Cost analysis of South African electricity generation plants

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Abstract

South Africa has got a large array of natural resources involving some of the most envied sustainable energy resources such as sunlight and wind. Despite this, the country's electricity is consistently and largely produced from fossil fuels sources. To mitigate, this dependence and move towards a power supply system allowing bigger room for flexibility, without economically degrading power cuts or electricity buy-backs from intensive energy consumers, the electricity utility decided to step up renewable energy sources. All of this came at a cost. To date, in South African electricity sector, such decisions were basically made with the objective of meeting electricity demand from consumers, without giving an important consideration to the environmental impacts of all options. To this end, this study proposes renewable energy sources as a roadmap for future electricity generation in South Africa. This will assist decision makers with a more accurate picture of the trade-offs involved in decisions affecting the electricity utility. To achieve this objective, various costs analyses were conducted including sensitive ones. The findings demonstrate that renewable energy sources are costlier than thermal power plants. However, it was concluded that due to environmental degradation issues caused mainly by fossil fuels power plants, the construction of renewable energy plants should be prioritized and given more weight.

Keywords

Fossil fuels, renewable energy sources, cost of generating electricity, South Africa.

I. Introduction

Electricity is the main key in the development of a country. A lack or shortage of electricity has a serious negative impact over the economy. Due to its magnitude and economic importance, the energy sector often requires significant investments to increase supply capacity to meet demand from consumers. The problem is that, over the last decades such decisions were basically made regarding maintain supply security, without giving an important consideration to the economic, environmental and impacts of all options [14].

Electricity plays a crucial role in the South African economy. Without a doubt, electricity is of fundamental significance in any economy. Since electrical energy is an important key input to the production process that transforms inputs into products and services. It is also significant to the daily workings of South African households. Therefore, power policy and management practices in the electricity sector may have important impact on the macro economy as well as on individual South African households. Thus, understanding the costs of saving energy is important for assessing existing energy policy and for managing the development of future energy policy [3]. An important contribution of the research presented in this paper is the evaluation of the costs of saving energy. Because in the past and current most of studies have focused on evaluating the costs of generating electricity rather than those of saving energy [3]. The South African economy is counted among the developed and emerging economies across the globe. South Africa is rich in coal, and consequently has an infrastructure to harness the energy it has in her domestic resources stock. In the other world, South Africa is counted among the countries that deploy coal at large-scale. For example, Burnard, & Bhattacharya [3] report that, the share of coal in producing electricity locally was approximately 93% in 2011 and coal counted for nearly 70% of total South African primary energy supply. This may not be unexpected knowing that South African coal export prices range amongst the lowest in the world. South Africa is the most progressive economy across Africa. Griffin [14] States that, the healthier an environment becomes, the

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more significance is given to clean energy supply and to energy security matters. Although competitive companies such as mining, automotive, agriculture, food processing, manufacturing and a thriving service area has emerged in South Africa, both energy security and clean energy supply still represent a big obstacle for the country. External impacts from air pollution, usage of insufficient water facilities and carbon dioxide emissions from a considerable burning of hydrocarbons are a huge issue, especially in the Mpumalanga region, where coal power stations with a capacity of 30 GW are installed [10]. The South African government has acknowledged the necessity for a clean and reliable energy system for its environment and economy. In 2003, the Department of Minerals and Energy (DME), predecessor of today's Department of Energy (DoE), has made an agenda for future energy planning. This agenda was called the Integrated Energy Plan (IEP) and includes South Africa's main principle files for energy planning. The Integrated Resource Plan (IRP) is placed in the IEP and controls the production of electricity and transmission capacity planning. It is regularly re-viewed, in accordance with the new technological and cost developments [7]. In addition, to environmental deterioration, energy supply problems are considered as issues, which often take place. Generally, power outages occur during the period of peak demand and both generation and transmission systems are quite regularly under their utmost strain [10], [25].

II. Literature review

II 1. South African electricity sector

Griffin [14] reports that investment within the electricity sector involves the following components:

- Generation,
- Transmission,
- Customer, and
- Electricity market

II.2. Generation

Electricity generation plays an important role in the betterment of human life. Besides its social benefits, electricity is also a driving factor for the economy. Its deployment varies from communication, transportation to generation. Thus, electricity as a public product should be available at any time, mostly everywhere and must be deployed for a wide range of applications. For this reason, the idea of availability is considered as another significant aspect in a non-monetary assessment of numerous generation technologies. As electrical energy may not be economically supplied on a large-scale, it must be generated at the certain period and within the same quantity, which is practically demanded and must be conveyed instantaneously from power plant to the consumer through transmission lines. Due to these important features, the electrical energy supply system should be shaped for the utmost anticipated demand [7]. In South Africa, the production of electricity is dominated by Eskom. Thus, Eskom is the main South African electricity producer and there is no wholesale electricity market. In accordance with [28] the generation and supply (retail) factors of the power business are good for competition, whilst transmission and distribution are considered as natural monopolies. The major electricity source in South Africa is coal. The generation technology mix is not very diversified in the South African industry.

