research you will end up with real marketable IP, which is completely different from what we now have for our massive production expenses in the REIPPPP**.

- A **study to determine break-even prises during economic recessions** for all power sources, as opposed to the current strategy of comparing only their LCOEs based on the expected power prices during the good times. This will help us to **define least regret strategies in order to reduce our vulnerability to times of economic crisis.**
- Included in this approach should be a **study of optimal contracting strategies for the sake of robustness against economic crises.** the current strategy of concluding mainly take-or-pay contracts are death-traps during times of economic crises as the utility then loses the revenue form power sales, but still have to keep paying for fuel or other services that it no longer has a use for!
- **The validity of the power demand growth scenarios in the Draft IRP 2016 Update should be re-examined**, in view of the analysis given above **of the negative effects of increasing energy efficiency and grid defection.** In view of this analysis, it would appear that the current demand growth predictions are over optimistic, which could be disastrous for our energy planning.
- Coupled to this study on the validity of the demand growth scenarios should be a **study on ways to stimulate future investments in activities that will require substantial new energy consumption.** Many analysts simply assume that the reason for the current reduced demand is the fact that Eskom curtailed use though load shedding etc. However, Eskom had virtually no load shedding from 2009 to 2013, but that did not at all lead to a recovery in power demand. Similarly, there was virtually no load shedding from mid-2015 to the present, but that also did not result in a demand recovery.

  Apparently, the old adage that **trust comes on foot but leaves on horseback** is applicable in this case. So simply having excess supply is apparently not going to be good enough. **A better strategy might be to actively guarantee new investors security of supply**, i.e. to **guarantee them that if load shedding were to reoccur, which we must make sure that it does not, these new investors will be spared** from this menace. Such a guarantee should be greatly more effective in restoring trust that to just tell them that we feel sure that we shall not have load shedding again, but that we unfortunately cannot guarantee this!

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1 Introduction

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- **Draft Integrated Resource Plan for Electricity Update: Assumptions, Base Case Results and Observations (Draft IRP 2016 Base-Case**), Revision 1, November 2016.

Since we also reviewed the previous versions of these plans, this is a joint update of our previous reviews of the DRAFT 2012 INTEGRATED ENERGY PLANNING REPORT (IEP), released by the South African Department of Energy (DOE) for public comment during December 2013, and of the INTEGRATED RESOURCE PLAN FOR ELECTRICITY (IRP) 2010-2030 UPDATE REPORT 2013, released during February 2014. NIASA submitted these reviews to the DOE public participation process in 2014. The reports are still available on NIASA's website at the following links

- Review of IEP: http://web.vdw.co.za/niasa/Library.aspx
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As NIASA stands by the principles and analyses it lay down in these 2014 reviews, the details are not repeated here. Prices of the different technologies have certainly changed since then. However, the most contentious price, namely the overnight cost of new nuclear plants is currently outstanding, as we are waiting for Eskom to release its tender (Request for Proposal (RFP)) for the planned 9.6 GW of new nuclear plant capacity. Therefore, NIASA did not do any new cost simulations in this round of reviews. While we thus assume that our cost simulations in the 2014 reviews are now outdated, the principles which they demonstrated, such as the relationship between the Levellised Cost of Electricity (LCOE) and the Weighted Average Cost of Capital (WACC%) as well as the influence of external costs on the LCOE of the various technologies remain valid. NIASA will thus aggressively resume its program of nuclear cost simulations once the tender prices come in, probably early in 2018.

The current reviews will thus be aimed and determining whether the model input assumptions in the Draft IEP 2016 and Draft IRP 2016 Base-Case makes sense, and if not, what the consequences of the detected flaws were, how these assumptions can be corrected and to predict what differences such corrections could make to the results of these reports.

The previous versions of the IEP and IRP lay excellent foundations for modelling of South Africa's energy needs in that they presented a comprehensive set of data and an impressive array of test scenarios that allows the reader to assess South Africa's electricity future, regardless if his/her specific convictions about future trends. It also demonstrated and documented a sophisticated set of tools for modelling the most efficient combination of energy supply options. Unfortunately, both contained a number of unrealistic assumptions which seriously skewed their results. These flaws were pointed out in NIASA's reviews and NIASA would like to commend the DOE on the fact that many of these flaws have been corrected in the 2016 Draft Updates. Unfortunately, some flaws remained and some new ones cropped up. The result is that the 2016 drafts of the IEP and the IRP Base Case vary greatly in their assumptions and therefore also in their results, especially regarding the timeline for the deployment of new nuclear power plants. By definition, the IEP supplies the big integrated picture for future energy supply in South Africa, while the IRP focuses narrowly on only electricity supply. The IRP is thus supposed to be a branch that should grow directly from the main tree trunk of the IEP. It is therefore disconcerting to note such wide differences in their assumptions and results. Obviously, these differences greatly confuse the public and therefore serves to further increase the already alarming levels of polarisation and discontent within South-African society. Further they fuel conspiracy theories about corrupt energy deals. These speculations on corruption regarding power supply in South Africa has led to a movement where people who can afford it intentionally defect from the South-African grid by putting up rooftop solar panel. They do this as a form of political protest, even if it costs them more to generate their own power than to use power from the grid. So, during the day when Eskom, South Africa's single state owned power utility, has surplus power capacity and can easily and profitably supply these people with power, they prefer to generate their own solar power. However, during the early morning and evening demand peaks, when the sun does not shine, they revert to grid power from Eskom. As supply is constrained during these periods, more expensive power sources, such as gas turbines, have to be employed to meet this increased demand. Due to the higher production cost, Eskom often generates power at a loss during these demand peaks. This practice of defecting from the grid when Eskom can supply power profitably, only to reconnect to the grid when Eskom generates at a loss, has already hurt Eskom's revenue substantially. Due to the continuous rapid drop in the prices of solar-PV panels, this tendency can be expected to accelerate exponentially to the point where it can financially paralyse Eskom and the local municipalities, which all depends heavily on profits of power supply. A collapse in the finances of Eskom and the municipalities can be catastrophic for the country's infrastructure development. It is therefore in the national interest fix what is wrong in the IEP and the IRP.

In the 2013 IRP Update new nuclear power was seen as an essential element of Government's strategy to move to a low carbon economy. Government thus determined, by means of a Policy Adjusted Case that a new nuclear fleet of 9.6 GW_e capacity should be build and that the first new nuclear power should come online by about 2025. However, several studies have recently been published with negative conclusions on the future of nuclear power in South Africa. While the Draft IEP 2016 maintained a positive view of new nuclear, the Draft IRP 2016 Base-Case changed to a less positive view of new nuclear. The South-African energy community was thus immediately taken by storm when it was revealed that the Draft IRP 2016 Base-Case concluded that the commissioning of the first new nuclear plants should be moved out from about 2025 to 2037 and that the interim void left by this move should be filled with new coal, wind, solar-PV and gas power. These gas turbines will be fuelled with imported Liquefied Natural Gas (LNG).

The Minster of Energy therefore soon afterwards released a statement to clarify that the Base Case of the Draft IRP should not be viewed as the official take of the Draft IRP on the most appropriate energy mix for South Africa. Rather the **Base Case should be viewed as only the point of departure and point of comparison for the large number of special test cases proposed for the Draft IRP**. The Draft results for these test cases has not yet been released and is thus still open to debate. When the results for the Test Cases are eventually released, these will then be tested in robust debate, which should form part of the input that the DOE shall consider to arrive at a final Policy Adjusted Case for the IRP. The presently review should thus be viewed as part of this debate that should shape the Draft IRP 2016 Base-Case and Test Cases.

1.1 Differences between the Draft IEP 2016 and the Draft IRP 2016 Base-Case:

Several well-known academics and institutions recently claimed that it will be more profitable for South Africa (SA) to replace the said new nuclear capacity with a mixture of PV-solar panels, wind turbines and gas turbines. However, Eskom claimed that the wind and PV-solar power that DOE forces Eskom to buy through the REIPPPP is largely useless, as it arrives at the wrong time of day. Therefore, Eskom prefers stable base-load nuclear and coal power. Because of the following differences in their respective assumptions the Draft IEP 2016 came down more on Eskom's side of the argument with large allocations of new nuclear and coal earlier on in the program, while the Draft IRP 2016 Base-Case moved the deployment of new nuclear out to 2037:

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      Therefore, NIASA urgently calls on DOE to replace the current culture shocking the public by pulling new unexpected and unannounced policies out of the hat at the last moment, with transparent, openly published, scientific studies that clarifies such issues beforehand, so that different grouping in civil society, on different sides of the current pro- versus anti-nuclear debate, can work together in a spirit of trust and lack of suspicion of pro-nuclear Government corruption.

2 Reasons why new nuclear has been pushed out to 2037 in the Draft IRP 2016 Base-Case

Timelines for the deployment of different power plant technologies are an outcome of, rather than an input to, the IRP modelling process. Therefore, no single decision in the Draft IRP 2016 Base-Case was responsible moving the first commissioning of new nuclear out from 2025 to 2037. Rather the calculational model of the IRP optimises the power plant mix with a view to minimising the total discounted cost of supplying South Africa with power over the modelling period, subject to the assumed model constraints. Put differently, it minimises the Levelised Cost of Electricity (LCOE), expressed in R/kWh or R/MWh, over the modelling period. In principle, the process is thus technology neutral (also sometimes called technology agnostic). In practise, not all relevant cost factors were accounted for in the model input assumptions. Mostly it is the external costs that were sometimes ignored, or in other cases included at either relatively high or relatively low values that ended up advantaging or disadvantaging specific technologies. So, the outcome of the process was not necessarily technology neutral.

In this methodology, cheaper power sources are deployed first, until a certain constraint for their deployment is met, where after the next cheapest source is deployed, etc. Therefore, the fact that the deployment date of new nuclear moved out from 2025 to 2037 simply means that the model input assumptions changed such that the said other power sources are now viewed as cheaper as new nuclear power. However, it will be shown below that some input assumptions unfairly advantaged several of the competing power sources and disadvantaged new nuclear.

