Assessing the financial viability of renewable independent power production in South Africa

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Abstract

The cost of energy and national power utility Eskom, is currently under heated debate after the cost of electricity has more than doubled over the past three years, with another five annual increases of 8% approved by the National Energy Regulator of South Africa. The state owned utility has a monopoly on electricity production in South Africa having sole ownership over the transmission and distribution of electricity. Eskom produces 95% of South Africa’s electricity, predominantly from coal fired power stations, which is one of the leading causes why the country is one of the highest carbon dioxide emitters in the world. The question of independent power production and the use of our abundant renewable resources for electricity generation have been at the forefront with critics arguing against the heavy increases absorbed by industry and consumers.

Although the renewable energy space is a well discussed topic, it is not well scientifically documented from an economic standpoint. The primary objective is to determine if renewable energy is price competitive with Eskom, or non-renewable electricity generation, by not only looking at the current scenario but also the future price projection and point where renewable energy is on parity with the grid price. For this purpose the Levelised Cost of Energy calculation method was used.

Four different measuring instruments were produced for each technology namely, biogas, biomass, solar and wind and a financial model developed to determine the levelised cost, taking into consideration more complex financial structures, tax incentives, revenues and costs associated with by-products.

From the literature it is clear that wind and solar, on a large scale, are competitive with the levelised cost of Eskom’s new build coal power plants and particularly wind, is lower than the grid price in 2017. The empirical study focused on a smaller scale of 1 to 5 megawatt and concluded that the levelised cost of wind energy is lower than Medupi coal fired power plant, currently under construction. The study also determined that biogas and biomass, under certain conditions relating to feedstock costs, are able to compete with Medupi and offer real and sustainable benefits in long-term energy supply.

Keywords: biogas, biomass, Eskom, independent power producers (IPPs), levelised cost of energy (LCOE), National Energy Regulator of South Africa (NERSA), wind power

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Abbreviations

CAPEX	Capital Expenditure
CDM	Clean Development Mechanism
CER	Certified Emission Reduction unit
CPI	Consumer Price Index
CRF	Capital Recovery Factor
CSP	Concentrated Solar Power
DOE	Department of Energy
ESKOM	Electricity Supply Commission
FGD	Flue Gas Desulphurisation
FITS	Feed In Tariff System
GDP	Gross Domestic Product
GW	Gigawatt
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producer
kWh	Kilowatt-hour
LCOE	Levelised Cost of Energy see also LEC
LEC	Levelised Energy Cost
LHV	Lower Heat Value
MW	Megawatt
MYPD3	3rd Multi Year Price Determination
NERSA	National Energy Regulator of South Africa
NPC	National Planning Commission
O&M	Operations and Maintenance
OCGT	Open Cycle Gas Turbines
PV	Photo-Voltaic
REBID	Renewable Energy Bidding Programme see also REIPPPP
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
SLCOE	Simplified Levelised Cost of Energy
SPIPPPP	Small Projects Independent Power Producer Procurement Programme

UNFCCC	United Nations Framework Convention on Climate Change
VS	Volatile Solids
WACC	Weighted Average Cost of Capital

CHAPTER 1

NATURE AND SCOPE OF THE STUDY

1.1. INTRODUCTION

The cost of energy and national power utility Eskom, is currently under heated debate after the cost of electricity in South Africa has more than doubled over the past three years, with another five annual increases of 8% approved by the National Energy Regulator of South Africa (NERSA) (Yelland, 2012). The question of independent power production and the use of our abundant renewable resources for electricity generation have been at the forefront with critics arguing against the heavy increases absorbed by industry and consumers (Yelland, 2012).

The Department of Energy (DoE) has now obtained Government and Treasury approval under section 78 of the Public Finance Management Act number 1 of 1999, to enter into long-term, 20-year agreements with preferred independent power producers (IPPs) for the supply of renewable energy into the Eskom grid (South Africa, 2010). The former Eskom chief executive officer, Brian Dames, has indicated that Eskom was required to pay an average of about R2.00 per kilowatt-hour (kWh) for renewable energy from IPPs in the five year period from 2013 to 2017. This, Dames said, was significantly higher than the average price of non-renewable electricity from IPPs that it currently procures at R0.71 per kWh (Yelland, 2012).

Dames further indicated that the levelised cost of energy from Medupi and Kusile would be significantly lower than R0.71 per kWh and that Eskom’s average cost of electricity, at the time, was R0.31 per kWh (Yelland, 2012).