In 2012, power generation kept on being much depended on coal, even if IPPs participated in power production with more than 4.1 TWh. Because of strains from the demand side, the mothballed coal power plants Komati, Camden and Grootvlei had to be re-commissioned. Consequently, a massive 92% of Eskom's 2012 electricity output of 237.3 TWh was produced in coal power plants with a total nominal capacity of 37,745 MW. For the remaining 8% of electricity produced, nuclear power amounted to 5.7%, whilst pumped-storage hydro power contributed 2% to the electricity supply. Other technologies that contributed to the remainder were OCGT (fired with diesel oil) and wind, whilst PV and biomass were only used on a non-commercial scale [7]. It should be noted that, the South African government has developed the Integrated Resource Plan (IRP) as a long-term policy document for the future electricity planning, which is expected to run from 2010 until 2030. The IRP was presented by the Department of Energy (DoE) in 2010 with the goal of identifying needed investments for the power supply sector that are most beneficial to South African interest, given technical, economic and environmental issues [27]. Therefore, the IRP provides a probable composition of South African energy mix to meet the demand of 454 TWh in 2030. As input factors such as technology, demand, financial conditions, electricity prices or emission costs could be subject to change in the future, the IRP will need to be revised every two years, although an update has not yet been released since the end of 2012 [7].

II.3. Transmission

The legal basis for regulation of grid management and operation is provided by The Energy Act [7] "The goals are to direct monopoly functions to safeguard end-users' rights, and to guarantee effective operations of the grid" [48]. Electricity generation and use are linked together through the electricity grid that consists of power lines, cables, transformers and numerous other elements [10]. According to Eskom [11] the South African transmission grid includes nearly 31 107km of transmission lines and 160 substations with a total of 139 610MVA of installed transformer capacity. The distribution network transmit energy from the high-voltage transmission network to end-users, comprising municipalities, which control their own distribution networks, via infrastructure consisting of 48 278km of distribution lines, 281 510km of reticulation lines and 7 436km of underground cables, as well as 99 880MVA of installed transformer capacity [27]. Important lengths of new transmission lines and associated substations and substation facilities are being added to the system. These extra additions are mostly because of the main 765 kV network reinforcements needed for the supply within the provinces of Western Cape and KwaZulu-Natal. The introduction of Medupi power plant within the emerging Limpopo West Power Pool also needs important lengths of transmission line, since it is a long distance away from the main load centres. The high-voltage direct current (HVDC) lines/system needed for another generation improvements within the region of Limpopo are as well not considered, because they shall simply be needed in the coming decade [27].

II.4. Customer

Customers or consumers are described as people who purchase electrical power for their own use. Generally, small and private users purchase electrical power through an intermediary such as a trading industry or a distribution utility, whilst bigger consumers usually purchase directly within the wholesale market [20]. Consumers are free to select which electricity producer they wish to deploy. The total electricity price for consumers consists of the wholesale price of electricity, network charges and taxes. The charges faced by households are significantly higher than industrial prices in accordance with [27]; this is mostly a reflection of the extra costs of distribution charges. Residential customers may select among different kind of contracts for electrical energy. The most common is based on a variable price, another type is based on fixed price contracts and the third type of contract is based on the spot price movements with a fixed retailer margin. Industrial customers, generally in smelting industry, usually have long-term contracts. The sector also meets its requirements from its own power plants' long-term commercial contracts and purchases on the spot market [27].

II.5. Important parameters within the electricity sector

II.5.1. Security of energy supply

One can define security of energy supply as an ongoing availability of electricity, in sufficient amounts and at acceptable price [15]. Supply security has physical, economic, social and environmental sides or risks in accordance with [3] physical interruption may be caused when a power source is depleted or generation is turned down, either for a short or long period [14]. This system failure can take place because of weather conditions, absence of capital investment or more often poor conditions of the power system [16]. Economic interruption is caused when there are unpredictable changes in the worldwide markets within the price of energy goods [18]. Change may be caused by for instance a threat of a physical interruption of equipment, or prediction of such interruption, and absence of investment or inadequate contracting [9]. Lack of stability of energy equipment can also cause important social interruption. This is because of the demand and dependability for energy within nowadays' world, where instability has a big influence over both private and commercial interest [17]. The last parameter in the definition, environmental interruption, is concerned with the damage to the ecosystems caused by the energy chain. One may further distinguish between short and long run energy security. The first one is concerned with interruption and alleviation of these or rises in prices. Whereas long-run security considers the energy system and as such the reasons of interruptions together with the availability of adequate energy to enable stable and economic development [1].