T**he focus of this study will be to thoroughly review all the important input assumptions, including those that caused new nuclear to be pushed out to 2037. If it were to be found that some of these assumptions were faulty, proposals for the correction of these assumptions will then be made. Obviously, if the Draft IRP 2016 Base-Case model calculations were then to be rerun with such corrected model assumptions, nuclear will automatically move earlier** and those technologies that were unfairly advantaged will automatically be pushed out to later deployment dates.

In the following paragraphs the most important input assumptions will be assessed.

2.1 Lack of penalisation of the external costs of Solar-PV and wind power

Coal power plants have a substantial ability to vary their load so they are normally used by Eskom in load-following mode, which helps Eskom to balance supply and demand. Furthermore, the inertia of the heavy steam turbine spinning reserve helps to maintain the stability of the power frequency (50 Hz) of the grid during sudden variations in load or power supply. Very expensive peaking backup power from Eskom's diesel-fuelled Open Cycle Gas Turbines (OCGTs) are thus normally only needed during South Africa's large early evening demand peak. However, due to subdued demand for power and improvement of the load factor (i.e. the average % of the year that each plant managed to deliver full power), Eskom had almost not need to run these expensive OCGTs since the middle of 2015.

Unlike coal, the output of wind turbines is unstable and also cannot be varied at will. Even so, the wind at the South-African coastline, where most wind turbines will be deployed, often blows during this early evening demand peak, which means that a substantial fraction of South Africa's wind power naturally comes at the time of day when it is most needed. Hopefully South Africa's economy will at some point resume vigorous economic growth, at which point power shortages are likely to reappear, and thus Eskom will need to again start running these expensive diesel-fuelled OCGTs. When that happens the presence of a fleet of wind turbines is likely to substantially reduce the consumption of this expensive diesel fuel. Since wind power is much more intermittent, i.e. wind power output is much more variable than that of solar phot-voltaic (solar-PV) panels, there will also be many evenings when the wind will not blow and therefore we will have to burn expensive diesel.

The ability of wind power to save diesel fuel also applies to only relatively to small wind capacities, up to about the amount by which the evening demand peak exceeds the demand during the rest of the day, as this is the only part of the demand curve that is normally subject to load shedding or the running of very expensive diesel-fuelled gas turbines. **If the wind power capacity were to be increased substantially beyond this point, as is proposed in the Draft IRP 2016 Base-Case, the extra wind power would no longer displaces load shedding or OCGT power, but rather only relatively cheap base-load coal fuel.** Therefore, **the economics of wind power decreases strongly as its capacity increases**.

The wind intensity is of course very variable, which means than on many evenings the wind will not blow during the evening demand peak, which will potentially expose the country to diesel burning or even extremely expensive load shedding. Large scale deployment of wind turbines will therefore also require large scale deployment of new back-up gas turbines, fuelled with imported Liquefied Natural Gas (LNG). The wind power will thus act as a cheap fuel saver for the gas turbines. However, due to the large fractions of many days that the wind will not blow, these gas turbines will have to be run for substantial fractions of the year, which means that massive deployment of wind power will lead to massive consumption of imported LNG, with associated massive external costs.

Solar-PV power, unlike wind power, naturally arrives at the wrong time of day, as South Africa normally has surplus power during mid-day (about 10h00-14h00) when the sun gives its peak irradiation. More seriously, the sun never shines during the early morning or early evening demand peaks. The decreased demand for power during mid-day can partly be explained by the fact that then uptake of air-conditioning in South Africa is tiny, compared to for instance hot desert climates, such as California in the US. Low uptake of air conditioning is partly due to South Africa's mild climate, partly due to cultural preferences and partly due to the high cost of air conditioning, which makes it an unlikely choice for poverty stricken developing countries, such as South Africa. These factors suggest that power demand during mid-day is likely to remain prevalent for the foreseeable future and that the mismatch between peak solar-PV power production and subdued power demand during mid-day is likely to remain an obstacle to the usefulness of solar-PV power.

This mismatch between supply and demand means that Solar-PV almost never displaces load shedding or expensive OCGT peaking power. (The CSIR's claims to the contrary will be discussed below.)

Solar-PV can thus only be integrated meaningfully into the grid if:

- **Solar-PV power is stored during the mid-day for later use** during the early evening demand peak.

  Battery storage costs are dropping rapidly. However, storage cost with the current state-of-the art lithium-ion (Li-ion) batteries, as recently proposed by Tesla's Elon Musk as a solution to load shedding in Southern Australia, still amount to about R2.00/kW power stored and retrieved. This excludes the cost of the original power that has to be stored. So, with wind and solar-PV power from the South Africa's Renewable Energy Independent Power Producer Procurement Program (REIPPPP) currently trending towards R0.60/kWh, the total cost of the stored power that will be retrieved during the evening demand peak will be about R2.60/kWh, which is much more expensive that the estimated cost of about R1.50/kWh for power from the planned new Combined Cycle Gas Turbines (CCGTs) fuelled with imported LNG. Therefore, battery storage currently almost quadruples the cost of solar-PV power.

  Pumped (water) storage is a much more viable option, as the storage cost of the newly commissioned Ingula pumped storage scheme is only about R1.00/kWh. However, it should be remembered that, due to friction in the pipes and pump, pumped storage is only about 80% efficient, i.e. for every 100 kWh of power pumped into the storage scheme, only 80 kWh can be retrieved later. This loss means that the cost of the solar power increases from R0.60/kWh to R0.75/kWh. Adding that to the R1.00/kWh storage cost results in a total cost of the retrieved solar-PV power of R1.75, which is not much more than the said R1.50/kWh cost of LNG-fuelled CCGT power. It should again be noted that storage almost triples the original R0.60/kWh cost of solar-PV.

It should, however, be noted that the Ingula construction project was, similar to the Medupi and Kusile coal plants, plagued by large budget and schedule overruns. If these construction challenges can be solved, it should be possible to reduce this storage cost considerable, in which case stored solar-PV power should become cheaper than the said gas power.

It should, on the other hand, be noted that there is the possibility, although it has not yet been verified, that shale gas from the Karoo region, mined by means of hydraulic fracturing ("fracking"), could in the long run (starting about 15 years from now) become available much cheaper than the imported LNG. Cheap shale gas could reduce the cost of gas power to much lower than that of the said stored solar-PV power, which will bring as back to the concept that that cheap mid-day solar-PV power will only be useful if we can move power demand also to mid-day.

It should also be noted that the lead-times for pumped storage schemes is currently very long. While Elon Musk famously promised to deliver battery storage to South Australia in 100 days, it took South Africa eight years to build the Ingula pumped storage scheme. This could hopefully in the future be reduced to three to four years. **Whatever the case might be, the point is that in the medium term, gas power will most probably be cheaper than stored solar-PV power.**

- **Solar-PV power during the day is supplemented with peaking gas back-up power during the small early morning demand peak and especially the large evening demand peak.** In the planning in the Draft IEP and Draft IRP, this option of gas supplementation was indeed the preferred Solar-PV strategy. **The problem is that inclusion of a large Solar-PV capacity then leads to the need for importing huge amounts of LNG to fuel the gas turbines, which brings huge external costs**, which will be discussed in the next section.
- **There is one serious problem with gas backup, though, namely that it might take approximately five years to construct the infrastructure for LNG imports. This means that in the next five year the intermittent renewables on our grid will come without the stabilising effect of affordable gas power and, therefore,**

these renewables will be largely useless to our economy and will also destabilise our grid.

2.1.1 Lack of penalisation of the external costs of imported energy, especially lack of penalty for methane gas emissions during the mining of shale gas for imported LNG

2.1.1.1 Global warming damage of methane gas leakage during shale gas mining

According to a policy decision, **neither the Draft IEP nor Draft IEP penalised imported energy for its external costs, such as release of CO_2 and other Green House Gases**. The idea is that every country from which South-African imports such energy should domestically tax or otherwise penalise each energy source for its external costs, so that these penalty costs should then already be included in the importation price of each energy source. If South Africa were to then also impose penalties on these external costs, it would obviously lead to double counting of the external costs, which would skew market forces.

The problem with this theory is that the world is currently in the grip of a low intensity trade war, especially between China and the US. In order to win extra export markets, governments therefore often turn a blind eye to external costs, such as Green House Gases emissions. By not penalising their energy sources, they can then export at lower prices, thereby undercutting their competition. **It is thus virtually certain that many countries will not penalise external costs on shale gas exports on their side of the border**. With President Donald Trump having won the US election partly on the ticket of believing that the theory of anthropogenic (man-made) global warming is a scam, it is practically certain that LNG imports from the US will not be penalised with carbon tax in the US.

So, far from double counting, South Africa's policy of not applying these penalties on imports will therefore almost certainly mean that no externality penalties will be applied on imported energy at all. This will create the absurd situation where South Africa discriminates against itself by penalising local power sources for their external costs, while allowing imported energy to go scot-free for exactly the same externalities!

- **Therefore, NIASA proposes that DOE should adopt a policy that these external costs, including global warming costs (i.e. carbon tax or environmental levy) on methane leaked during shale gas mining, should be allocated at least once and once only.**

  So if we import LNG we should enquire whether the country from which we import allocated a reasonable levy for the external costs. If so, South Africa should then not add more carbon tax on our side if the border. If not, the appropriate carbon tax should then be added. It should however be noticed that that is a technical problem that will be negotiated with those countries at the implementation stage.