These numbers are seriously challenged by critics who argue that the levelised cost of new electricity from the Medupi and Kusile coal-fired power stations will be much higher than reported by Dames and whilst Eskom prices are ever increasing, the levelised cost of electricity from renewable energy is dropping to the extent that price parity is imminent (Yelland, 2012).

A major development for IPPs in South Africa was the announcement of three further ministerial determinations on 29 October 2012 by Minister Peters in agreement with NERSA:

- Additional base load generation capacity of 7760 megawatt (MW), comprising 2500 MW of energy from coal in the system between 2012 and 2024; 2652 MW of gas power in the system between 2021 and 2025; and 2609 MW of imported hydro power from regional projects in the system between 2022 and 2024.
- Additional renewable energy generation capacity of 3200 MW, comprising concentrated solar power (CSP), solar photovoltaic (PV), biomass, biogas, landfill gas, and hydro power between 2017 and 2020.
- Additional power for the mitigation of medium term risk, comprising 800 MW from cogeneration to be on the system as soon as possible; and 474 MW from natural gas between 2019 and 2020 (Yelland, 2012).

Up and till now the energy department and treasury have facilitated the entry of independent green energy providers through the renewable energy independent power producer procurement programme (REIPPPP). The programme has received several international awards and is currently rated the seventh best of its kind internationally (Department of Trade and Industry, 2013:3).

However, it only represents a small portion of the new capacity required by the grid. According to Rajen Ranchhoojee, the projects and energy director and head of Africa at the law firm Routledge Modise, the complexity of the bidding programme has made it increasingly expensive for investors, encouraging them to look toward more competitive investment opportunities into other parts of Africa. The cost of bidding compliance was estimated to be between US$1,5m and $2m, he said, roughly twice as expensive as in other parts of the world. In addition, the maximum or ceiling tariffs offered per kilowatt for a number of renewable energy technologies had also dropped substantially, further decreasing the participation from private sector developers (Donnelly, 2013).

The current shortfall of electricity under peak demand and high tariffs has placed a serious restraint on industrial growth in South Africa. This has resulted in unprecedented static electricity demands, still at 2007 levels. This requires an urgent change in future energy plans according to National Planning Commission (NPC) member, Anton Eberhard (Anon., 2013).

The construction of the said two new coal power stations is estimated to cost around R340 Billion. The Medupi power station in Limpopo was expected to make its first contribution to the grid later in 2014 and Kusile, in Mpumalanga, in 2015. Eberhard said it was a risky strategy to be investing in large capital plants that took years to build when demand might vary in that time. "It's much better and a more smart strategy to adopt smaller scale plants, more flexibly and more quickly to match demand in the country. Of course, gas and renewables lend themselves to that much more (Anon., 2013)."

1.2. PROBLEM STATEMENT

Although the renewable energy space is a well discussed topic, it is not well scientifically documented from an economic standpoint. The research evaluates the levelised cost of electricity for wind, solar, biomass and biogas renewable energy technologies, and provides an economic basis for determining the financial viability of these technologies on small, medium and large scale. Note that not all of these technologies are necessary scalable which will assist in focusing on each technology where it fits best.

Given the current situation and climate for renewable energy IPPs in South Africa it is important to understand when these technologies will reach price parity with the state owned utility Eskom, or with non-renewable electricity generation as this would be a game changer in terms of future resource planning and development. It is thus the intention of this study to determine the financial viability and practicality of renewable energy technologies as solution to the short and medium term energy crisis in South Africa. The research questions as formulated from the problem statement are as follows:

- Is renewable energy price competitive?
- Is renewable energy a practical solution to the current energy crisis in South Africa?

- Does renewable energy have a future in South Africa?

1.3. OBJECTIVES

1.3.1. Main objective

The primary objective is to determine if renewable energy is price competitive with current state owned utility Eskom or non-renewable electricity generation. The objective is to not only look at the current scenario but also the future price projection and point where renewable energy is on parity with Eskom. For this purpose the Levelised Energy Cost (LEC) calculation method will be used.

1.3.2. Secondary objectives

The practicality of renewable energy as solution to the current energy crisis in South Africa addresses the scale and marketplace where renewable energy is advantageous. Therefore the secondary objectives are to:

- Evaluate the financial viability of renewable energy technologies (solar, wind, biomass and biogas)
- Determine the space/scale where these technologies could be applied.
- Address the outlook (future) of renewable energy in South Africa from an economic and fiscal perspective.