II.5.2. Consequences of supply interruptions

[3] argue that there is an agreement within the literature that the costs of supply interruption go beyond the economic measures of national accounts. The reason is that "energy consumption flows through daily life in such a continuous and ever-present manner, which is why, it is hard to make a difference between all the short- and long-run negative

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impacts". Supply interruption may be divided into either short-, medium or long run, where the following results would generally be highest for long-interruptions, but less probable to take place.

II.5.3. Measuring supply security

Today, a lot of people see supply security of power to be very important, but the value that society places on it is not an important parameter. Generally, this information can be derived from a market, even though there is no market in which power-supply outages are traded [3]. As developments within supply security would come at a cost, these costs should inevitably be paid by the society in accordance with [9] "either by increasing energy bills or through public financing". These investments should thus be based on cost analysis. In the lack of a market to determine the costs of supply outages, economists and academics have developed several methods for calculating the impacts of a supply outages [26].

II.6. Electricity Market

In 2010, South Africa was the largest African market in terms of electricity supply. In all, the country generated nearly 39.8% of electricity use across the continent that ranked at the first position, followed by Egypt and Algeria [26]. During Eskom's financial year 2012, the overall electrical energy supply accounted for up to 254.4 TWh, with an important share producing from Eskom's own power generation plants and minor shares generated from electricity imports and IPP production. Internal deploy for wheeling, pumping and internal sales amounted to 7.6 TWh. A further 22 TWh were lost in the process of transmission and distribution and in the end 224.8 TWh were available for market to meet the electricity demand. Despite a huge demand during the past years, physically Eskom was not capable to meet the South African entire electricity demand with the 224.8 TWh it delivered in 2012. Burnard, & Bhattacharya [3] argues that the supply/demand gap for 2012 was nearly 6-9 TWh. However, as initiatives to cut down the demand were developed, it is really very hard to come up with a significant figure concerning the supply outages in 2012. The situation was mainly problematic during evening peak demand hours and it was indicated that Eskom was not able to meet the weekly peak demand from its own generation portfolio on 43 out of 52 weeks in 2012 [7]. To shadow the gap, electrical energy had to be imported through the SAPP. Furthermore, programs to save energy were developed under the Integrated Demand Management Program (IDM), in which Eskom had adopted components from Brazil that coped with a similar situation in 2001. Programs involved for example the "49-million campaign" targeted at the private sector to conserve electricity, and contracts with industries from the Energy Intensive User Group (EIUG), which enabled for load shifting [10] depicts that these two sectors amounted to the largest share of electricity demand in 2012, followed by the commercial sector which was as important as the mining sector.

Future electricity demand as designed in the IRP scenario is expected to increase on average by 2.8 %7 per year until 2030. But, there is discordance between economists concerning the approaches deployed in the forecast and numerous authors have illustrated several option projections. For example, several sectors may respond differently to price changes in the future because of their differing price elasticity of demand. In their decomposition analysis, and maybe noticed that extra elements with important impact over the South African future electricity demand were altered in generating outputs, energy efficiency programs and structural variation. electricity demand from the South African residential sector will not be influenced much by electricity price variation and utilization will not grow considerably with higher revenues because of his low estimates on price and revenue elasticity of 0.011 and 0.33. By now it should have become clear to the reader that present generation capacity is not sufficient to meet the South African electricity demand. Investments into capacity expansion become important and certain programs are being built [11].

III. Methods

The costs of producing electricity are generally evaluated according to the LCOE approach. Because it shows the minimum marketing price of the electricity generated through a generating technology, assuming constant within real currency units, which can be needed to ensure all operating costs, interest and primary reimbursement obligations on debt, taxes and offering the investors an acceptable market return for the assumed risk. LCOE is estimated as the actual cost of the electrical energy, which makes the present worth of the returns earning from the selling of the electrical energy equivalent to the present worth of all costs met throughout the plant life-cycle. LCOE is an essential key that aims at offering the break-even of sale price and it enables the costs comparison between various electricity generating technologies. Additionally, LCOE plays an important role in the context of a free market, therefore contributing to the incorporation of market uncertainties and risks in the worth of the cost of capital cast-off to discount cash-flows. LCOE can also be defined as an indicator of the cost incurred to producing electrical energy. It should be noted that LCOE does not consider the costs associated with transmission and distribution of electricity. According to [1], [2], [4], [5], [9], and [26] state that the Levelised Cost of Electricity (LCOE) is an important tool for an economic assessment of various electricity generation technologies and it is the most consulted method in electricity sector when investment and planning decisions are to be made [16], [17], [21], and [28]. Further-more, presently it represents the most transparent approach being used for power planning and policy development [19]. The reason of this methodology being the most used is because it allows cost comparison of several forms of electricity generation, which differ from physical principles, fuel types, and their lifespan [22], [6], and [26].