However, currently the IEP and IRP is just about theoretical planning. Therefore, it is just about fairly allocating the carbon costs in the input assumptions of the model. **As has been explained above, it is virtually certain that the current international import price of LNG does not include any carbon tax or other external costs. Therefore, double counting is at this stage not a risk.** Therefore, **as far as the input assumptions for the IEP and IRP are concerned, NIASA proposes that an average carbon cost for methane leakage during shale gas mining should be added to all imported LNG prices.**

- The current glut of LNG on the international market comes largely from mining of shale gas, especially in the US. Substantial amounts of methane gas (CH_4) leaks out into the atmosphere during such shale gas mining operations. The problem is that methane is a 22-times more powerful Green House Gas than CO_2. While the literature shows large variations in methane leakage rates, the average Global Warming potential of this leaked methane gas (per kWh of electrical power produced) is roughly the same as that of coal power, which the Draft IEP estimated to be R0.26/kWh. Therefore, **NIASA proposes that**, until more detailed studies are in on the exact value of the carbon damage of the LNG we intend to import, **the level of the said carbon cost should be R0.26/kWh for all gas power produced using imported LNG.**

2.1.1.2 External cost of other types of imported energy

The large amounts intermittent renewables included in especially the Draft IRP 2016 Base-Case result in unnecessarily large energy i**mports, which will of course lead to losses of local job opportunities and to problems on our balance of payments, which will put the Rand under further pressure. External costs on the following imports are of particularly concern:**

- **Imported hydro power from African countries**
  Imported hydro power, particularly through multiple countries, as will be the case for the Inga project, caries a substantial risk of sabotage by terrorist groups/freedom fighters or from political interference after regime changes. If South Africa were to depend on such power for a substantial fraction of our power consumption, we would be left vulnerable to such attacks. Table 12 of the Draft IRP

2016 Base-Case shows that **imports of 2,500 MW new power capacity from the Inga project was one of the decisions that pushed nuclear out to 2037**.

- **Imported LNG through multi-country pipelines as fuel for gas turbines:**
    - Transporting **imported LNG by sea and thereafter by gas pipelines are potentially vulnerable to terrorist attacks and to political boycotts**, as happened with oil imports from the Middle-East during the oil crisis of the seventies. These factors add further external/hidden costs.
    - The US natural gas price is now at a multi-decade low and thus the option of relying heavily on imported LNG looks attractive to South Africa. However, the US and international natural gas prices are also infamous for being extremely volatile. There is thus the risk that after South Africa has built the planned gas turbines, the price of natural gas could spike aggressively, which could leave South Africa exposed to substantial power price increases, which would harm our economy. This is an additional hidden cost of the imported LNG option.
    - **The result of this underestimation of the external cost of imported shale gas** is that the **Draft IRP 2016 Base-Case (Table 12) deploys a massive 8,448 MW of new OCGT and 9,660 MW of new CCGT capacity, fuelled with imported LNG before 2037. Bearing in mind that this total of 18,108 MW of imported LNG capacity is about twice that of the planned 9,600 MW of new nuclear capacity, this over deployment of gas LNG gas power certainly contributed to pushing nuclear out to 2037.**

      Comprising such a large fraction of the national power capacity, it will also substantially expose the South Africa economy to the risks described above.

The point is that **the large amounts of hydro power and LNG that South Africa will have to import in future will largely be needed as peaking power to supplement the large amounts of Solar-PV and wind power that the Draft IRP 2016 Base-Case proposes to deploy**. **The external costs of the imported gas and hydro power should thus rightly not be viewed as external costs of gas and hydro, but rather largely as the external costs of Solar-PV and wind power**, since it is the presence of these intermittent power sources that necessitated these hydro and LNG imports in the first place.

For the sake of the national interest NIASA proposes such a detailed DOE study to determine the full external costs for the proposed large LNG imports, which will then reveal the full external cost of Solar-PV and wind power, which can be expected to be substantially higher than currently portrayed in the Draft IRP 2016 Base-Case.

This underestimation of the external cost of Solar-PV and wind power certainly contributed to the fact that the Draft IRP 2016 Base-Case deploys a massive 8,160 MW of new Solar-PV and 15,100 MW of new wind power before 2037, which certainly contributed strongly to pushing the 9.6 GW of nuclear out to 2037.

2.2 Lack of explicit assessment of the effect of the intermittency of wind and Solar-PV power on the stability of the power grid

A cornerstone of the Draft IRP 2016 Base-Case deployment strategy was that yearly capacity additions for intermittent renewables was restricted to 1000 MW for Solar-PV and 1600 MW for wind, due to the instabilities that their intermittencies cause on the grid. This means that even if wind and PV were to become much cheaper than the competing options, they will only be deployed in limited quantities, which created scope for nuclear and/or coal. **This strategy was severely criticized by proponents of wind and solar at the recent launch of the Draft IEP and Draft IRP 2016 Base-Case. The problem was that these restrictions were not properly justified in the Draft IRP 2016 Base-Case and were therefore perceived by opponent of nuclear as a pro-nuclear anti-renewables conspiracy to put purely artificially restrictions on the deployment of wind and solar-PV, purely for the sake of creating room for new nuclear.**

It is therefore imperative that DOE should motivate these restrictions in detail and in a transparent manner.

Rather than to apply a limit on wind and solar, it would probably better to explicitly state requirements for grid stability and to explicitly state how the addition of intermittent wind and solar-PV reduced the grid stability. The IRP 2016 calculation model should thus be supplied with explicit inputs for the contribution to grid stability or grin instability for each power generation technology. All output results should then state the grid stability factor for the combined fleet and the contribution of each portion of the fleet should be discussed. In this manner explicit limits for grid addition of intermittent renewables can then be developed which will be transparent, i.e. members of the public who wants to participate in this debate could then use these formulae to estimate the influence of their proposed modifications to the composition of the fleet on the stability of the grid.

Our own very preliminary search for information on this topic revealed that internationally some of the following techniques are included in strategies to guarantee grid stability:

- Load following power plants such as coal.

- Peaking power plants such as gas turbines.

  However, gas turbines still take about 10 minutes to start up and ramp up to meaningful power levels. They are thus way to slow to act as response to an instantaneous drop in power supply, such as the trip of a 600 MW coal unit.

- **Spinning reserve** is a standard pillar of grid stability in South Africa. When the load on the steam turbines of the South-African coal and nuclear fleet is suddenly increased due to for instance the said trip of a coal unit, the drag that this produces start to slow all the turbines in the fleet down, which reduces the frequency of the electrical sinus wave produced for the grid. The grid is extremely sensitive to frequency variations, so even just a tiny decrease in frequency can cause the grid to collapse catastrophically. An obvious solution to counter this decrease in frequency is to increase the steam pressure from the coal boilers in order to increase the spin rate of the turbines. However, it takes a substantial time to burn enough extra coal to create enough extra steam pressure. Therefore, this is not a viable instantaneous solution.

  However, the very large inertia of the steam turbines counter the drag put on it and therefore this inertia alone can counter the drag on the frequency for about half a minute, which is long enough to allow the system operator to take emergency action such as to start up a hydro power unit or to manually shed some loads.

  The inertia of spinning gas turbines are also good sources of spinning reserve. However, the problem is that, due to their high fuel costs, gas plants are normally shut down as soon as they are not needed. They are thus often not spinning when a crisis unexpectedly appears. Coal and nuclear steam turbines thus remain the mainstays of spinning reserve for grid stability.

- **Hydro power plants**, such as normal hydro power or pumped storage could be included in the mix as they can ramp up to full power in seconds.

- **Dynamic demand response**: However shedding load supplies backup power to the grid faster than any of the other options as a load can be shut off in fractions of a second. The UK, with a 60 GM grid, i.e. about 50% larger than the South-African grid, deploys about 2 GW of such Dynamic Demand response (https://en.wikipedia.org/wiki/Dynamic_demand_(electric_power); https://en.wikipedia.org/wiki/Demand_response). It consists of large power users (> 2MW) that are willing to, without any prior notice, forego electricity supply during a crisis, provided that they are paid well enough for supplying this service. Steel smelters and water pump stations are typically used for this purpose. These loads are then controlled by frequency sensitive trip switches: the switches measure the grid frequency in real time. When the frequency drops from 50.0 Hz to 49.9 Hz the switch trips immediately, thereby releasing all the power it was consuming back onto the grid in order to help supply extra power to meet demand. A whole fleet of small privately emergency diesel generators, such as the back-up generators at hospitals, are then summonsed to start up and replace the lost load, until the crisis is resolved.

Similarly, frequency sensitive switches are also used to switch on certain large loads when access power supply drive the frequency up above a set limit.

- Longer term **Demand Side Management (DSM)**, such as Eskom's previous Buy Back Program where users are phoned up and asked to reduce load during a crisis, in exchange for payment.
- **Time-of-use tariffs**, such as Eskom's Megaflex price structure, where prices are constantly set higher during normal peak demand times of day and lower during timeslots normally associated with low demand. Users can then set timer switches in order to run non-essential large loads, such as water heater, only during the lower price timeslots.
- Smart grids: The grids communicate electronically with computers that control large grids, for instance it can transmit variable prices in real time. In times of power shortage, the grid control computer can then automatically increase the power price and notify all connected user computers. Owners of such devices can then set trip levels, depending on their personal needs, so that they can then either choose to pay the increased prices and retain the privilege of having power, or switch off and enjoy escaping the price increase.

In the past South Africa's large cola fleet supplied abundant abs stable power and therefore there was little need to implement many of the grid stability tools mentioned above. However, the large amounts of intermittent wind and solar-PV proposed by especially the Draft IRP 2016 Base-Case will definitely require a large investment in such grid stability tools. However, such an investment will have to be preceded by detailed studies on the topic.

The maximum penetration levels of non-synchronous renewable PV solar and wind farms require detailed studies to be performed over various time frames. The North-West University is at the point of launching an investigative study (which will be conclude within the following two months) which will only determine the proper scope for such a detailed study, regarding the following topics:

- grid stability in the first few seconds as the grid could collapse in seconds;

- minute to minute balancing of the system, effectively counteracting non dispatchable power plant output variations;
- day-ahead / week-ahead forecasting, ensuring security of supply is maintained;
- year ahead planning for seasonal variations; and
- long term planning in determining the appropriate technologies for future secure and economic power supply.

