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Assessing the costs and risks of the South African electricity portfolio: A portfolio theory approach

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Abstract
Portfolio theory is used to evaluate the cost and risk of the South African electricity generation portfolio in a bid to find out how the costs and risks of the South African electricity generation portfolio were managed following the 2007 and 2008 load-shedding events. The costs considered are fuel, environmental levy and operating and maintenance costs, for the Eskom power stations from 2008/09 to 2013/14. The results show that the current electricity generation mix is not efficient, due to high cost and risk; and following the 2007 and 2008 load shedding events the entire portfolio capacity was increased marginally and the open cycle gas turbine stations' fuel costs increased substantially. Future work would be to apply this study to the period following load-shedding in 2014 and 2015.

Keywords: efficient portfolio, risk, electricity, cost

Highlights
- The 2013/14 South African electricity-generating portfolio is not efficient.
- The portfolio has high cost and high risk.
- The OCGT's fuel cost and risk contributed to the 2013/14 portfolio's inefficiency.

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1. Introduction

1.1 South African generating landscape

Eskom generates approximately 95% of the electricity used in South Africa (Eskom, 2011). Eskom Holdings SOC Limited (Eskom) is a state-owned company. In the study period the South African electricity portfolio consisted of coal, hydro, open cycle gas turbine (OCGT), nuclear, pumped storage (PS) and wind stations. Table 1 presents the generation capacities that were used to assess the costs and risks of the South African electricity portfolio. It shows that from 2008/09 (1 April 2008 to 31 March 2009) to 2013/14 South Africa's electricity generation capacity increased slightly. Minor changes are observed in coal and nuclear capacities because Camden, Grootvlei, and Komati coal stations which had been mothballed were returned to service; Arnot coal station was upgraded; and Koeberg nuclear power station was enhanced. During the period covered in Table 1, total capacity increased by 1 492 MW.

Figure 1 presents the normalised electricity consumption met by each technology in the generating portfolio during the study period. Electricity consumption for coal was calculated using energy sent-out data and operating hours per coal power station. The power plants that were returned to service were excluded from the calculations as some of the units were commissioned during the period, 2008/09 to 2013/14. The data was normalised because of the huge differences in the technology capacities. Figure 1 indicates that the electricity consumption met by coal stations started to decrease from 2011/12. The coal stations' unplanned capacity loss factor increased from 2.95% in 2010/11 to 14.24% in 2013/14 as observed in the data provided by Eskom. It is possible that the consumption met by coal stations' decrease was influenced by the increase in the unplanned capacity loss factor, which is a measure of lost energy caused by unplanned production interruptions due to equipment failures and other plant conditions.

As seen in Figure 1, with the exception of the capacity met by OCGT stations, electricity consumption met by other technologies also decreased as from 2011/12. Consumption met by coal and hydro stations continued to decrease in 2012/13. In the period 2012/13 to 2013/14 the consumption met by OCGT stations continued to increase to 1.77. Consumption met by nuclear stations increased to 1.14 and that of PS stations increased to 0.65. This implies that, to a large extent, electricity consumption not met by the coal stations was met by OCGT stations and to a lesser extent by nuclear and PS stations. Normally, OCGT and PS stations are peaking stations, which are operated during peak periods and in emergency situations (Eskom, 2011; 2012; 2013), while coal stations are base stations.

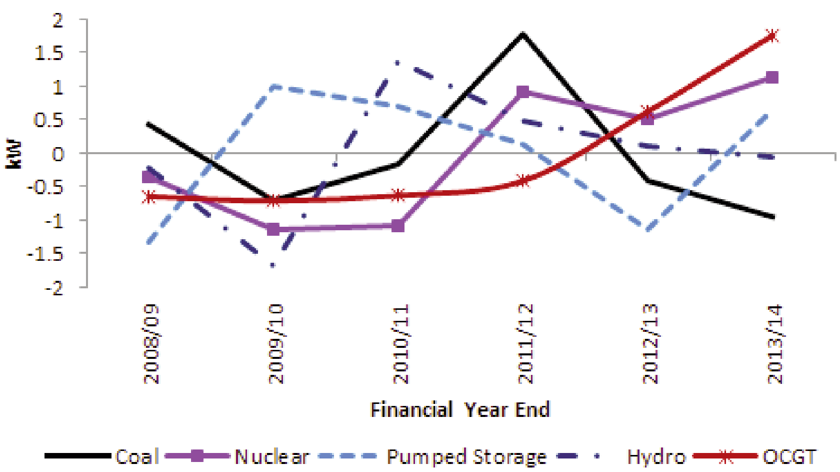

Figure 1: Normalised electricity consumption per technology.

Table 1: Generation capacities of South Africa's electricity portfolio, 2008–2014.