When calculating the LCOE of a power plant, all discounted direct plant costs over the lifespan of the plant are divided by the discounted sum of the electricity that it would pro-duce over its lifespan [15], [17]. In the context of financial, LCOE may also be defined as the constant level of inflows important per year to recover all outflows over the lifespan of a power plant [26]. In the standard method, these outflows involve capital costs, Operation & Maintenance costs (O&M), and fuel costs. In the end, the calculation will enable a cost comparison among various alter-natives over a constant unit cost basis; in this study ZAR/MWh will be used. Practically, there are two methods that can be used to determine LCOE of a power plant. It should also be noted that LCOE may be addressed within real or nominal dollars' way. When addressing LCOE in real dollar way, the effects of inflation are removed. However, in nominal dollar way the effect of inflation is considered [4], [5], [9], [26].

III.1. Keys input to calculate LCOE

Typically, the calculations of LCOE of a power plant consider three cost components, which are added up.

- Capital cost,
- Operation and Maintenance (O&M) cost, and
- Fuel cost

In the following lines, these three cost factors will separately be explored and then mixed into a complete LCOE formula.

III.1.1. Capital cost

Capital cost is an important key for calculating LCOE of a power plant, and it is generally based on the plant costs (C_p) that are described as the costs set up to build a power plant. Generally, for such analysis, the idea of overnight costs is considered, which has been defined by Klein [22] and Jason [20] as the costs that incurred for the construction of a power plant immediately, and it does not consider any assumptions upon interest expenses that happen during the construction period. Often, such data is designed based on currency per unit of capacity. As all costs must be levelized over a unit of electricity produce, e.g. in ZAR/MWh. According to Daniel [5], and Guzmán [16] plant costs should be divided by the amount of electricity produce within a year. This is given by the 8760 that is the number of hours of one year (h), which are multi-plied by the total size of the plant (C) and the capacity factor of the plant (Cf) stating the percentage of the time the power plant produces electricity. For example, a power plant that has a rated capacity of 4 800 MW, when operates with an 85% capacity factor, it will generate 35 740 800 MWh per year. It is important to notice that no power plant can operate at capacity factor of 100%. Since, regular maintenance should be done and over time some components will be replaced, and the maintenance process will require the plant to stop [20]. So far, this illustration is for capital cost per unit of power produce during one year. As matter of fact, a power plant runs over decades. That is why a Capital Recovery Factor (CRF) must be taken into consideration. Leland and Anthony [24] describe CRF as the equivalent annual amount that the asset, process, or system should earn each year just to re-cover the initial investment at a specified discount rate over its expected life. The CRF thus converts a flow of annual payments over the lifespan of the plant into a present value. It depends on the discount rate (d) applied to the project and plant operation time (t). according to [22], [26] [19], [2], [9], and [4] capital cost should be calculated as presented in the equation (1) below:

$$\text{Capital cost per MWh} = \left(\frac{(\mathrm{C_p} \times \mathrm{C}) \times \mathrm{CRF}}{\text{Annual electricity produce}}\right) \tag{1}$$

$$\mathrm{CRF} = \frac{\mathrm{d}(1+\mathrm{d})^{\mathrm{t}}}{(1+\mathrm{d})^{\mathrm{t}}-1} \tag{2}$$

$$\text{Annual electricity produce} = \mathrm{C} \times \mathrm{C_f} \times \mathrm{h} \qquad (3)$$

Where :

- $\mathrm{C_p}$: is the Plant costs
- CRF: is the Capital Recovery Factor
- d : is the discount rate
- t : is the lifespan of the plant
- C : is the rated capacity of the plant
- $\mathrm{C_f}$: is the capacity factor of the plant
- h : is the number of hours within a year

III.1.2. Operation and Maintenance (O&M) costs

O&M costs are the costs that incurred for the operation of a power plant and generally are expressed in terms of fixed (C_{fom}) or variable(C_{vom}). Fixed O&M costs, these are the costs that do not depend on the generated amount of electricity [22], [19]. Generally, they are set up for the things like loan payment, required maintenance, site security and staff [12]. Like the plant costs the fixed O&M costs are as well divided by annual electricity produce to determine how much of them take place during one year of production. Whilst, Variable O&M costs depend on the generated amount of electricity, these costs are set up for the things like fuel costs, additional staffing, and additional maintenance. According to [19]; [26]; [12]; and [13] the O&M costs equation should be computed as presented in the equation (4) below.