In view of the fact that such a detailed study will obviously be in the national interest, **NIASA proposes a full detailed study into the issue of grid stability in the face of high penetrations of intermittent renewables.**

2.3 Lack of appreciation of the potential of time-of-day Demand Side Management (DSM) to smooth out the peaks in the South-African power demand curve and thus to create more scope for base-load nuclear power

2.3.1 Nuclear benefits from a flat time-of-day demand curve.

The current sharp time-of-day peaks, especially the large early evening demand peak, are not very user friendly for nuclear plants. While South-African coal plants are normally used in load-following mode, it is uneconomical to use nuclear plants in this manner, due to nuclear's high capital cost and low fuel cost. Nuclear plants are normally used in pure base-load mode, which means that they produce at 100% power output all the time and thus cannot ramp up their power output in order to meet the said demand peaks. The only kind of load following nuclear can thus do is power output reduction, which will save mainly fuel cost, but will increase capital cost, due to the resulting lower load factor. Due to the said high capital and low fuel cost, the increase in capital cost will outweigh the reduction in fuel cost, which will make the nuclear load following uneconomical. The task of load following is thus normally reserved for plants with low capital and high fuel costs, such as coal plants and especially gas turbines.

The current sharp peak in the South Africa time-of-day demand curve thus limits the amount of nuclear generation capacity that can meaningfully be deployed on the grid. For this reason, nuclear is often partly squeezed out by plants with load-following capability, such as coal and peak-following gas turbines.

However, large scale roll-out of Demand Side Management (DSM) techniques, such time-of-use smart meters, coupled to aggressive incentives by means of time-of-day pricing, and

Dynamic Demand response, i.e. automatic switches that either shut of certain non-essential loads, such as water heaters and swimming pool pumps, when the grid frequency drops too low and then switch them back on again when the grid frequency goes too high can potentially be a cost-effective strategy to shift peak demand to those times of day where there is over-supply of power. This time-of-use demand side management is fundamentally different from that type of demand side management that aims to reduce the total demand for power. Where such reductions in demand would hurts Eskom's power sales and thus its revenue, time-of-day demand side management just moves the demand from high-demand periods to low-demand periods during the day, where Eskom's coal and nuclear base-load stations can easily supply this demand. As these base-load plants produce power much cheaper than gas turbines, shifting the demand in this manner will maintain Eskom's power sales, but will strongly reduce its expenses on diesel or gas fuel for the peaking gas turbines. This will obviously increase Eskom's profitability substantially.

Unfortunately, the Draft IRP Base-Case paid almost no attention to this strategy and thereby underestimated the potential space for nuclear power, which contributed the nuclear being squeezed out to 2037. Therefore, studies will be recommended below aimed at determining the appropriate place and strategies for time-of-use DSM.

2.3.2 Time-of-use DSM also reduces the cost of renewable power

However, implementation of time-of-use DSM will not only help baseload coal and nuclear. The recent CSIR study in which Prof. Tobias Bischof-Niemz presented a method for supplying all South Africa's power needs with a large fleet of wind turbines, solar-PV panels and Open Cycle Gas Turbines (OCGTs) produced what appears to be good results, except for the fact that he neglected certain externals cost of his plan, which will be discussed below. However, his study encountered one challenge that substantially increased the Levellised cost (LCOE) of the combined electrical power output. Due to the extreme intermittency of especially the wind turbines, he chose to back them up with a large fleet of LNG guzzling OCGTs. This resulted in a high LCOE for these gas turbines of R2.00/kWh. He chose OCGTs because of their ability to follow load very fast. If however the variations in the load could have been smoothed out with time-of-use DSM, the load following could have been done with Combined Cycle Gas Turbines (CCGTs), which follows load slower, but also uses much less fuel than OCGTs. This would have reduced the LCOE of the gas power to about R1.50/kWh, which would have reduced the LCOE of the combined power output substantially.

2.3.3 Time-of-use DSM will benefit energy intensive users.

Increasing penetration of renewables in the grid is globally a given. As the capital costs for the construction of these wind and solar-PV plants are sunk costs, there variable costs, which normally corresponds fuel costs in the case of fossil fuel plants, are close to zero and the wind and sun are free. So, when the sun shines brightly and/or the wind blows strongly these renewables produce large oversupplies of virtually free power. However, due to the said mismatch between time-of-day supply and demand, this power often goes to waste. However Dynamic demand response can automatically alert intensive power users to greatly increase consumption at such times of oversupply. This could help to stabilise the grid and simultaneously supply such energy intensive users with abundant cheap power, which could increase production and thus economic growth.

2.3.4 Conclusion

Time-of-use DSM is thus not simply a gimmick designed to boost nuclear power, but rather a common sense technique that can benefit all power sources on the grid, while increasing Eskom's profitability and boosting the economy for the whole nation. Therefore, a study on time-of-use DSM will be proposed below.

2.4 Lack of penalisation of coal CO_2-emissions in the Draft IRP 2016 Base-Case

2.4.1 Draft IEP-2016 penalised coal with the estimated full environmental costs.

This consists of health costs due to the pollutants released by coal and Global Climate Change costs due to Global Warming caused by the release of CO_2 as a Green House Gas (GHG). This penalty was applied by including these costs in the production costs of coal in the input assumptions of the calculation model. In fact, the Draft IEP took quite a stern view on carbon costs:

- Climate change cost of CO_2 emissions were upped from Government's previous determination of a Carbon Tax of R150/ton to the new climate damage cost of R270/ton CO_2. With 947.3 g CO_2 released/kWh that translated into a CO_2 climate damage cost = R0.26/kWh.

- This increased the LCOE of coal power to the point that it was largely squeezed out and nuclear, renewables and gas were thus brought in stronger and earlier, in order to fill the resulting void. The **Draft IEP therefore allocated between 10 to 29 GW of new nuclear capacity 2050, depending on the scenario selected, which is quite an aggressive nuclear program.**

2.4.2 Draft IRP 2016 Base-Case does not include carbon costs for coal

While the assumptions for the **Draft IRP 2016 Base-Case** does include health costs due to coal pollutants, it **assumes a zero carbon climate damage cost**. **Instead it opted to limit CO_2 emissions by applying a maximum annual limit to CO_2 emissions.** Coal is thus not at all penalised for CO_2-emissions until the annual emissions limit is reached in a decade or two. From that that point onward, new coal is severely curtailed as any additional coal would then push the total South-African CO_2 emissions over this limit.
The effects of this policy were:

- Before the annual emission limit kicks in, the total LCOE of coal power is artificially lowered to only R0.89/kWh by ignoring its carbon cost.
- Coal power is thus initially assessed as cheaper than nuclear power at an LCOE of R0.97/kWh and nuclear is therefore initially squeezed out by a combination of coal, wind, Solar-PV and gas. (The underestimation of the external costs of especially Solar-PV and gas, which unfairly contributed to this process, will be treated below.)
- It is only when the annual CO_2 emission limit is reached that the deployment of new coal is practically stopped. This then created scope for new nuclear after 2037.
- **This practice of bundling all coal construction together in the first years of the planning window and to then abandon coal construction and switch abruptly to new nuclear construction has the unintended consequence of making localisation of coal and nuclear construction much more difficult:**
    - **In the first years coal is first built at a rate that is so high that there is little time to train local artisans** etc.
    - However, just when a decent number of these local artisans have been trained, **coal construction is stopped abruptly and replaced with nuclear** construction. **As the required skills levels for nuclear construction are much higher than for coal construction, the trained coal construction artisans then lose their jobs.**
    - The whole roller-coaster ride then starts again with feverish training of nuclear artisans, only to lose their jobs once the nuclear construction comes to an end…
    - **So, from a localisation perspective, it would be much better to find a compromise between the Draft IEP 2016 and Draft IRP 2016 Base-Case so that new coal and nuclear construction starts simultaneously, but proceeds at a slower pace, so that artisans that are trained on the first coal and nuclear plant can then find work on the subsequent coal and nuclear plants etc.**

- However, **if carbon costs were to be applied to coal power from the start, nuclear would from the start be cheaper than coal power, which would lead to the early deployment of new nuclear.**
  There is of course substantial uncertainties about what the tendered Overnight Cost of new nuclear plants will be, so it cannot be asserted here that if carbon costs were to be added from the start, that new nuclear power would in practice always be cheaper than new coal power. (Some of these issues surrounding the cost of new nuclear plants will be discussed below.) So, the only point that is made here is that, **under the assumed costs of the Draft IRP 2016 Base-Case, the addition of full carbon costs would make nuclear power cheaper than coal power**.
- Even in spite of a higher LCOE than nuclear, new coal could take away some capacity from new nuclear due to coal's superior ability to do load-following, its shorter lead times than nuclear and because of the large number of local jobs it will create, especially in coal mining.

It is clearly problematic that the Draft IEP, which is designed to paint the big picture for the combines mix of all energy sources for South Africa, of which electricity is only one component, uses very different assumptions that the Draft IRP 2016 Base-Case, which focusses exclusively on the energy mix for electricity. **If chaos is to be avoided, it is clearly necessary to align the model input assumptions of the IEP and the IRP**, regarding electricity.

Proponent of the strategy of the Draft IRP 2016 Base-Case to only limit the maximum annual release of CO_2, without penalising CO_2 emissions with carbon climate damage cost, state that to also penalise it with carbon climate damage cost would lead to double counting. It is obviously true that once the limit is reached and Eskom is then forced to abandon new coal, which was traditionally seen as the cheapest large scale dispatcheable power source, Eskom would then incur a cost because it would then have to switch to other, presumably more expensive power sources. So, if a carbon cost were to at that stage also be applied to coal, obviously, that would lead to double counting. However, **the problem is that, up to the point when this emission limit is reached, carbon costs are in the strategy of the Draft IRP 2016 Base-Case not at all allocated to coal, which initially skews the market in favour of coal and against nuclear. A better strategy might thus be to initially apply a carbon cost, until the limit is reached, and to then switching to only enforcing the limit.**

However, the whole problem needs first to be studied in more detail, as is proposed below.