MW	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14
Coal	34 294	34 658	34 952	35 487	35 718	35 726
Hydro	600	600	600	600	600	600
Nuclear	1 800	1 800	1 830	1 830	1 860	1 860
OCGT	2 409	2 409	2 409	2 409	2 409	2 409
PS	1 400	1 400	1 400	1 400	1 400	1 400
Wind	3	3	3	3	3	3
Total	40 506	40 870	41 194	41 729	41 990	41 998

1.2 Portfolio theory

The objective of this paper is to apply portfolio theory to assess the costs and risks of the South African electricity generation portfolio following load-shedding in 2007 and 2008.

It can be noted that the application of portfolio theory (PT) to assess the costs and risks of the South African generating portfolio has not been done before. PT applied in this paper is as defined by Harry Markowitz in Markowitz (1952) and in Markowitz (1959) and not by Maslow (1943). Portfolio theory is sometimes referred to as modern portfolio theory (model), Markowitz model (theory), mean-variance model (theory), and portfolio optimisation theory (model) (Skarica & Lukac, 2012). PT has been used in other countries to evaluate electricity-generation portfolios and this is discussed in Bar-Levy and Katz (1976), Awerbuch (1993), (Awerbuch & Berger (2003), Beltran (2009), Krey and Zweifel (2006), Zhu and Fan (2010), and Cunha and Ferreira (2014).

1.3 Markowitz efficient portfolio

Markowitz (1959) defined a good financial portfolio as more than just a long list of financial securities and bonds, a balanced whole that provides the investor with protection and opportunities with respect to a wide range of contingencies. Markowitz defined portfolio as an efficient portfolio if:

- the *P* is obtainable;
- there is portfolio *Q* whose expected return is greater than *P*'s, then the risk of *Q* is greater than *P*'s; and
- there is portfolio *S* whose risk is less than *P*'s then the expected return of *S* is less than P's.

A curve that joins all the portfolios that behave like portfolio *P* is called an efficient frontier, and all other portfolios that do not lie on the efficient frontier are inefficient portfolios. Mathematically, PT reduces to Equations 1–5 in the case of a portfolio made up of *N* securities (Markowitz, 1959):

$$\text{Max } R = \sum_{i=1}^{N} X_i \mu_i,$$

$$\text{s.t. } \sigma = \left[\sum_{i=1}^{N}\sum_{j=1}^{N} X_i X_j \rho_{ij} \sigma_i \sigma_j\right]^{1/2} \quad (1)$$
$$\sum_{i=1}^{N} X_i = 1, \text{ and } X_i \geq 0 \ \forall\, i$$

Where:

$$\mu_i = \frac{1}{T}\sum_{t=1}^{T} r_{it} \quad (2)$$

$$cov(r_i, r_j) = E\left[(r_i - \mu_i)(r_j - \mu_j)\right], i \neq j \quad (3)$$

$$\rho_{ij} = {cov(r_i, r_j)}\Big/{\sigma_i \sigma_j} \quad (4)$$

$$\sigma_i = \sqrt{E(r_i - \mu_i)^2} \quad (5)$$

- X_i is the weight of a financial security in the portfolio, financial securities and their weights are chosen by an investor;
- μ_i is the average return of a financial security over a given period;
- r_{it} is the actual return of a financial security at time;
- *T* is the total historic period (number of: years or months or days, etc);
- σ is the portfolio standard deviation, representing portfolio risk;
- σ_i is the standard deviation for security;
- *E* is the expectation or average;
- ρ_{ij} is the correlation coefficient between securities; and
- $cov(r_i, r_j)$ is the covariance between securities and emphasises portfolio diversification.

Diversification is about investing in many securities from different industries, where securities' gains and losses will be influenced by different factors. Diversification also reduces the portfolio's risk, but does not eliminate it (Markowitz, 1959).

1.4 Portfolio theory in electricity generation

Although PT has been widely used in electricity generation, this section is limited to cases where actual historic electricity generation costs were used in the assessment. This approach excludes cases where: data was estimated (Zhu & Fan, 2010); proxy data was used (Beltran, 2009); and data was gathered from literature (Paz et al., 2014).

United States utility companies were facing a problem of optimising their fossil fuel mix. Bar-Lev and Katz (1976) applied PT on a regional basis to determine if the 1969 US electricity utilities were efficient users of fossil fuel. The regions were using a combination of coal, oil and gas. The results showed that, although the regions fuel mixes were efficiently diversified, fossil fuel mixes in three regions were on the respective efficient frontier, and below the efficient frontier in another six regions. The risk for these regional portfolios was also found to be high.