1.4. RESEARCH DESIGN

1.4.1. Literature review

A systematic literature review will be conducted using trusted sources such as scientifically approved articles and previous research; government published and accepted information on the specific renewable technologies as compiled by well-known consultants and financial reports, the views of experts in the financial and banking sector on the current status of energy supply and demand in the South African context and internationally accredited renewable energy journals.

1.4.2. Empirical research

The study specifically focuses on the South African context and is aimed at renewable energy independent power producers. The focus of the research is on economic viability which means that the data and analyses will have a strong financial setting and will not necessarily encompass the softer non-monetary benefits of the renewable technologies. These benefits are incorporated when evaluating the complete impact of energy generation, which is not the intent of this study. The companies that were approached during the data gathering phase are all in a corporate environment where the ultimate objective is to increase shareholder's wealth. Electricity generation in South Africa is well regulated by government and it is important for the reader to first get acquainted with the inherent difficulties and barriers to entry facing renewable energy independent power producers, as this will result in a better understanding of the current status of renewables in the country.

The researcher has used an already well-established network in the South African renewable energy sector. Various consultants and technology providers will be approached with whom the researcher has already built long-standing relationships and a strong engineering background will assist in obtaining/calculating the technical information accurately and timeously.

1.5. EXPECTED CONTRIBUTION OF THE STUDY

The study will assist future renewable energy project developers and industry in strategic planning and positioning in the marketplace in terms of specific renewable energy technologies and scale of projects. It would also provide for a holistic summary and comparison of renewable energy technologies and highlight the technologies that will be feasible given a free market situation after government incentivised programmes and tariffs have passed on.

It could give greater insight into the South African energy mix and improve our understanding of the viability of renewable energy and the practicality thereof, given our current economic situation. Independent power production can be done on a domestic level and the financial evaluation and comparison will aid the individual in determining when it makes sense to use these technologies for self-generation.

1.6. OVERVIEW

This chapter has outlined South Africa’s current position towards renewable energy and the challenges that the national utility, Eskom, is facing. A problem statement was defined and the research questions were formulated for the specific study. The primary and secondary objectives were outlined and the study is expected to make a meaningful contribution towards future project developers and industry in the selection of technologies on an economically viable scale.

The entree to the study is a literature review on the current status of South Africa’s energy supply. It is important to understand the current setting and baseline for energy production. The literature study further investigates South Africa’s contribution to global warming and carbon emissions from its coal fired power stations. The possibility and likelihood of a carbon tax will be discussed and the financial impact thereof on the industry and consumer. Eskom’s future planning and new infrastructure development will be scrutinised in light of the renewable energy programme and tariffs offered by alternative technologies. South Africa’s overall position and cost of electricity is important to conceptualise in a global setting and the current grid price will serve as baseline for comparison with the renewable technologies.

The empirical design and information obtained from the measuring instruments are used to calculate the levelised cost of energy for renewable technologies. Finally, the results from the study will be compared with the current grid price and future price projection of Eskom. Key findings and conclusions are summarised and used as basis to establish recommendations that could benefit the country and policy makers in future resource planning.