$$\text{O\&M costs per MWh} = \left(\frac{\mathrm{C_{fom}} \times \mathrm{C}}{\text{Annual electricity produce}} + \mathrm{C_{vom}}\right) \qquad (4)$$

Where:

- $\mathrm{C_{fom}}$: is the fixed operation and maintenance costs
- $\mathrm{C_{vom}}$: is the variable operation and maintenance costs
- C : is the rated capacity of the plant

III.1.3. Fuel costs

Fuel cost is the cost of fuel, most often designed based on currency per megawatt-hour. For a thermal power plant, it is the heat rate (Btu/kWh) multiplied by the cost of the fuel (ZAR/MMBtu). This involves upfront fuel costs, and the on-line operating fuel usage [13]. Allowance is made in the calculation for the degradation of a power plant's heat rate over time. Fuel cost are not considered for renewable energy. [12], [13], [9], [17], [21], and [26] all describe fuel cost like the equation (5) address below:

$$\text{Fuel costs per MWh} = (\text{fuel price} \times \text{heat rate of the plant}) \qquad (5)$$

When we include all cost components, the full LCOE formula is then:

$$\text{LCOE per MWh} = \text{Capital cost} + \text{O\&M cost} + \text{fuel costs} \qquad (6)$$

It should be noted LCOE may be addressed within in real or nominal dollars' way. When addressing LCOE in real dollar way the effects of inflation are removed. However, in nominal dollar way the effect of inflation is considered [6] and [21]. In this study, real dollar method will be used in next section.

III.2. Sensitivity analysis

[23], [19], [9], [6], and [21] all state that LCOE for all technologies has always been affected by various inputs such plant cost, O&M cost and fuel cost. When all these components are kept constant, LCOE could be sensitive to the changes of capacity factor or discount rate. Therefore, this point aimed at demonstrating the impact of the variation of capacity factor and discount rates over the LCOE for all generating technologies

IV. Results

In this section data will be presented as calculated through different equations and, they will be analysed. We used secondary data from [23], [7], and [27]. The reason for using secondary data since industry specific data are always hard for outsiders to obtain. This section develops three levels of cost comparison. The first section attempts to analyse the costs of building power plants, costs of producing electricity among power generating technologies. Lastly the results are tested by a sensitivity analysis to discount rate variation and sensitivity analysis to load factor variation.

IV.1. Investment costs and electricity generating costs

Table 1: capital investment costs and electricity generating costs

	Coal	Gas	Nuclear	Wind	CSP	Solar PV	Sources
Capital cost							
Plant cost, USD/kW)	3 000	800	5 400	3 100	10 300	4 100	Lazard [23]
Rated capacity, MW net	4 500	115	1 600	100	125	0.005	DoE; [7]; Lazard, [23]
Lifespan, years	40	20	40	20	35	20	Lazard, [23]
Real Discount rate, %	8.8	8.8	8.8	8.8	8.8	8.8	DoE [7]
Capital Recovery Factor, %	9.11	10.79	9.11	10.79	9.28	10.79	Equation (2)
Capacity factor, %	85	10	92	30	42.80	25	DoE [7]
Annual operating hours	8 760	8 760	8 760	8 760	8 760	8760	DoE, [7]; Lazard, [23]
Annual electricity produce, MWh	33 507 000	100 740	12 894 720	262 800	468 660	10.95	Equation (3)
Capital cost, ZAR/MWh	**533.31**	**1 431.76**	**886.92**	**1 849.36**	**3 704.27**	**2 935.12**	Equation (1)
O&M cost							
Fixed cost, USD/kW	40	5	135	60	115	17.50	Lazard [23]
Variable cost, USD/MWh	2	4.70	0.50	13	-	-	Lazard [23]
O&M cost, ZAR/MWh	**107.11**	**151.22**	**250.65**	**520.62**	**445.67**	**116.10**	Equation (4)
Fuel cost							
Fuel price, ZAR/MMBtu	26.39	73.91	10.56	-	-	-	DoE, [7]; [23]
Heat rate, Btu/kWh	8 750	10 300	10 450	-	-	-	Lazard [23]
Fuel cost, ZAR/MWh	**230.91**	**761.27**	**110.35**	-	-	-	Equation (5)
Official exchange rate 2016							
ZAR/USD	14.53	14.53	14.53	14.53	14.53	14.53	World Bank [28]
Cost of electricity							
LCOE, ZAR/MWh	**871**	**2 344**	**1 248**	**2 370**	**4 150**	**3 051**	Equation (6)