Awerbuch, 2000 applied PT to the 1998 US electricity portfolio, which was made up of coal and gas. The results showed that the US mix was not on the efficient frontier. Awerbuch showed that by adding 6% of renewables the 1998 portfolio risk would be reduced. The efficient portfolio reduced coal from 77% to 65% and increased gas from 23% to 35%. Awerbuch (2006) used PT in analysing the following portfolios: year 2000 and projected to 2010 for the European Union generating portfolio; year 2002 for the US, and year 2000 and projected to 2010 for Mexico. The results showed that all these portfolios were not efficient because of high costs and high risks. The efficient alternative portfolios replaced the fossil fuels with renewables.

Krey and Zweifel (2006) applied PT to determine if the year 2003 electricity generation technology mix for Switzerland and US were efficient. The Swiss portfolio consisted of nuclear, run-of-river, storage hydro, and solar, whereas the US portfolio was made up of coal, nuclear, gas, oil and wind. The results showed that Swiss portfolio was inefficient, due to high costs and high risk, and the US portfolio was not efficient due to high costs.

Cunha and Ferreira (2014) applied PT to Portugal's 2012 electricity generation portfolio, which was made up of renewable resources (wind, small hydro and photovoltaic), fossil fuels and imports. The results showed that the portfolio was not efficient, but close to the efficient frontier.

The review above shows that in almost all the cases, irrespective of the electricity portfolios used, the mixes are inefficient according to the PT. In this paper we seek to answer the question: What is the case of the South African electricity generation portfolio? Section 2 discusses the data used in the assessment period; Section 3 represents the methodology; Section 4 discusses the results and Section 5 is the conclusion.

2. Data

The costs focused on are the fuel costs used in the electricity generation plants, the generating maintenance costs, and the environmental levy.

2.1 Fuel costs, environmental levy and maintenance costs

The fuel costs data was obtained for coal, water, diesel, and uranium. There is no carbon tax in South Africa, but an electricity environmental levy was introduced in 2009 by the Department of Finance to apply to the sales of electricity generated from non-renewable sources (Eskom, 2009). Environmental levy rates are presented in Table 4 (Gordhan, 2011, 2012, 2013, 2014; Eskom, 2009).

Table 2: South African environmental levy rates.

Effective date	*Cents/kWh*
1 July 2009	2
1 April 2011	2.5
1 July 2012	3.5

In the absence of carbon tax, the levy serves to promote energy efficiency and encourage lower greenhouse gas emission (Nene, 2015). According to Nene, steps are being taken to make sure that electricity users also pay the levy.

In 2015 a carbon tax bill was released for comment by the Treasury (Republic of South Africa, National Treasury, 2015). The bill states that the tax will be levied in respect of the sum of the greenhouse gas emissions expressed as carbon dioxide equivalent resulting from fossil fuel combustion, fugitive emissions in respect of commodity, and industrial process or product use. The carbon tax rate will be R120 per tonne of carbon dioxide equivalent of the greenhouse gas emissions from 1 January 2017. At this stage it is not clear if the environmental levy will be phased out when as the carbon tax becomes effective. The maintenance costs discussed in this paper are the operating and maintenance costs per power station, excluding head office operating costs.

2.2 Data collected for the study

Data collected was the actual annual fuel costs in rand, actual maintenance costs in rand, and actual annual energy sent out in GWh for each of the 22 power plants (Eskom, 2013). The maintenance and operating costs are made up of the respective stations' actual operating, repair and maintenance costs. The environmental levy costs in c/kWh were calculated using Table 4 and actual annual energy sent out for coal, nuclear and open cycle gas turbines stations. Fuel and maintenance costs in c/kWh were calculated from the costs in rand and the actual annual energy sent out for each generation technology.

Data was collected from 2008/09 to 2013/14, but the fuel cost data for OCGT, PS and hydroelectric power stations was available only from 2009/10. The 2008/09 fuel costs data for the OCGT, PS and hydroelectric power stations were derived by reducing the 2009/10 fuel cost data by 5.93%, which is the Eskom cost of electricity increase between the two years (Eskom, 2010). The start in period of 2008/09 data corresponds with Eskom's first financial year following load-shedding in 2007 and 2008. The data was analysed using Matlab software with the financial toolbox.

3. Methodology

It is important to note that there are major differences between financial market portfolios, for which PT was first developed, and portfolios in electricity generation. The major differences are that:

- financial market portfolios focus on returns whereas electricity generation portfolios focus on costs. The objective of the financial markets is to maximise portfolio returns whereas the objective of the electricity generation is to minimise portfolio costs;
- financial assets are more easily disposable than electricity generation assets like coal-fired plants (Awerbuch & Berger, 2003); and
- financial securities are almost infinitely divisible, such that a portfolio can contain between 0% and 100% of a given security, which is not the case with electricity generation assets (Awerbuch & Berger, 2003).