CHAPTER 2

LITERATURE REVIEW

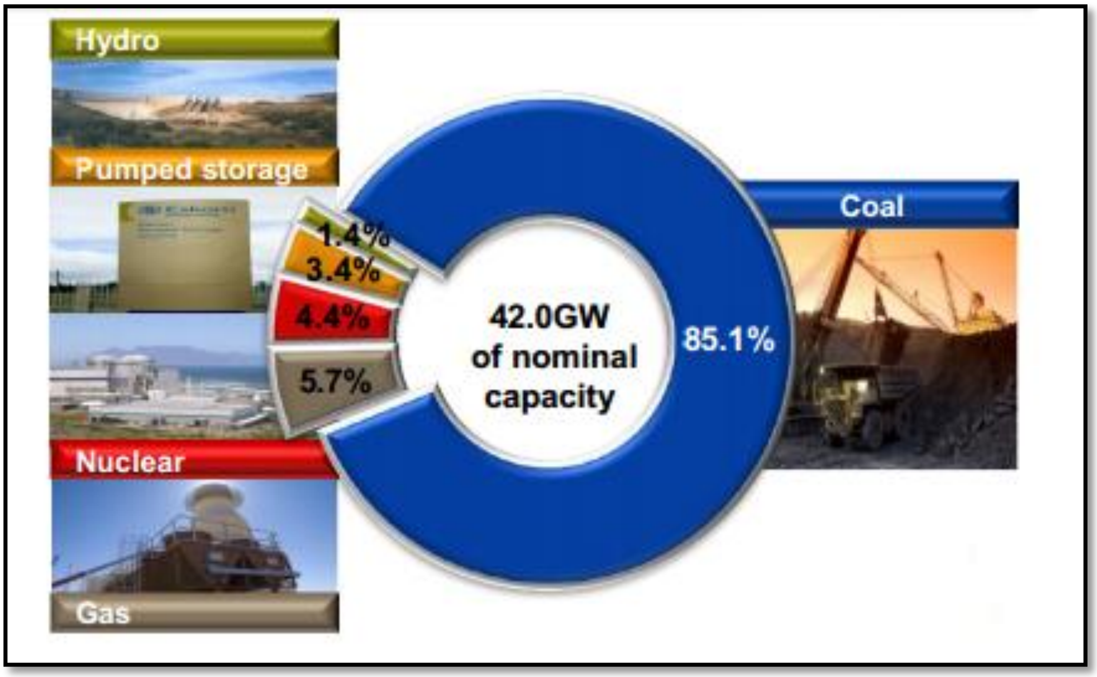
2.1. SOUTH AFRICAN ELECTRICITY SUPPLY

South Africa produces approximately 240 300 gigawatt-hours (865 000 TJ) of electricity annually. The majority of this electricity is consumed domestically, but approximately 12 000 gigawatt-hours is annually exported to Swaziland, Botswana, Mozambique, Lesotho, Namibia, Zambia, Zimbabwe and other South African Development countries participating in the Southern African Power Pool. South Africa supplements its electricity supply by importing around 9 000 gigawatt-hours per year from the Cahora Bassa hydro-electric generation station in Mozambique via the 1 000 MW Cahora Bassa high-voltage direct current transmission system (Department of Minerals and Energy, 2010:15).

Most power stations in South Africa are owned and operated by Eskom and these plants account for 95% of all the electricity produced in South Africa and 45% of all electricity produced on the African continent. Eskom was established in 1923 and converted into a public company on 1 July 2002. The utility is the largest producer of electricity in Africa and whilst Eskom does not have exclusive generation rights, it has a monopoly on bulk electricity. It also operates the integrated national high-voltage transmission system and supplies electricity directly to large consumers such as mines, mineral beneficiates and other large industries (Department of Energy, 2013a:19).