3 Mismatch between IRP policies and market players

The greatest problems with the Draft IEP 2016 and Draft IRP 2016 Base-Case is that it assumes market realities and behaviours of market players, which, in reality, do not exist. By this is meant that these plans calculate optimal behaviours for producers and consumers, and the implicitly assumes that these market players will obey these guidelines. Therefore, it creates no financial incentives to enforce these optimal behaviours. **The main examples of the mismatch between ideal modelled behaviour and actual negative behaviours are the REIPPPP program and the influence of Eskom's tariff structure on grid defection by means of the implementation of energy efficiency measures by business and by rooftop solar owners**.

3.1 Mismatch between IRP and REIPPPP policies

3.1.1 IRP principles:

- Minimisation of Levellised cost in a technology neutral fashion.
- Therefore, there is no room for subsidies of favourite technologies.
- Consumer pull rather than producer push: So, production units are brought online as and when consumer demand requires it. Furthermore, the mix of power generation technologies is optimised to supply power at the times of day when consumer demand requires it.
- This means that gas backup power is deployed together with intermittent wind and solar-PV, so that the gas can stabilise the grid

Proponents of the REIPPPP regularly claims that the REIPPPP makes economic sense as it follows the lead of the IRP, which is obviously designed to make economic sense. However, the REIPPPP aggressively violates all the principles of the IRP in that the REIPPPP is built on the following principles:

3.1.2 The REIPPPP violates all the IRP principles

3.1.2.1 The REIPPPP supports renewables, regardless of cost

While the IRP carefully waits until the prices of renewables decrease to the level of cost competitiveness before deploying it, the REIPPPP rushed in and deployed renewables in Bid Rounds 1,2 and 3 when prices were clearly insanely high. Prices have now dropped to acceptable levels, so if we still had the money which we signed away in Rounds 1 to 3 we could have bought an amazing amount of energy. However, that money is now down the drain and thus we no struggle to finance new build of any kind.

3.1.2.2 The REIPPPP favours preselected technologies, regardless of their lack of merits

If merit had anything to do with the design of the REIPPPP, Round one to 3 would have deployed only wind and LNG-fuelled Combined Cycle Gas Turbines (CCGT) in equal capacities, with no solar-PV:

- At the time of the start of the REIPPPP in 2011 South Africa's power supply was still constrained after the 2008 load shedding crisis and it was heading for the load shedding crisis of 2014/2015 when the coal silo at the Majuba power station collapsed. However, due to South Africa's large evening demand peak, burning of expensive Open Cycle Gas Turbine (OCGT) diesel occurred mainly during the early evenings when the sun does not shine. The same applies to hyper expensive load shedding (unserved energy). Solar-PV could not possibly contribute to the solution of that problem. However, the wind at the coast fortunately often blows during this early evening demand peak. The only problem is that wind power is much more intermittent that solar-PV power. So without gas back-up the wind power would be quite undependable. However, together with the gas back-up, the fleet of wind turbines would have resulted in a cost-effective early evening peaking power station, which could deliver power at say R2.00-R2,50/kWh. As it would compete with OCGT diesel fuel at about R3.00/kWh thus would have been a profitable option which would have required no or very little subsidy. Once commissioned, the CCGTs would also be available for power back-up during any other times of day, regardless of the presence of wind power. These CCGT would thus have been a mighty help during the 2014 load-shedding crises.
- However, for apparently completely Green ideological reasons, the gas back-up in the plan above was replaced with insanely expensive solar-PV power (>R3.00/kWh). There appears to be no logical reason for this as South Africa almost never had shortages during mid-day when the sun gives peak power. If some concern for the needs of power consumers prevailed and CCGTs had been added to the combination of solar-PV panels and wind turbines, the gas back-up could have strung the solar power during mid-day together with the intermittent power during the rest of the day to result in expensive, but at least dependable dispatcheable power. Such power could have been used to hook up new power intensive users such as mines or factories. However, without the gas backup the remaining combination of solar-PV was both very expensive and useless as it was too undependable to be used to hook up new customers. So, the first Bid Windows of the REIPPPP solely served to make power in South Africa substantially more expensive, without making it more abundant or accessible to consumers.

3.1.2.3 The REIPPPP is built on producer push rather than consumer pull

Normally power plants have very long lead times, e.g. 12 years for the first nuclear reactor. Therefore, energy palling projects at least a decade into the future. It therefore happens that a utility build a power plant in the belief that there will be demand for its power. However, when it comes on line one might find that the required demand is not there. Since it is not possible to make the plant disappear it is accepted practice to force consumers to subsidies the plant, although they might at that stage have no need for it. However, the very short lead times for solar-PV of 18 months for the first time puts us in the position to delay construction to when we see a need arising. The prices of PV panels are dropping every year and Eskom currently has surplus [power capacity, especially during mid-day when sola output peaks. So, the logical thing would be to wait with new PV deployment until the need arises. However, as the recent showdown between Eskom and the DOE/REIPPPP/renewables community showed the rules of the REIPPPP is structured such that Eskom is simply forced to sign on contracts for which it has no need. This is producer push rather than consumer pull

3.1.2.4 The REIPPPP optimising contracts to suit producer time-of-day output patterns, with total disregard for consumer time-of-day demand patterns

As has been pointed out above, South Africa has a need for additional power during the evening demand peak, when wind power often produces maximum output. However, we have virtually no need for extra power during mid-day, as power demand is normally slightly reduces during mid-day and the country therefore already has too much power at that time. Therefore, the value of wind power is obviously higher than that of solar-PV. However, the REIPPPP this far consistently gave higher tariffs to solar-PV than for wind power. This demonstrates that the REIPPPP is designed to suit the needs of the power producers not the need of South Africa's power consumers.

3.1.3 Some REIPPPP claims found to be false

3.1.3.1 The claim that the REIPPPP caused the great reduction in the cost of solar-PV power prices is false

This reduction in power prices was caused by a massive subsidy by the Chinese government to solar-PV panel factories in China, in order to create a monopoly. The REIPPPP's policy to buy large amounts of solar panels when they were still much too expensive had little to do with this drop in prices.

3.1.3.2 The REIPPPP does not simulate research into new and better solar panels

The said subsidies went into silicon crystalline technology, in which China acquired the said monopoly. China has overbuilt and is now dumping these panels below cost on the world market. This actually prevents new technologies from gaining a foothold. The Chinese monopoly, which the REIPPPP subsidised is thus holding new developments back, rather than to stimulate it.

3.1.3.3 The REIPPPP did not give local South Africa industries a foot in the door

As explained above, the REIPPPP actually helped to subsidise the Chinese monopoly on solar-PV panels. Any South Africa factories that are created with South Africa subsidies are this doomed to be crushed by this Chinese monopoly and is thus likely to cause further hardship in South Africa.

If South Africa invested the billions used to subsidise the REIPPPP directly in leading overseas technology companies, we would now have been owners of strong new technologies. Due to the irrational REIPPPP policies all this money is however now down the drain.

3.1.4 Conclusion on the REIPPPP

It has been shown that while the principles on which the IRP are squeaking clean in that it really aims to supply South Africa with clean power at the lowest possible price, the renewables part of this mission falls flat the moment the execution is handed to the REIPPPP, as the REIPPPP by design violates all these lofty economic principles.

The flaw of deploying intermittent REIPPPP wind and solar-PV, before the required gas back-up to stabilise their intermittent outputs, should be stopped immediately. The REIPPPP is on this point totally out of line with the IEP and IRP: The IEP and IRP modelling rolls out gas back-up power together with intermittent wind and solar-PV, so that the gas can stabilise the grid. There is a problem with the REIPPPP, namely that it might take approximately five years to construct the infrastructure for LNG imports. This means that in the next five year the intermittent renewables on our grid will come without the stabilising effect of affordable gas power and, therefore, these renewables will be largely useless to our economy and will also destabilise our grid.

Therefore, the REIPPPP resulted in great squandering of money. As fruitless expenditure is by definition illegal and unconstitutional, it would appear that the time is now ripe to challenge the constitutionality of the REIPPPP in court.

3.2 Mismatch between IRP policies and the behaviour of grid defectors

3.2.1 Eskom no longer has a captive client hood

For decades, power prices in South Africa were well below the value of power to consumers, partly due to lack of allocation of external costs, such as carbon costs, and partly due to subsidies by the Old South Africa Government. This means that whenever Eskom faced a financial need, it could simply increase power pieces and consumers would simply grin and bear it as it would be way too expensive for them to implement energy efficiency measures, let alone defect from the grid. All of that changed since about 2008. Eskom has for a long time been systematically increasing power prices faster than inflation. However, round about 2008 a series of price increases were effected that were much faster than inflation, i.e. the real prices of power increased dramatically. The prices of energy efficiency technologies have also been dropping fast for a long time, so that it became in principle possible to greatly reduce one's power consumption in a cost competitive manner by implementing energy efficiency technologies. However as South Africans did not have a culture of power saving, this did not happen on a large scale. However, the load shedding crisis of 2008 was a tipping point. Many consumers became so disillusioned with the timely and untimely load shedding that they made it their mission to greatly reduce their consumption of Eskom power. Therefore, sales of energy efficiency technology skyrocketed. Coupled to this came some perceived government corruption.. In response, some people made it their mission to disconnect from the Eskom grid as a form of political protest. The result was that people who could afford it were willing to spend substantially more on temporarily disconnecting from the grid (during mid-day when solar-PV produces peak power plus than it would have cost them to remain on the grid. There efforts were assisted by the impressive drop in the prices of solar PV panels that occurred during the same period. The result was that many people installed rooftop solar, even though it did not make economic sense.