Irrespective of these differences, PT is commonly used for valuation of electricity portfolios (Awerbuch & Berger, 2003). Equations 1–5 are modified by replacing securities with the technology cost under consideration. In the case of fuel costs, Equations 6-11 are obtained, and used to analyse fuel and environmental costs and also fuel and maintenance costs.

Min total fuel cost (c/kWh) = coal fuel cost + hydro fuel cost + nuclear fuel cost + OCGT fuel cost + pumped storage fuel cost

$$\text{s.t } \sigma = \left[\sum_{i=1}^{N}\sum_{j=1}^{N} X_i X_j \rho_{ij} \sigma_i \sigma_j\right]^{1/2}$$

i,j = fuel cost of coal, hydro, nuclear, OCGT and pumped storage

$$X_{coal} + X_{hydro} + X_{nuclear} + X_{OCGT} + X_{pumped\ storage} = 1,\ X_i \geq 0 \quad (6)$$

where Equation 7 was used to calculate the weight of coal fuel cost and the fuel cost weights for other technologies by substituting coal by the respective technologies.

$$X_{coal} = \frac{\text{Coal fuel cost}}{\text{Total fuel cost}} \quad (7)$$

Equation 8 was used to calculate the average of coal fuel cost and the average fuel costs for other technologies by substituting coal by the respective technologies.

$$\mu_{coal} = \frac{1}{6}\sum_{i=2008/09}^{2013/14} \text{coal fuel cost}_i \quad (8)$$

Equation 9 was used to calculate the standard deviation of coal fuel cost and the standard deviations of fuel costs for other technologies by substituting coal by the respective technologies.

$$\sigma_{coal} = \sqrt{E(\text{coal fuel cost} - \mu_{coal})} \quad (9)$$

The standard deviation is the measure of the fuel cost risk (Markowitz, 1959). The higher the standard deviation the higher is the risk and vice versa. Also, the more stable the fuel cost movement along the study period the less the fuel cost risk, and the more fluctuations on the fuel cost movement the higher the risk. Equation (10) was used to calculate the covariance between coal fuel cost and hydro fuel cost and the covariance of other pairs of fuel costs for other technologies.

$$\text{cov(coal fuel cost, hydro fuel cost)} = E[(\text{coal fuel cost} - \mu_{coal})(\text{hydro fuel cost} - \mu_{hydro})] \quad (10)$$

Covariance is a measure of the extent to which the pair of fuel costs moves up or down together. A portfolio with diversified electricity generation technologies will have low covariance, because the fuel costs for the generation technologies' fuel costs will not be affected by same factors. Low covariance also indicates lower portfolio risk (Markowitz, 1959).

$$\rho_{coal,hydro} = \text{cov(coal fuel cost, hydro fuel cost)}/\sigma_{coal}\sigma_{hydro} \quad (11)$$

The correlation coefficient in Equation 11 is derived from Equations 9 and 10. 'The correlation coefficient provides a more easily interpreted measure, than does the covariance, of the extent to which the two variables tend to move together' (Markowitz, 1959).

$$-1 \leq \rho_{coal,hydro} \leq 1 \quad (12)$$

Equation 11 shows that if coal fuel cost is always an exact positive multiple of hydro fuel cost, then $\rho_{coal,hydro} = 1$. If coal fuel cost is always an exact negative multiple of hydro fuel cost, then $\rho_{coal,hydro} = -1$. If coal fuel cost moves independent of , then $\rho_{coal,hydro} = 0$. Independence always imply zero correlation coefficient but zero correlation coefficient does not imply independence (Markowitz, 1959).

4. Results

4.1 Case 1: Fuel costs

Eskom generation fuel-mix cost data from 2008/09 to 2013/14 was used to obtain the correlation coefficients presented in Table 3 Pearson's correlation coefficient is used which measures the linear relationship between two variables (Stopher, 2012). Although there are other correlation coefficients which measure more relationships than the linear one, as discussed in Maturi and Elsayigh (2010) and Reshef et al. (2011), Pearson's was used by Markowitz (1959) for portfolio theory.

Table 3 shows that the fuel costs tend to move up and down together but not in perfect unison, hence their correlation coefficients lie between zero and one (Markowitz, 1959). Ideally, fuel costs that move independent of each other would be better, as they would reduce the portfolio risk. Correlation coefficients in Table 3 were calculated using Equation 11. Figure 2 displays the efficient frontier calculated using Equations 6–11.

The efficient frontier is a solid curve formed by the efficient portfolios. The average fuel costs and standard deviations (risks) of the different technologies displayed in Table 4 were obtained from Figure 2. From this point onwards, average fuel costs and costs will be used interchangeably.