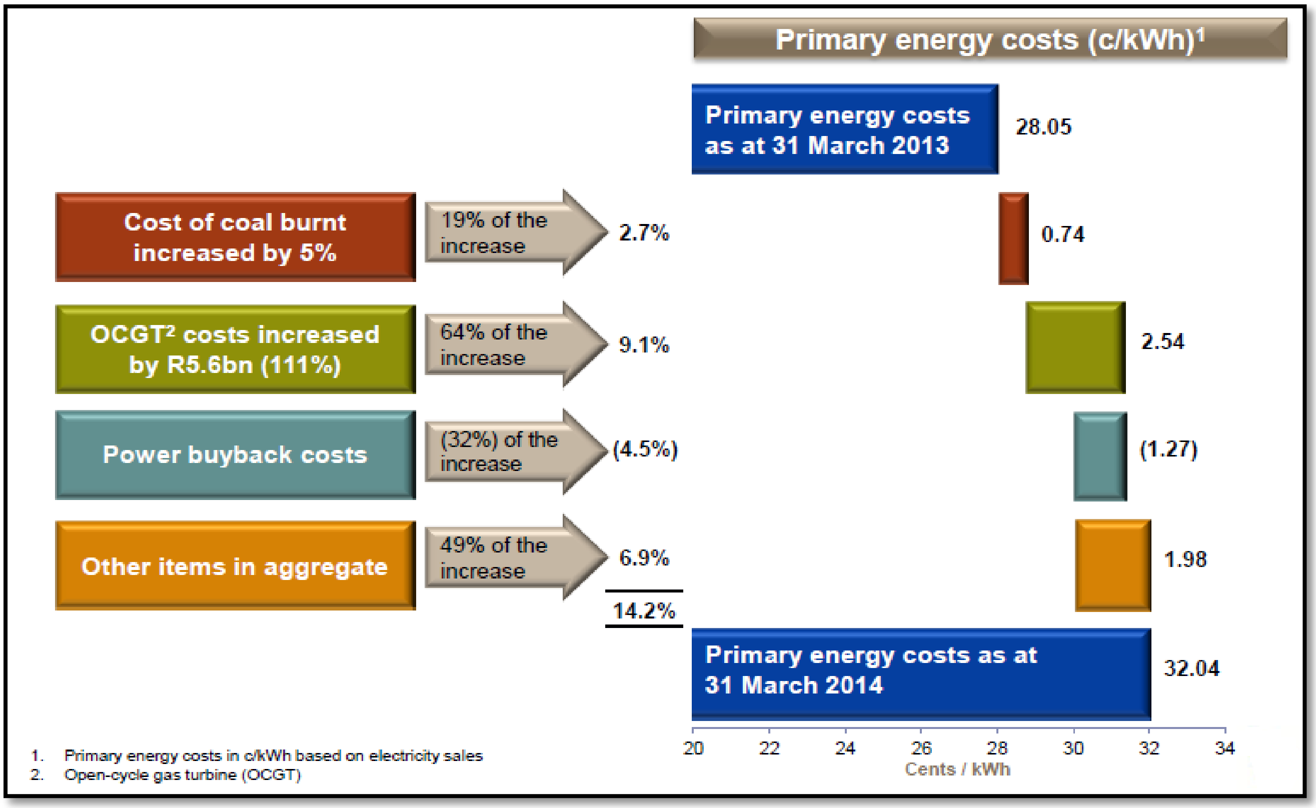
According to Eskom's integrated results for the year ended 31 March 2014, 85.1% of its current capacity is from coal fired power stations with 5.7% supplied by Open Cycle Gas Turbines (OCGT) used as backup generation during peak periods when demand is exceeding its current base load capacity. During the past financial year, Eskom faced great challenges in keeping the lights on and suffered higher than expected increases in operational expenditure due to the significant reliance placed on the OCGT fleet. In the 2014 financial year, R10.6 billion was spent to produce 3 621 GWh which equates to R2.92 per kWh generated, compared to R5.0 billion for 1 905 GWh equal to R2.62 per kWh in the previous year. The load factor for the OCGT fleet was 17.16% in 2014 (2013: 9.31%) against a budgeted load factor of 6.08% which contributed to 64% of its total 14.2% increase in primary energy costs (ESKOM, 2014a:107).

Figure 2.1: Eskom generation capacity by energy source



Source: (Matjila, 2014: 8)

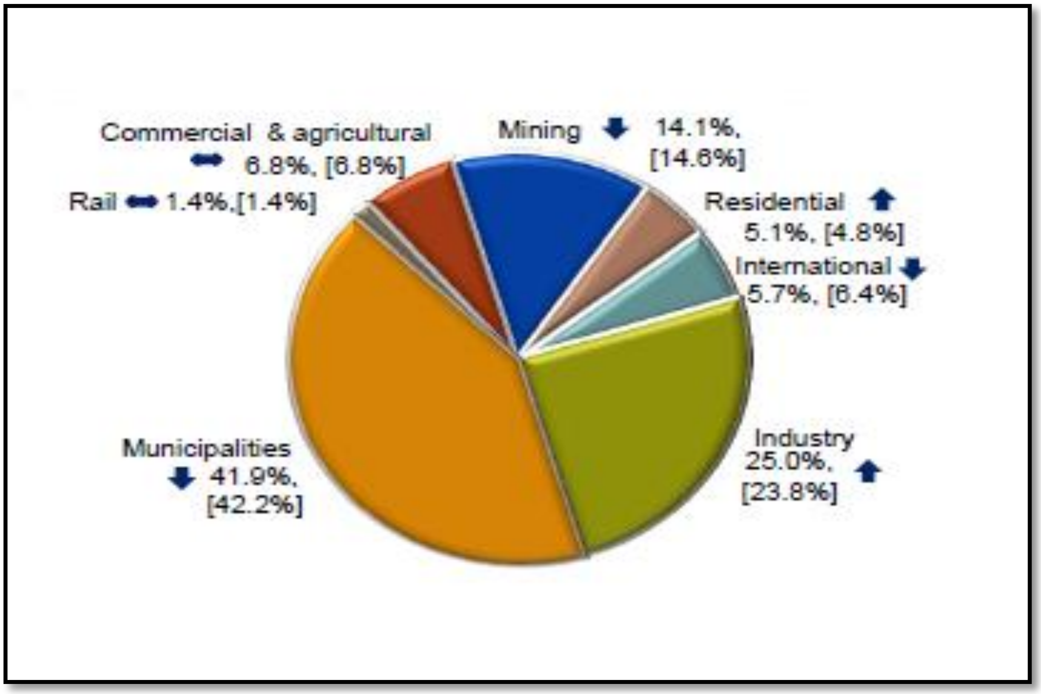
Figure 2.2: Increase in Eskom's primary energy costs as at 31 March 2014