From the findings in the table 1 above, we notice that gas power plant is the least cost alternative to build with capital investment costs 800 USD per MW. While, investment cost for coal-fired power plants is 3 000 USD per MW. In contrary, nuclear plant is expensive to build, with a capital cost of 5 400 USD per MW. The reason of gas power plant being the cheapest option among thermal power plants, is because of gas technology does not require huge space of land, and its components are brought to site ready-built. Therefore, it is fast and less expensive to build. Hence, merely based on capital investment cost, gas technology is a best alternative. The figure also shows that renewable energy plants are costlier to build. The reason may be the extent to which the unit should be imported. For example, CSP and Solar PV are specialized high technology machines, which are not manufactured by many firms across the world. That is why, electricity utility industries within many countries across the world purchase the equipment from abroad. This process necessitates the availability of foreign currency with which to pay for the transaction and this affects the total cost. In some circumstances this can also prevent this type of electricity generation technology to be made online if the necessary foreign currency is not available. It can also be depicted from the table 1 above that electricity generating costs depends on the technology, and is mostly influenced by the capital investment costs. For example, of fossil fuels sources, a coal supercritical power plant will generate electricity at ZAR 871/MWh, which is significantly cheaper than either gas (ZAR 2 344/MWh). This is because of the abundant availability of coal across the world. Among thermal power plants, nuclear is a sustainable alternative, because it does not produce greenhouse gas emission into the environment. However, the problem with nuclear is that it does not guarantee safety to the environment. Among the renewable energy sources, the least cost option is wind with cost of producing electricity of around ZAR 2 370/MWh, followed by solar PV that has cost of generating power of about ZAR 3 051 /MWh. Solar PV, however, is costly with a LCOE of ZAR 4 150/MWh. When assessing the costs of thermal power plants against costs of renewable energy plants, the latter ones are costlier. One possible explanation is that renewable energy sources offer a sustainable solution within a long run because they are inexhaustible and they are environmental friendly.

IV.2. LCOE sensitivity analysis to discount rate variation

the results regarding the LCOE sensitivity analysis to discount rate variation ranging from 1-20% can be observed from the table 1 below:

Table 2: LCOE sensitivity analysis to discount rate variation

	Electricity Generating Plants (LCOE, ZAR/MWh)											
Discount rate (%)	Coal		Gas		Nuclear		Wind		CSP		Solar PV	
	CRF (%)	LCOE (ZAR/ MWh)	CRF (%)	LCOE (ZAR/ MWh)	CRF (%)	LCOE (ZAR/ MWh)	CRF (%)	LCOE (ZAR/ MWh)	CRF (%)	LCOE (ZAR/ MWh)	CRF (%)	LCOE (ZAR/ MWh)
1	3.02	515	5.54	1 648	3.02	655	5.54	1 470	3.38	1 795	5.54	1 623
2	3.65	552	6.11	1 723	3.65	716	6.11	1 568	3.99	2 038	6.11	1 778
3	4.32	591	6.71	1 803	4.32	781	6.71	1 671	4.65	2 302	6.71	1 941
4	5.05	634	7.35	1 888	5.05	853	7.35	1 780	5.35	2 581	7.35	1 999
5	5.82	679	8.02	1 977	5.82	928	8.02	1 895	6.10	2 880	8.02	2 298
6	6.64	727	8.71	2 068	6.64	1 007	8.71	2 013	6.89	3 196	8.71	2 485
7	7.5	777	9.43	2 164	7.5	1 091	9.43	2 137	7.72	3 527	9.43	2 681
8	8.38	828	10.18	2 263	8.38	1 177	10.18	2 265	8.58	3 870	10.18	2 885
9	9.29	882	10.95	2 365	9.29	1 265	10.95	2 397	9.46	4 222	10.95	3 095
10	10.22	936	11.74	2 470	10.22	1 356	11.74	2 538	10.36	4 581	11.74	3 310
11	11.17	992	12.55	2 578	11.17	1 448	12.55	2 672	11.29	4 952	12.55	3 530
12	12.13	1 048	13.38	2 688	12.13	1 542	13.38	2 814	12.23	5 327	13.38	3 756
13	13.09	1 104	14.23	2 801	13.09	1 635	14.23	2 959	13.18	5 707	14.23	3 987
14	14.07	1 162	15.09	2 915	14.07	1 731	15.09	3 107	14.14	6 090	15.09	4 221
15	15.05	1 219	15.97	3 032	15.05	1 826	15.97	3 258	15.11	6 477	15.97	4 460
16	16.04	1 277	16.86	3 150	16.04	1 923	16.86	3 410	16.08	6 864	16.86	4 702
17	17.03	1 335	17.76	3 269	17.03	2 019	17.76	3 565	17.07	7 259	17.76	4 947
18	18.02	1 393	18.68	3 391	18.02	2 115	18.68	3 722	18.05	7 651	18.68	5 197
19	19.01	1 451	19.60	3 513	19.01	2 212	19.60	3 880	19.04	8 046	19.60	5 448
20	20.01	1 509	20.53	3 637	20.01	2 309	20.53	4 039	20.03	8 441	20.53	5 701