Table 3: Correlation coefficients for Eskom's fuel mix.

	Coal	*Nuclear*	*PS*	*Hydro*	*OCGT*
Coal	1.000	0.792	0.893	0.741	0.820
Nuclear		1.000	0.740	0.690	0.629
PS			1.000	0.867	0.905
Hydro				1.000	0.575
OCGT					1.000

Table 4: Technologies' fuel average costs and standard deviations.

Technology	Fuel average cost (C/kWh)	Fuel costs risk (c/kWh)
Coal	12.34	2.96
Hydro	2.97	0.51
Nuclear	4.85	1.30
OCGT	243.96	46.49
PS	12.75	1.94

The centres of the circles in Figure 2 on the efficient frontier represent ten equally spaced efficient portfolios. Looking the efficient frontier from the bottom left to the top right, one can observe that:

- The centre of the first circle on the left has hydro. This shows that the efficient portfolio consisting of hydro only has less risk and cost compared to other nine efficient portfolios. Hydro's average fuel cost was calculated using Equation 8 and hydro's fuel cost standard deviation was calculated from Equation 9. Also, as can be seen in Table 4, hydro has both the least average cost and least risk compared to other technologies.
- The 2013/14 fuel portfolio is the square between the 8th and the 9th efficient portfolios. This part of the efficient frontier has portfolios with high cost and high risk. The 2013/14 fuel portfolio weights were derived from Equations 6 and 7, using 2013/14 fuel costs. The 2013/14 mix is dominated by OCGT's, this explains its location in Figure 2. The average cost of the 2013/14 fuel portfolio is 213.63 with a corresponding risk of 40.68 .
- The centre of the last circle on the right has OCGTs. This shows that the efficient portfolio with highest risk and cost compared to other nine efficient portfolios consist of OCGTs. Also, as can be seen in Table 4 OCGTs have both the highest average cost and the highest risk compared to other technologies.

Table 5 displays the average fuel costs and standard deviations (risks) of the ten efficient portfolios starting from bottom left to the top right of Figure 2. The first efficient portfolio on the left will be labelled

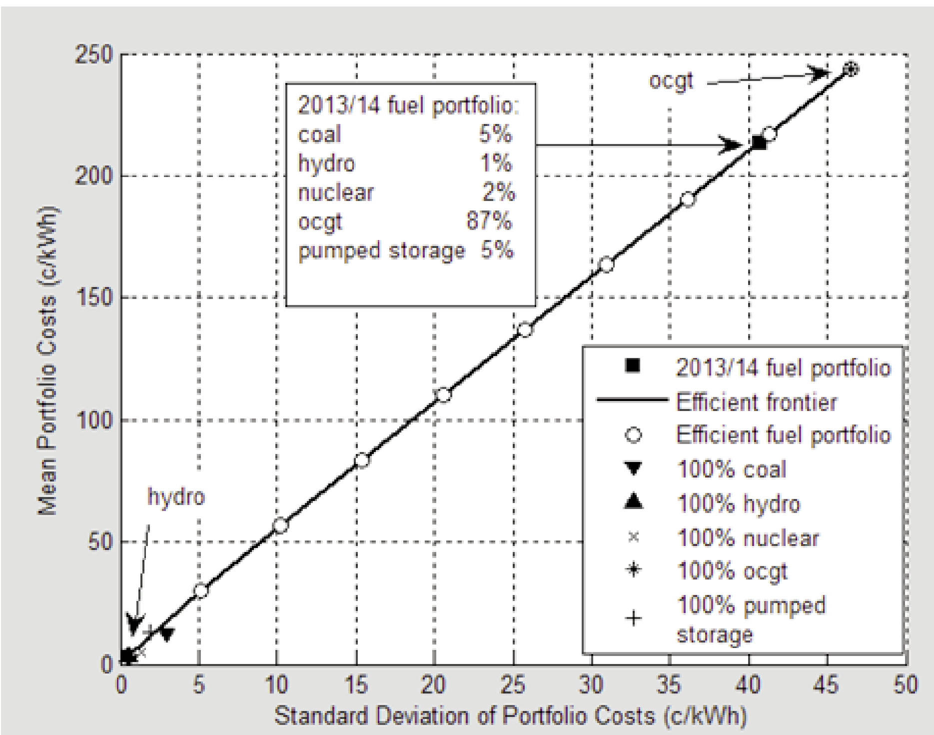

Figure 2: Technology allocation portfolio – fuel costs.

Table 5: Costs and risks of the 10 efficient portfolios in Figure 2.