Source: (Matjila, 2014: 35)

In addition, Eskom's sales have decreased as the current economic growth has been stagnant, specifically in the industrial and mining sector. Sales to municipalities have also decreased from 2013 as indicated below.

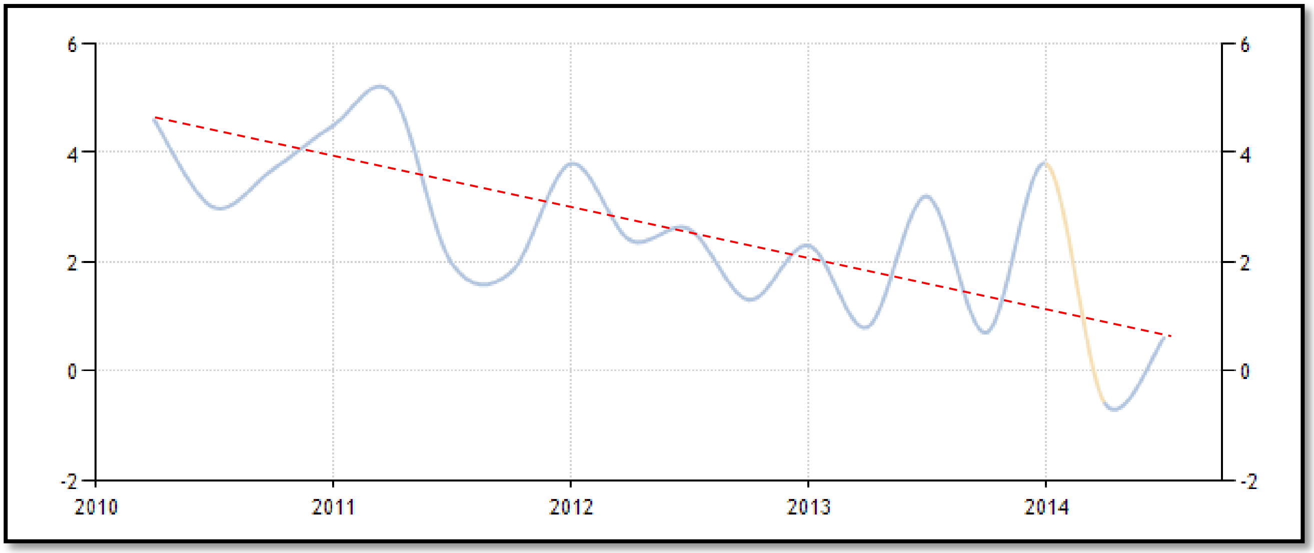
Figure 2.3: Eskom electricity sales by customer type



Source: (Matjila, 2014: 32)

The stagnant growth of South Africa is reflected in the year-on-year change in gross domestic product which is shown in the figure below (Bouwer, 2014:4):