3.2.2 Price increased are now punished with more grid defection

Up till 2008 power demand increased strongly in a simple predictable linear fashion, proportional to economic growth. This pattern was interrupted only minimally for only very short periods by times of economic recession. However, 2008 wax the tipping point: after the economic crises of 2008 the South Africa economy recovered and has since grown to substantially higher output levels than just prior to the economic crisis. However, power consumption flattened after 2008 so that current power consumption is practically identical to the level just prior to the 2008 economic crisis. This is the longest flat period in South-African history and is clearly the advent of a new and uncharted phenomenon of economic growth in spite of lack of growth in electricity consumption. The lack of demand growth has hurt Eskom's revenues and has resulted in a situation where Eskom now has oversupply of power. However, in spite of zero sales growth, Eskom's expenses kept growing due to factors such as increases in cola prices, increasing labour unrest and the cost of subsidising the REIPPPP. Eskom applied for and to a certain extent obtained price increases from the National Energy Regulator (NERSA). However, for the reasons explained above, many consumers are retaliation against this by increasing their investment in energy efficiency and by defecting from the grid. Therefore, price increases are now punished by reduced consumption.

3.2.3 Partial grid defection during mid-day reduces Eskom's revenue, without reducing its expenses.

Complete grid defection would free up the power infrastructure owned by Eskom and the local municipalities, which would create the opportunity for generating new revenue by hooking up new customers. However, the current habit of disconnecting from the grid only during mid-day when rooftop solar-PV output peaks, but to then return to the grid during the evening demand peak when the sun does not shine, means that this type of grid defection decreases the revenue of Eskom and the municipalities, without freeing up their power infrastructure during peak demand. Therefore, they cannot hook up new consumers to generate new revenue. This puts Eskom and the municipalities in a bind where their only option for increasing revenue is increasing power prices, which is simply punished by a new round of grid defection…

If increasing use of solar-PV is part of the problem, it is clear that the quickly expanding capacity of solar-PV form the REIPPPP only makes matters worse.

3.2.4 Rooftop solar-PV receives the largest subsidy of all power generation technologies in South Africa.

Formally there is no subsidy for rooftop solar in South Africa. Most towns and cities also does not allow net-metering and therefore it is not even possible to sell one's excess solar-PV power back into the grid. For this reason rooftop solar-PV is hardly discussed in the Draft IRP 2016 Base-Case, as it does not feature in the REIPPPP contracts.

However, informally rooftop solar owners do sell their power to the municipalities in the sense that the use this power to reduce their power that they buy from the municipalities.

Power sales are used by South-African municipalities as an easily enforceable means of taxing residents. These "taxes" are then used to maintain also other infrastructure, such as roads and water works. The result is that municipal power prices are substantially higher than the actual cost of supplying the power. For instance, Eskom generates coal power at bout R0.50/kWh and the municipalities sell this power at about R1.50/kWh. Rooftop grid defectors thus gets to escape paying these "taxes" as the get to reduce their municipal power bill by R1.50 for every kWh of rooftop solar they generate. When that is compared to the latest subsidised prices for utility scale solar-PV in the REIPPPP of R0.60/kWh, it is clear that rooftop solar owners get to sell to the municipalities at much higher prices that the REIPPPP contractors. If it is further assumed that the marginal cost of coal power, i.e. fuel cost, variable O&M and external costs (i.e. pollution costs such as carbon costs) amounts to about R0.51/kWh the subsidy on REIPPPP solar-PV that is sold to Eskom at R0.60/kWh is only R0.09/kWh. By the same logic the subsidy on R1.50/kWh rooftop solar-PV is a massive R0.99/kWh, i.e. 11 times the subsidy received by the REIPPPP contractors! Rooftop solar-PV grid defectors thus get to escape the municipalities' *de facto* taxation at a massive rate of R0.99/kWh. Unfortunately, this does by no means reduce the revenue needs of the municipalities. The result is that they tend to revert to taxing those that remained on the grid even more, which just results in a new wave of grid defections…

It is therefore clear that the current vicious cycle is unsustainable and if left unchecked will in the end bankrupt both Eskom and the municipalities, which will lead to substantial infrastructure collapse in South Africa. It is thus in the national interest to act now to stop this vicious cycle, before it is too late.

Since the Draft IEP 2016 and Draft IRP 2016 Base-Case only did theoretical modelling of demand and supply, without considering responses of real world of market players to their policies, this looming crises is hardly even mentioned in these energy plans.

3.3 Demand Side Management (DSM) through time-of-use metering and pricing is the best way to stop partial grid defection and save the system

3.3.1 Sharply reducing mid-day power prices will remove the system cost of grid defection

In a liberal democracy such as South Africa, it is obviously impossible to legally stop people from partially defecting from the grid. However massive rollout of time-of-use metering and accurate setting of prices according to time-of use supply and demand dynamics will remove the financial incentive for defecting from the grid. For the examples above, reducing municipal power prices during mid-day from R1.50/kWh to R0.51/kWh will make partial grid defection inconsequential to the profitability of Eskom and the municipalities because Eskom/municipalities will then be able to buy the rooftop solar-PV at exactly the same price as they the can themselves generate it from coal. Their cost will this remain identical, regardless of which source they use for procuring their power.

3.3.2 Increasing power prices during demand peaks will flatten the demand peaks

By the same logic of balancing supply and demand municipal power prices during the early morning and early evening demand peaks will then have to be increased from R1.50/kWh to say R2.50/kWh. This will then serve as a great incentive for users to shift their demand to the low demand timeslots of the day. This will substantially reduce the need for using expensive peeking gas power during demand peaks, which will substantially reduce the overall production cost of power.

3.3.3 Reducing power prices during high supply and low demand periods will create great opportunities for power intensive users

The profitability of many power intensive activities is sensitive to the price of electricity. Bringing large capacities of wind and solar-PV onto the grid will create times of massive over supply of power when the wind blows and the sun shines brightly. Without dynamic time-of-use metering and pricing it will be impossible to stimulate demand during such periods and therefor this excess, virtually free, power will simply have to be thrown away. However dynamic price setting can attract large loads by setting very low prices, which will create a win-win situation for both suppliers and consumers.

4 Reasons for the negative view on nuclear in the public domain

4.1 Lack of penalisation of the external cost of Solar-PV in the CSIR studies

The CSIR recently published two major studies that presented an extremely optimistic view of wind and PV solar and a very negative view on nuclear power:

1. ***Financial Costs and Benefits of Renewables in South Africa in 2014, published on 10 Feb. 2015 by Dr.*** **Tobias Bischof-Niemz from the CSIR.**
2. **"*Wind, solar can supply bulk of South Africa's power at least cost, CSIR model shows.*", an opinion piece by Dr. Tobias Bischof-Niemz of CSIR Energy Research: - Engineering News (22 Aug. 2016)** (http://www.engineeringnews.co.za/article/wind-solar-can-supply-bulk-of-south-africas-power-at-least-cost-csir-model-shows-2016-08-22/rep_id:4136; http://us-cdn.creamermedia.co.za/assets/articles/attachments/63272_high_re_scenario_-_csir_-_22aug2016.pdf)

Although the calculations of these studies have not yet been checked in detail, Prof. Dawid Serfontein has reviewed them intensively on a conceptual level. So far he has not detected any calculational errors in them. However, major conceptual flaws and flaws of interpretation have been uncovered.

The first study appears to contain major flaws of interpretation. The study showed that the wind and PV solar power that Government forced Eskom to buy via the REIPPPP helped Eskom and the country by averting load shedding (Unserved Energy), by saving expensive diesel fuel for Eskom's Open Cycle Gas Turbines (OCGTs) and by saving coal fuel for its coal stations. From this it concludes that the country made a substantial profit on the money spent in 2014 to buy this power through the REIPPPP. The author based these calculations on hourly power data for 2014 which Eskom supplied to him.

In Prof. Serfontein's preliminary analysis of his report, he showed that **its logic seems to be flawed in the following respects**:

- It compares the financial position of the country after having procured the said wind and Solar-PV power through the REIPPPP with the position the country would have been in if this power were not produced and procured through the REIPPPP. **By implication it thus assumes that the logical alternative to producing and procuring this power through the REIPPPP was to do nothing at all. The report thus shows that, in 2014, South Africa was better off because of having produced and procured this power through the REIPPPP, than it would have been if we did nothing.** In effect the report thus demonstrate the unsurprising truth that it is better to have additional expensive intermittent and undependable power than to have a large power shortage.
- **The report is thus flawed in that it asked the wrong questions** (and then answers them correctly):
  The options in Government's Integrated Resource Plan for Electricity (**IRP**) was never to produce wind and solar power or to produce nothing. The assumption was always that more than enough power shall be produced, i.e. **if we produce less wind and Solar-PV power, we must then produce more gas, coal, hydro, pumped storage and nuclear power**. In particular, the IRP assumes that the power generation mix must be selected such that the total output of all sources shall always meet South Africa's time-of-day demand curve, i.e. that the mix will contain enough pumped storage and power peaking plants (mostly Combined Cycle Gas Turbines (CCGTs) fuelled with imported LNG) that the morning and especially the much larger evening demand peak shall always be fully supplied.
- **Therefore, the right question to have asked would have been:**
  Would South Africa have been better off if we produced and procured the said amounts of intermittent wind and Solar-PV power through the REIPPPP, or if we had rather produced or procured this amount of power from a mix of alternative power sources.
- **2014 were a freak power shortage year that caused the REIPPPP contracts to look better than they really are**.
  Because of the well-publicised collapse of a coal silo at the Majuba power station, Unserved Energy and running of Eskom's OCGTs in 2014 many times occurred during mid-day, which created the opportunity for Solar-PV from the REIPPPP to prevent these two events and thus to save the country substantial amounts of money. However, the CSIR report's whole "REIPPPP renewables are profitable" narrative fell flat on about August 8, 2015, when Eskom restored sufficient power supply, due to subdued power demand and major improvements in the load

factor performance of its coal fleet, brought about by an improved maintenance program. From that point on the REIPPPP contracts saved almost exclusively cheap coal fuel an external cost at about R0.51/kWh, which means that both before and after this tiny 2014/2015 window of opportunity, the REIPPPP program has always run and will always run at a massive loss to South-African society, as was highlighted above. The report also failed to report its own finding that, even in the bumper year of 2014 the solar-PV contracts in the REIPPPP ran at a loss and that the joint small profit of renewables was solely supplied by the larger profit of the wind contracts. This proves what NIASA's studies have claimed all along that, although the wind power in the REIPPPP might make some sense, as the wind often blows during South Africa's evening power demand peak, the solar-PV contracts are completely irrational and therefore unconstitutional. Therefor the whole optimistic vibe of this CSIR report is misleading as it selectively uses one year of tiny profits to camouflage 20 years of massive losses for the South-African economy. This suggests an anti-nuclear and especially a pro-solar-PV bias.