Efficient portfolio	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Cost (c/kWh)	2.97	29.75	56.53	83.30	110.08	136.86	163.63	190.41	217.18	243.96
Risk (c/kWh)	0.51	5.11	10.25	15.42	20.60	25.77	30.95	36.13	41.31	46.49

as efficient portfolio 1, the next as efficient portfolio 2 and so on until efficient portfolio 10 on the top right.

Table 5 confirms that hydro is in the centre of efficient portfolio 1, as this efficient portfolio cost and risk matches hydros as displayed in Table 4. Similarly, OCGTs are in the centre of efficient portfolio 10, as this portfolio cost and risk matches OCGTs as displayed in Table 4. The actual technology allocation of the efficient portfolios in Table 5 is shown in Figure 3.

As seen in Figure 3, efficient portfolios 2–9 consist of pumped storage on a decreasing scale from 93% to 12% and OCGTs on an increasing scale from 7% to 88%, respectively.

Figure 3 and Table 5 show that the portfolios with less cost and risk are dominated by hydro and pumped storage. As seen in Table 1, the capacity of both these technologies will not be sufficient to provide electricity in South Africa. Figure 3 and Table 5 also show that the portfolios that are dominated by OCGTs have high cost and risk.

As per results, the efficient portfolios in Figure 3 suggest that South Africa has to move away from coal and nuclear completely. It would take a while for Eskom to do this because it is currently building two new coal power stations with a total capacity of 9564 MW. Also there are about five existing coal stations which are below 30 years and the nuclear station is about 30 years old. These stations still have another 20 to 30 years before decommissioning (Eskom, 2013). Currently, South Africa does not have much choice but to use all the technologies that are available due to electricity generation capacity constraints. Figure 4 is obtained by taking a closer look at the efficient frontier starting on the bottom left-hand side of Figure 2.

Figure 4 shows that the pumped storage is above the efficient frontier and both the nuclear and coal are below it. As we have seen in Figure 3, pumped storage appears on the efficient portfolios unlike coal and nuclear.

Figure 5 shows that the 2013/14 fuel portfolio is below the efficient frontier. Portfolios P and Q are the efficient alternatives to the 2013/14 fuel portfolio. Portfolio Q is desirable because of less cost and risk, compared to portfolio P. Even though portfolio Q is on the efficient frontier it is on the high cost side of the efficient frontier, which is not desirable.

4.2 Case 2: Fuel and environmental costs

In this section the same analysis presented in section 4.1 is performed, except that the environmental costs are added to the fuel costs for coal, nuclear and OCGT stations. Coal, nuclear and OCGT are the technologies affected by the environmental levies. From the data analysis Figure 6 is obtained. The average costs increased as follows:

- coal from 12.34 (fuel only) to 14.47 c/kWh (fuel and EL), a 17% increase;
- nuclear from 4.85 to 6.99 c/kWh, a 44% increase; and

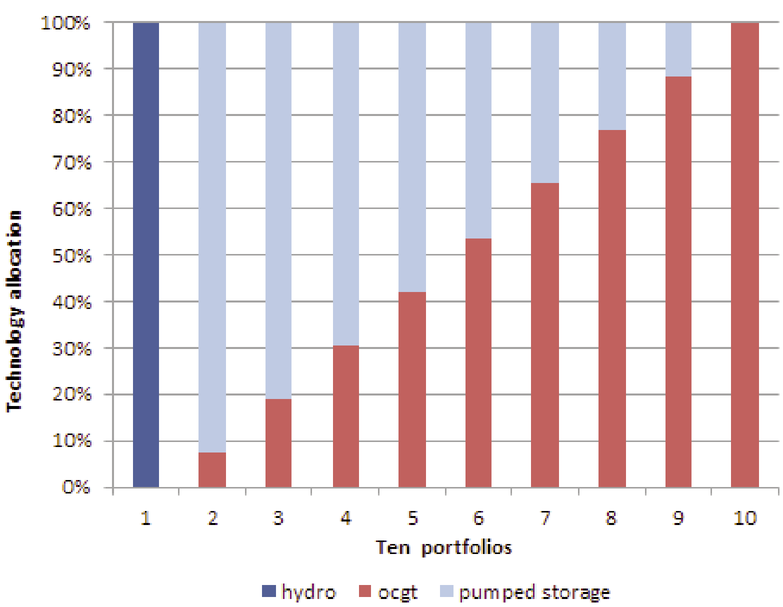

Figure 3: Technology allocation of the ten efficient portfolios.