Figure 2.4: South African change in GDP since 2010

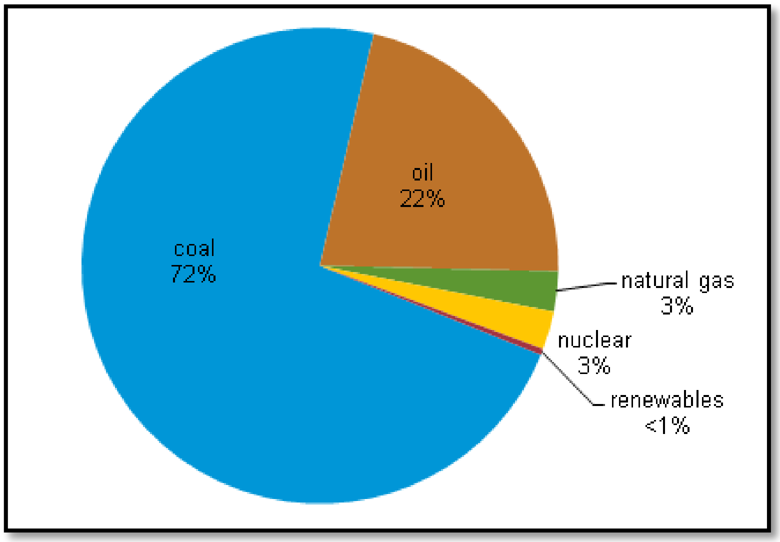


Source: (Bouwer, 2014:4)

2.2. CARBON EMISSIONS AND GLOBAL WARMING

South Africa’s reliance on coal, not only for electricity supply but total energy is significant. Presently, about 72% of the country's primary energy needs are provided by coal and 81% of all coal consumed domestically goes towards electricity production (Department of Energy, 2014). Historically this has given South Africa access to cheap electricity, but it is also one of the leading causes why the country is in the top 20 list of carbon dioxide emitting countries. This is unlikely to change significantly in the next decade, due to the relative lack of suitable alternatives to coal as an energy source (Ferreira, 2009).

Figure 2.5: Total primary energy supply in South Africa



Source: (BP, 2013:40)

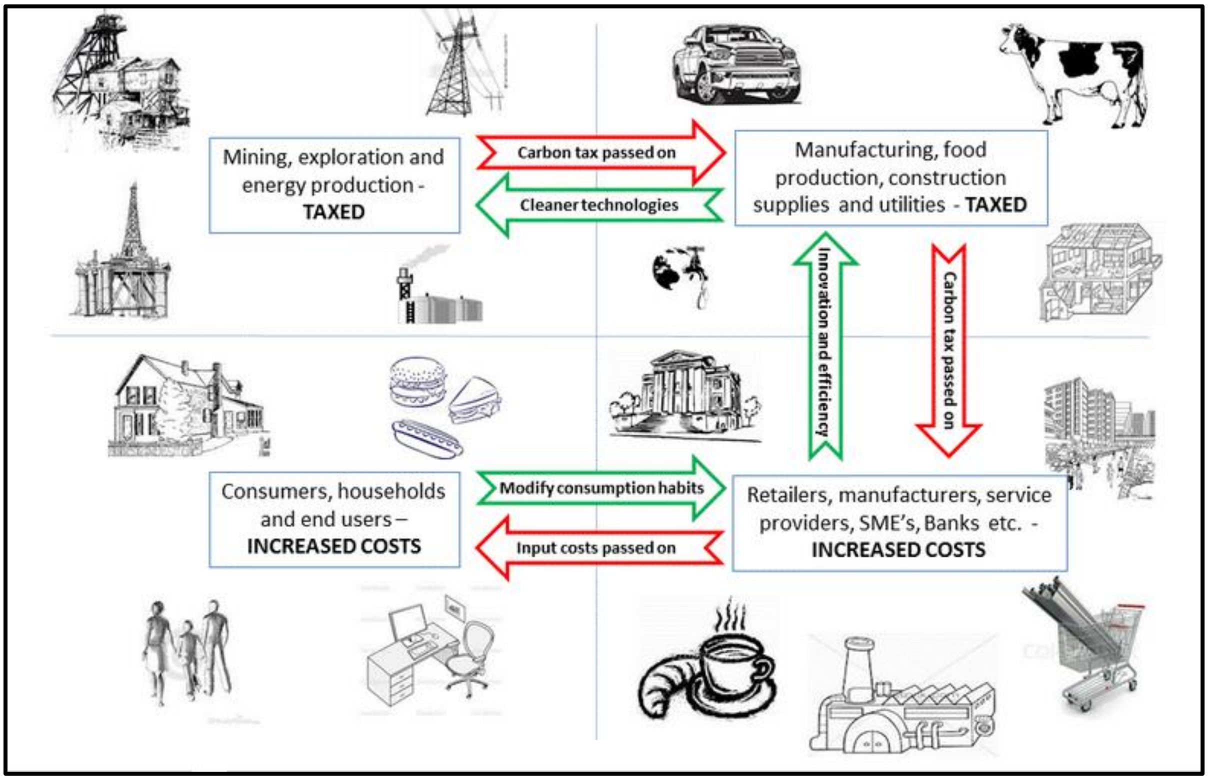
Carbon dioxide is a greenhouse gas, making South Africa one of the largest contributors to global warming per capita and GDP in the world. The burning of fossil fuels such as coal, oil and natural gas and extensive deforestation has contributed to a 40% increase in the atmospheric concentration of carbon dioxide, from 280 to 392.6 parts per million in 2012 and has increased to 400 parts per million in the northern hemisphere. Supporting these findings in 2013, the Intergovernmental Panel on Climate Change (IPCC) stated that the largest driver of global warming is carbon dioxide emissions from fossil fuel combustion, cement production and deforestation. The IPCC