From the table 2 above, it can be depicted that the cost of generating electricity for all technologies increase due to the growth of discount rate. Between all power plants, coal has the lowest LCOE irrespective of the change in discount rate. The results also demonstrate that among fossil fuel sources and nuclear technology, nuclear technology is more sensitive to the fluctuations of discount rate than coal and gas technologies. One possible explication is that nuclear always has higher capital investment cost and lengthier construction period than coal and gas technologies. Among renewable energy sources including wind, CSP, and solar PV, we have noticed that wind is not sensitive to discount rate variation like solar PV and CSP irrespective of the discount rate variation. The reason may be because wind has lower capital investment cost and shorter lead time than solar PV and CSP. Additionally, we also observed that the raking order does not change between wind and CSP regardless of discount rate change. The reason is due to CSP that has got a higher capital investment cost and a longer lead time than wind technology. To sum up, we observed that among all power generating plant, gas was less sensitive at the discount rate variation. The explanation is due to lower capital investment cost of gas technology.

IV.3. LCOE Sensitivity analysis to load factor variation

The capacity factor of an electricity generation plant shows the amount of the electricity generated by power plant. The capacity factor is an important key for the economics of the power plant, because it shows the magnitude of electrical energy generated per unit of producing capacity, which will yield returns to cover the initial capital investment and the operating costs of the power plant. Sensitivity analysis to capacity factor changes was performed to test the sensitivity of cost of electricity generation for various generating technologies. Figure 1 shows the evolution in the LCOE as a function of capacity factor changes at the real discount rates used in this study.

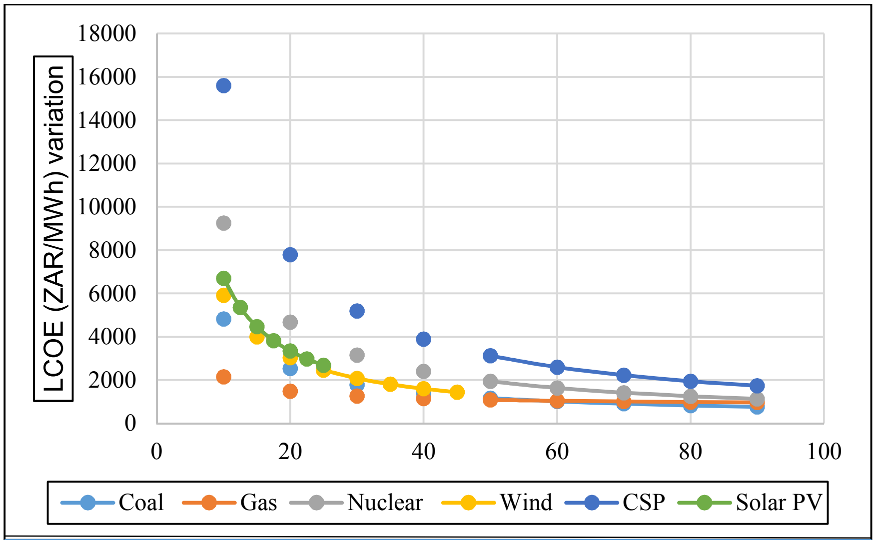

Figure 1. LCOE sensitivity analysis to capacity factor

The first observation from the figure 1 above, is that the change in load factor influence considerably the plants that have high fixed costs. For example, it can be observed that of conventional technologies including coal, gas, and nuclear, the LCOE of coal and nuclear technologies is more affected by the load factor variation. One possible explanation is that coal and nuclear technologies have higher fixed cost than gas technology. We also noticed that renewable energy sources are seriously affected by the variation of load factor. One possible explanation is that the fixed costs of renewable energy sources constitute an important portion of total costs. Between all power generating plants, gas is less sensitive to the capacity factor variation. The reason is that variable costs of gas technology weigh most in total cost than fixed cost.