The second report, namely the opinion piece by Dr. Tobias Bischof-Niemz of CSIR Energy Research: **"*Wind, solar can supply bulk of South Africa's power at least cost, CSIR model shows*" seems to be of a much better quality than the first**, but also repeats the typical mistakes of the Draft IRP 2016 Base-Case and the IEP, in that **it does not allocate the external costs** (which were explained above) **of the large amounts of imported LNG fuel for the gas turbines, necessitated by intermittency of its large fleets of wind turbines and solar-PV panels:**

- **The Global warming costs from the release of methane during shale gas mining.** As has been explained, this is much larger than the global warming cost of the small amount of CO_2 released by burning methane gas (CH_4), which produce more clean water than CO_2 in its exhaust gas.
- **The external cost of the strategic and economic risks involved in importing such a large fraction of our energy.** Since the CSIR's wind, solar-PV and gas proposal would become completely unstable in the absence of the stabilising gas power, it would completely cripple the country of foreign gas lines were to be cut during times of military conflict, as happened during the oil crisis of the 1970-ties.
- **The cost of supplying spinning reserve or other methods to stabilise the grid at times when the back-up fleet of gas turbines is not running.** In the CSIR's plan the gas turbines run only during times that the wind and solar-PV cannot supply the demand. During the times that the gas turbines are running, they would supply

good grid stability, especially since the CSIR proposed using the more expensive Open Cycle Gas Turbines (OCGT) which can ramp up much faster than the more fuel efficient Combined Cycle Gas Turbines (CCGTs). However, during the times of day that they are shut down, their 10-minute start-up time will preclude provision of spinning reserve. Therefore, other measure will have to be taken to solve this problem, or some of the gas turbines will have to spin continuously, just for spinning reserve, which will substantially increase fuel cost.

In view of these problems, the energy security of South Africa cannot be entrusted to the plans contained in these CSIR studies, until all these loose ends have been tied up by means of independent verification studies

4.2 Incorrect assessment of the "white elephant risk"

A statement that has been used repeatedly by the opponents of nuclear power is that in case of an oversupply of power, the new nuclear plants will become "white elephants" "that will bankrupt the country".
This statement requires further study, as it appears to be flawed on several levels:

- Nuclear power has a lower marginal cost than gas plants and coal plants, because its fuel cost is much lower than that of these fossil fuel plants. Therefore, in case of an oversupply of power, it is these fossil fuel plants, rather than the nuclear plants that will be shutdown first. This could have many benefits, such as:
    - Reduction of the release of pollutants, including CO_2.
    - Allowing Eskom the time to shut old coal plants down for longer maintenance outages, which would afford Eskom the opportunity to overcome the current maintenance backlog on its coal plants, which will lead to less plant breakdowns and thus lower operational costs.
- The break-even cost of nuclear plants are very low:
  The current calculational methods prescribed by treasury requires that the calculation of the Levellised Cost of Electricity (LCOE) of any power plant should cover all its lifetime costs plus an additional 8.3% yearly real rate of return on the invested capital.
  The capital cost for a nuclear plant is normally about twice that of a coal plant, but its variable costs (including fuel) are only about half that of a coal plant. Depending on the capital cost of the nuclear plant, its lower variable costs might then result in a lower lifetime LCOE.

- Due to the said higher nuclear capital costs, the amount in its LCOE that consists of profit for the state (i.e. return on this invested capital costs) will thus be about twice that of a fossil fuel plant. This means that in times of recession, all this profit can first be stripped out of the nuclear power selling price, before the plant will begin to produce at a loss. The break-even cost of nuclear plants is therefore much lower than for its fossil fuel competitors, as is shown in the next graph two graphs from our 2014 review. Although the numbers in this graph are outdated, the principle they demonstrate remains valid: In the good time when high power prices can be obtained, the real rate of return is higher for the coal than for the nuclear plant. However, during times of recession when power prices drop, the profitability of the nuclear plant is much more resilient than that of the coal plant and therefore the coal plant already starts to run at a loss when the power (generation) price drops below R0.72/kWh, while nuclear can sustain a profit down to R0.45/kWh. It is thus coal, rather than nuclear that will become the proverbial "white elephant" during a recession.

  This stands in stark contrast to the current REIPPPP renewables contracts where the contract price of intermittent Solar-PV and wind power is fixed and where Eskom will be forced to buy the REIPPPP power during times of recession at the full extravagant prices, even though it will have no use for this power.

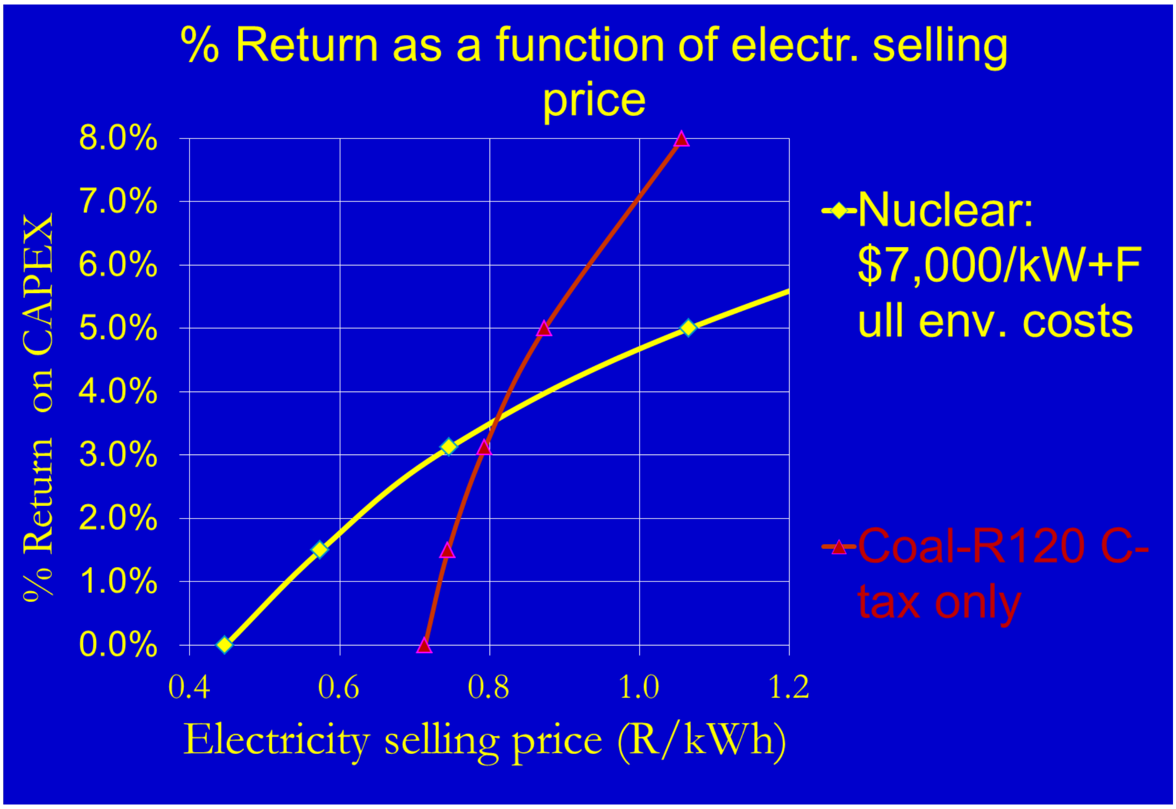

Figure 1: **Rate of return on capital, as a function of electricity selling price**.

In the figure below % returns from the figure above were converted to nominal returns per kW-installed by multiplying the Total Capital Required (TCR) with the % real return. The point was to show that, although coal gave higher % returns for high electricity selling prices, nuclear gives higher nominal returns. This change result driven by the fact that the capital cost of nuclear is about twice that of coal and that identical % returns for both plants would thus produce about twice the nominal return for the nuclear plant.

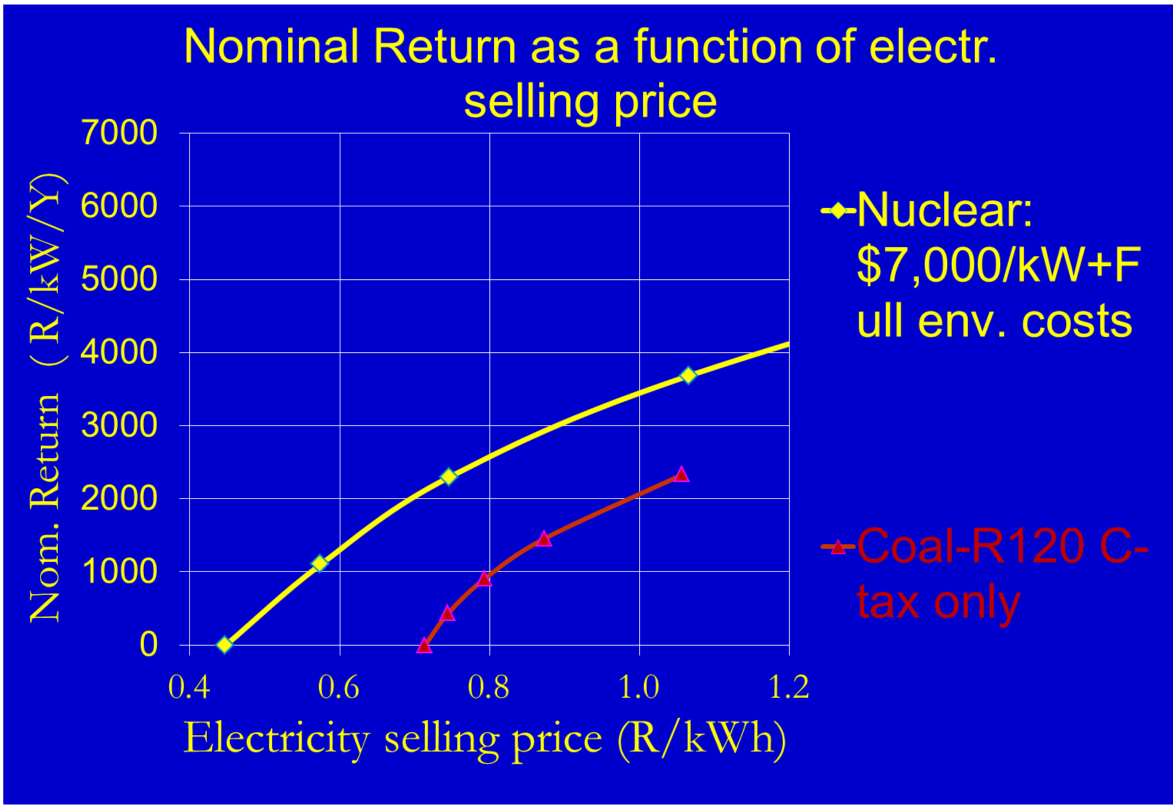

Figure 2: **Nominal return on capital, as a function of electricity selling price**.