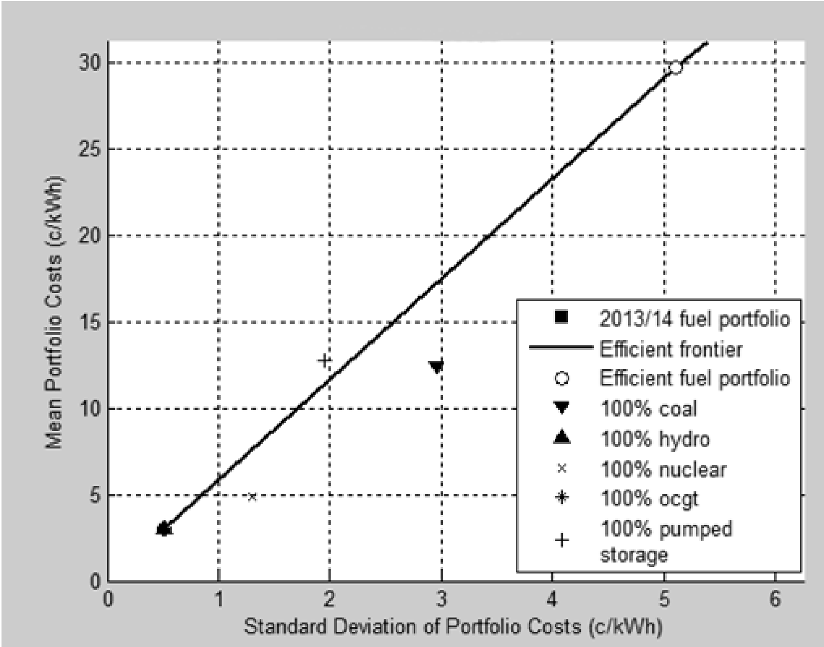

Figure 4: Figure 3 zoomed – 1.

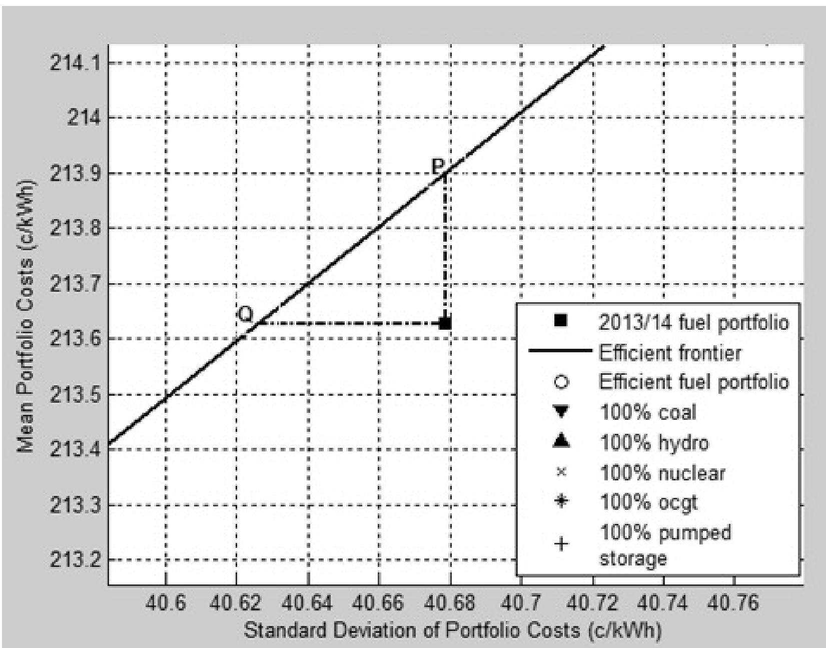

Figure 5: Figure 3 zoomed – 2.

- the OCGT from 243.96 to 246.17 c/kWh; a 1% increase.

The 2013/14 fuel and environmental levy portfolio's cost (210.99 c/kWh) decreased when compared to 2013/14 fuel portfolio's cost (213.63 c/kWh). This shows that environmental levy costs as currently determined have little effect in discouraging nonrenewable electricity generation.

4.3 Case 3: Fuel and operation and maintenance costs

Similarly to case 2, in this case the operation and maintenance (O&M) costs were also added to the fuel costs of each technology and the analysis results are shown in Figure 7. When adding the O&M costs to the fuel costs, the following major increases were observed when compared to fuel only costs:

- Nuclear's average cost increased from 4.85 (fuel only) to 11.48 (fuel and O&M), a 137% increase.
- Hydro's average cost increased from 2.97 (fuel only) to 5.44 (fuel and O&M), a 83% increase, and
- Coal's average cost increased from 12.34 (fuel