IV.4. LCOE sensitivity analysis to lifetime

The projected economic lifespan of operation varies between generating technologies. The general study assumptions hold that coal and nuclear plants last up to 40 years. While gas, wind, and solar PV power plants around 20 years, CSP 35 years. The sensitivity analysis tests were conducted by changing the lifetimes from 20 to 60 years. The results of the sensitivity analysis are summarized in Figure 2. On the vertical axis, 100% corresponds to the LCOE in accordance with lifetime variation

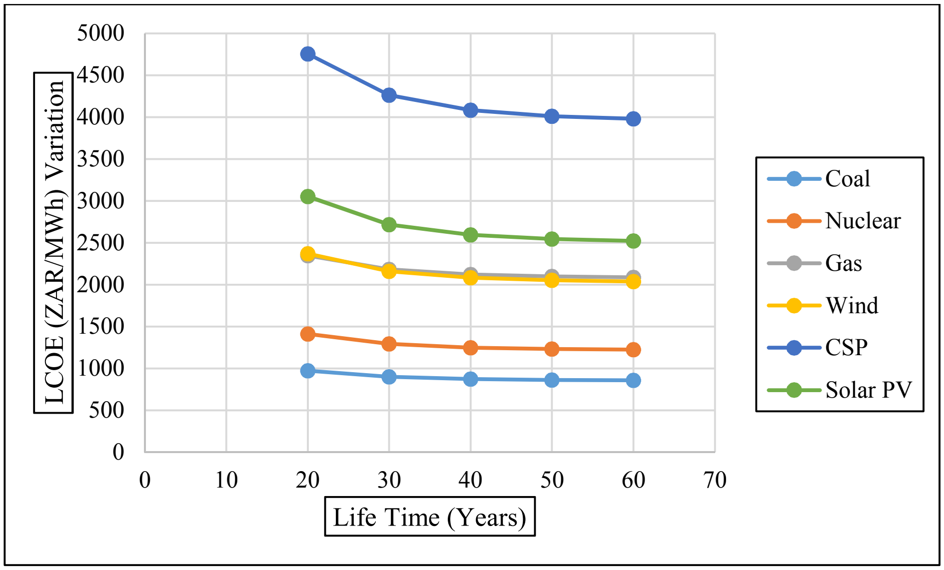

Figure 2: LCOE sensitivity analysis to lifetime

The most significant conclusion which can be drawn from this analysis is the noticeable asymmetric effect on LCOE of early retirement of plants when comparing to lifespan extensions at the real discount rate used in this study. Although early retirement considerably rises the LCOE, lifespan extensions do not have significant impact on LCOE. This is real for all generating technologies, even though the impact is more obvious for those powers generating plants that have shorter operating lifespans. As soon as the plant has been commissioned, and much of the investment cost has been acquired, an early retirement of the plant considerably influences its capability of recovering the initial capital investment. In contrast, in the case of lifespan extensions, when the plant has already paid back the initial capital investment during the expected payback period, additional extensions will logically produce extra returns for the plant; but, because of the discounting consequence, incomes accumulating far ahead in the future do not have much impact on LCOE after being discounted. Also because of the discounting consequence, power generating plants with longer lifespans are not much affected by relative changes in the operating lifespan of the plant. For instance, despite its high up-front costs, which must be paid back with the incomes generated during the entire lifespan, any extension of the lifespan of a nuclear power plant beyond 40 years has very little effect on the LCOE after costs and returns for the expected period are discounted. Beyond 40 years, which is the operating lifespan expected for coal plants, any change of this parameter does not have much effect on the LCOE. On the other hand, LCOE produced by gas, wind, and solar PV, with shorter lifespans, are the most affected by the change in the lifespan of the plant. The least affected technology is CSP, with an initial lifetime of 35.

V. Conclusion

In South Africa, nearly 95% of electricity is generated through fossil fuels sources. During the current decade, the utility electricity decided to mitigate this dependence on fossil fuels sources to move towards a power supply system allowing bigger room for flexibility, without economically degrading power cuts or electricity buy-backs from intensive energy consumers. One of the strategy put in place is to step up renewable energy sources. All of this came at a cost. Therefore, this paper aimed at offering policymakers a more accurate picture of the tradeoffs involved in decision affecting the electricity sector. To achieve this objective, the study used a cost analysis approach between conventional electricity generating plants and renewable energy sources. The findings demonstrate that renewable energy sources are costlier than thermal power plants. However, it was concluded that due to environmental degradation issues caused mainly by fossil fuels power plants, the construction of renewable energy plants should be prioritized and given more weight. The results regarding sensitivity analysis to load factor variation demonstrated that conventional generating technologies are less affected by the load factor variation than renewable energy sources. The reason is that the fixed costs of renewable energy sources constitute a significant share of total costs. It was also observed from the results regarding sensitivity analysis to discount rate variation that of all generating technologies, gas is the least sensitive as the discount rate changes. The reason is due to investment cost of gas that is lower than for any other technology. While, the results concerning sensitivity analysis to lifetime variation revealed a noticeable asymmetric effect on LCOE of early retirement of plants when comparing to lifespan extensions at the real discount rate used in this study.

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