5 Conclusions and recommendations

5.1 Corrections to the Draft IEP 2016

- It has been shown that the Draft IEP 2016 allocated most external costs well, except for the global warming cost of methane leakage during shale gas mining and the other external costs of all imported energies that were not allocated at all.

  NIASA therefore recommends that these external costs should be allocated according to the principles described in this study.

5.2 Corrections to the Draft IRP 2016 Base-Case

- As has been described above, the external cost allocation of the Draft IRP 2016 Base-Case was substantially inferior to that of the Draft IEP 2016. The main problem was the failure to allocate any carbon cost to coal emissions, but to replace this measure only with a limit to the maximum annual emissions.
- Identical to the Draft IEP 2016, the global warming cost of methane leakage during shale gas mining and the other external costs of all imported energies that were not allocated at all.

NIASA therefore recommends that these external costs should be allocated identically to our recommendation for the Draft IEP 2016.

5.3 Expected results of proposed corrections

Since it was shown that it was the above-mentioned flaws in the Draft IRP 2016 Base-Case that resulted in the first new nuclear being moved out from about 2015 to 2037, it is to be expected that correcting these flaws in the input assumptions should lead to new nuclear moving back to approximately its original place in the timeline i.e. 2025

5.4 Recommendations for intensive study

As has been pointed out above it is disconcerting to see that the assumptions and thus the results for the Draft IEP 2016 and Draft IRP 2016 Base-Case vary so greatly, especially in view of the fact that both reports were generated by the same entity, namely the DOE. It is furthermore not the first time that this happened as we previously pointed out similarly large differences between the 2014 versions of these two documents. **This suggest the groups that produce these documents are perhaps overworked and underfunded.**

5.4.1 Motivation for greatly increasing funding for study groups to resolve outstanding issues in the IEP and IRP

- Being underfunded is a major challenge that globally hampers good research. However, **when the magnitude of the national interest is considered, underfunding should not be allowed.**

  The total cost of the planned 9.6 GW of new nuclear capacity alone was estimated in our previous review to be about 650 Billion Rand (in 2012 Rands). Thorough study and planning normally lead to great cost reduction, typically much more than 5%. If, however we were to make the conservative estimate that we can save only 5% of this cost by detailed study and analyses, that would amount to a saving of 32.5 Billion Rand. Bearing in mind that the nuclear fleet is comprises only a fraction of the total new-build cost, it can safely be assumed that such detailed studies can shave R50 Billion of the total project cost.

  If one further assumes that you are making very good money if you make 10 Rand for every one Rand you spend, South Africa could safely afford to spend R 5 Billion Rand on optimising the IEP and IRP through intense study.
- If we compare that to current funding of research for the project, **we are currently probably underspending on research by a factor 100 to a factor 1000!** It is for instance well known that the cost of the recent study commissioned by the DOE to

determine the likely cost of new nuclear power plants was funded to the tune of only a few hundred thousand Rands.

- Furthermore, only a handful of such studies were commissioned.
- **Therefore, NIASA recommends that the number of such studies be greatly expanded, for instance by a factor of ten.**
- **Also, the funding of such studies also be greatly increased to for instance a couple of million Rand per study, as opposed to the current a couple of hundred thousand Rands per study.**
- Furthermore, the number of people working in such teams be greatly expanded and that top international consultants be added to their ranks.
- **NIASA would, however like to emphasise that its intention with recommending such detailed studies is not to delay the implementation of the IEP and the IRP, but rather to accelerate it: The 2014 versions of the IEP and IRP could not be implemented because they contained serious flaws, as was pointed out by NIASA and many others. If such high quality detailed studies had been performed prior to 2014, we could have implemented the 2014 versions immediately. By the same logic, the 2016 Drafts also cannot be implemented due to the flaws they contain. So studies must be accelerated in order to prevent any further delays, as delays are very costly to our economy.**

5.4.2 Recommended study topics for the DOE

- A detailed study to determine the full external costs for the proposed large LNG imports**, which will then reveal the full external cost of Solar-PV and wind power, which can be expected to be substantially higher than currently portrayed in the Draft IRP 2016 Base-Case. The** global warming cost of methane leakage **during shale gas mining should feature prominent in this study.**
- **It is recommended that DOE/Eskom should** conduct the full detailed study into the issue of grid stability **in the face of high penetrations of intermittent renewables. This should include the potential of rolling frequency sensitive trip switches for Dynamic Demand response out to smaller consumers so that frequency switches can be used to automatically manage demand, both up and down**
- **The** potential of massively rolling out time-of-use smart meters to households, coupled to aggressive time-of-use price incentives **aimed at shifting demand towards supply so that power can be supplied in the cheapest and most profitable possible way**

- An independent high power research team should be created to duplicate and verify the very important research published by Dr. Tobias Bischof-Niemz of CSIR Energy Research**: "Wind, solar can supply bulk of South Africa's power at least cost". Emphasis should be placed on all the aspects that were neglected in the CSIR study, as was pointed out above.**
- **The highest priority should be given to overhauling the REIPPPP**, in order to bring its policies in line with that of the IRP. The following should be emphasised:
    - **Since wind power and solar-PV power are now the cheapest readily available power types on the South Africa grid, these should now be viewed as fully matured technologies. Therefore, all subsidies should be removed from these** and they should simply compete with all the other technologies on a level playing field, especially regarding time-of day mitching between supply and demand. After all, the CSIR claim to have proven that wind, solar-PV and gas are now cheaper than any other combination of power sources. By definition, this should mean that they are now the senior kids on the block and that they thus can by no means anymore demand subsidies!
    - The **subsidies in the REIPPPP should this be moved to problems that has not yet been solved**, such as energy storage and fuel cell technology.
    - **The huge mistake of using REIPPPP subsidies to subsidise production, instead of research should never be repeated.** There is a valid adage in the R&D community that says that for every one Rand you spend on research, you will spend 10 Rand on demonstration of the technology and 100 Rand on actual production. In reverse, this statement means that **if you spend 100 Rand to subsidise on Production of immature technologies, only one rand of that will eventually trickle down to research**. **So, if you had spent the full hundred Rand on research in the first place, you would have increased you research impact a hundred-fold.**
    - Furthermore, **if you spent your subsidies on production of technologies that are not yet economically viable, your money simply drains away in the sand and you in the end have almost nothing to show for it,** as is presently the case with the Billions of Rand that South Africa annually waste on paying for the extremely expensive wind and solar power contracts from Bid Windows 1, 2 and 3 of the REIPPP.
    - However, **if you were to spend the same amount of money on investment in research** (as oppose to expenses in construction) **you could have acquired a top research company or hundreds of important patents or you could have sent hundreds of scientist and engineers overseas** to

collaborate and be trained on the relevant research projects. In short, **if you invest in research you will end up with real marketable IP, which is completely different from what we now have for our massive production expenses in the REIPPPP**.

- A **study to determine break-even prises during economic recessions** for all power sources, as opposed to the current strategy of comparing only their LCOEs based on the expected power prices during the good times. This will help us to **define least regret strategies in order to reduce our vulnerability to times of economic crisis.**
- Included in this approach should be a **study of optimal contracting strategies for the sake of robustness against economic crises.** the current strategy of concluding mainly take-or-pay contracts are death-traps during times of economic crises as the utility then loses the revenue form power sales, but still have to keep paying for fuel or other services that it no longer has a use for!
- **The validity of the power demand growth scenarios in the Draft IRP 2016 Update should be re-examined**, in view of the analysis given above **of the negative effects of increasing energy efficiency and grid defection.** In view of this analysis, it would appear that the current demand growth predictions are over optimistic, which could be disastrous for our energy planning.
- Coupled to this study on the validity of the demand growth scenarios should be a **study on ways to stimulate future investments in activities that will require substantial new energy consumption.** Many analysts simply assume that the reason for the current reduced demand is the fact that Eskom curtailed use though load shedding etc. However, Eskom had virtually no load shedding from 2009 to 2013, but that did not at all lead to a recovery in power demand. Similarly, there was virtually no load shedding from mid-2015 to the present, but that also did not result in a demand recovery.

  Apparently, the adage that **trust comes on foot but leaves on horseback** is applicable in this case. So simply having excess supply is apparently not going to be good enough. **A better strategy might be to actively guarantee new investors security of supply**, i.e. to **guarantee them that if load shedding were to reoccur, which we must make sure that it does not, these new investors will be spared** from this menace. Such a guarantee should be greatly more effective in restoring trust that to just tell them that we feel sure that we shall not have load shedding again, but that we unfortunately cannot guarantee this!

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