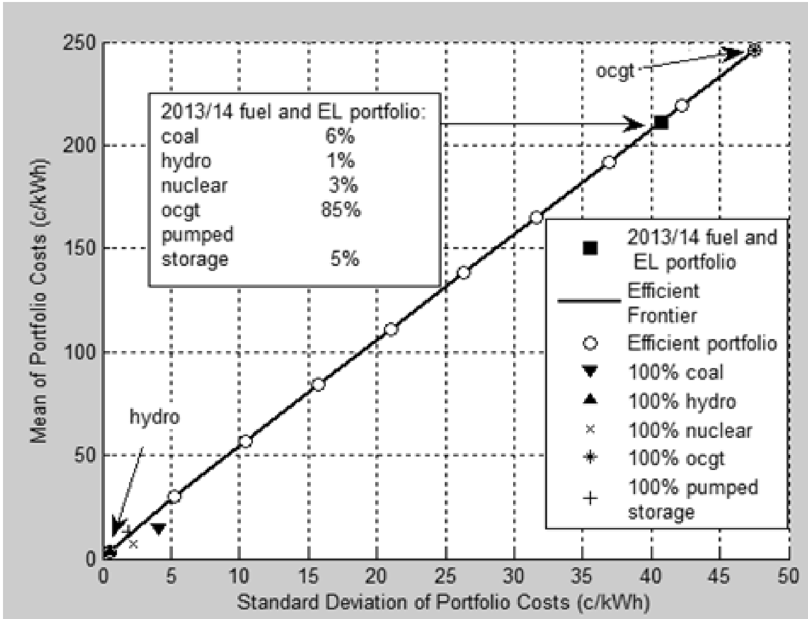

Figure 6: Technology allocation portfolio – Fuel and environmental costs.

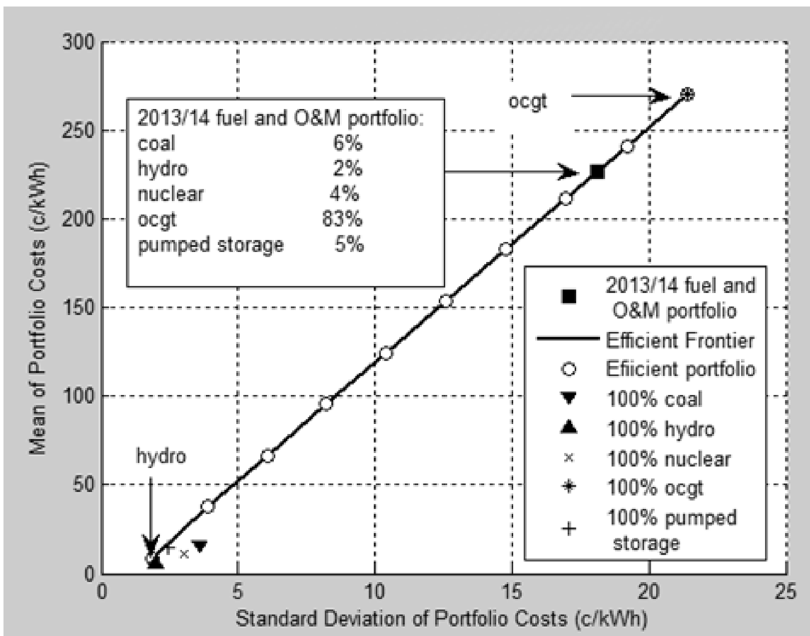

Figure 7: Technology allocation portfolio – fuel and O&M costs.

only) to 15.60 (fuel and O&M), an increase of 26%.

The 2013/14 fuel and O&M portfolio cost increased by 6% (226.18 c/kWh) when compared to 2013/14 fuel portfolio (213.63 c/kWh). Even though the 2013/14 fuel and O&M portfolio cost increased, the corresponding risk decreased from 40.68 to 18.14 c/kWh, 55% decrease. This shows that the fuel plus O&M costs were more stable compared to fuel only costs. The low risk is good, and it would have been better if it was observed in the case of fuel costs.

5. Conclusions

The analysis results show that South Africa's 2013/14 fuel portfolio is inefficient and has high risk. Following the 2007 and 2008 load-shedding, the entire portfolio capacity was increased by 3.7% and the OCGT stations fuel costs increased substantially. The high fuel costs have been incurred in producing electricity, when the electricity demand that was not met by coal stations was largely met by OCGT stations.

The efficient frontier based on fuel cost only shows that the efficient portfolios with minimum costs and low risk suggest that South Africa should move away from coal and nuclear, increase its exposure to hydro and pumped storage and reduce the exposure to OCGTs.

Adding environmental levy to the fuel costs, the analysis showed little to no impact in encouraging the lower green emission technologies indicating the limited effect on the levy in promoting green technologies and suggesting the need to reconsider this policy approach.

Operation and maintenance costs were added to the fuel costs and the analysis showed that the initial portfolio cost increased slightly and the risk was reduced. This low risk is desirable for the fuel only portfolio.

Future work would be to apply this study to the period following the 2014 and 2015 load shedding events.

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