also stated that there is more than 95% likelihood that human influence has been the dominant cause of global warming since the mid-20th century (Plattner *et al*., 2013:15).
To incentivise cleaner production and supporting the United Nations framework convention on climate change (UNFCCC), The Clean Development Mechanism (CDM) was established to provide for emissions reduction projects which generate Certified Emission Reduction units which may be traded in emissions trading schemes. CDM is one of the flexibility mechanisms defined in the Kyoto Protocol (IPCC, 2007) and allows for countries that signed the Kyoto Protocol, "Annex 1" countries, to meet part of their emission reduction commitments by buying Certified Emission Reduction units from CDM emission reduction projects in developing countries (Delay, 2009:14). This is a means of providing a much needed revenue stream for renewable energy projects that could otherwise not have been financially viable; however, in 2012 the CER price hit rock bottom at €0.15 per tonne CO_2 reduced from €13 per tonne in 2010 (Allan, 2012). This has brought the incentive for developing countries to implement emission reduction projects to a grinding halt.

However, in its commitments to prevent climate change and support the Kyoto protocol, the South African government is looking to implement a carbon tax from the 1st of January 2016. In last year's Carbon Tax Policy Paper, the National Treasury said that the proposed carbon tax would be levied at R120 per ton of CO_2 effective from January 1, 2015. The tax would be increased 10% a year, it said. This, to the relief of big industry players such as Arcelor Mittal, Sasol and Eskom, was postponed for another year to allow for further consultation (SAIT, 2014). Carbon tax is said to create incentives for companies, businesses and individuals that are able to change their behaviours and consumption patterns to reduce the reliance on polluting fossil fuels. However, for many established industries, changing "behaviours and consumption patterns" necessitates large capital layout and in some instances is virtually impossible (SAIT, 2014).

The effect of the carbon tax on electricity prices is estimated to be 12 cents per kilowatt hour which is sure to ultimately be passed onto the consumer as illustrated in the simplified diagram below (Carbon Report, 2014):

Figure 2.6: South African Carbon Tax cycle



Source: (Carbon Report: 2014)

2.3. ESKOM NEW BUILD PROGRAMME

Additional power stations and major power lines are being built to meet rising electricity demand in South Africa and as a means of replacing older power stations that are already running years beyond their original lifespan. Eskom's capacity expansion budget was R385 billion up to 2013 and is expected to grow to more than a trillion rand by 2026 as the long-term focus turns to nuclear power. Eskom is planning to double its capacity to 80 000MW by 2026 (ESKOM, 2013).

An additional 4453.5 MW has been commissioned since the programme's inception in 2005 and the plan is to deliver an additional 16 304MW in power station capacity by 2017. The formal opening of both Ankerlig and Gourikwa open cycle gas turbine (OCGT) stations took place in October 2007. Both these stations have subsequently been expanded. At Gourikwa two more units have been added, each with

148MW capacity. These were completed in March 2009. The building of five additional units at Ankerlig with capacities ranging between 148.3 and 149.2 MW were also completed in March 2009 (ESKOM, 2014b).

2.3.1. Medupi

Medupi is a green field coal-fired power plant project located west of Lephalale, Limpopo Province, South Africa. Medupi is the fourth dry-cooled, base load station built in 20 years by Eskom after Kendal, Majuba and Matimba power stations. The name "Medupi" is a Sepedi word which means "rain that soaks parched lands, giving economic relief" (ESKOM, 2014b).

The new power station will comprise six units with a gross nominal capacity of 800MW each, resulting in a total capacity of 4 800 MW. Construction activities commenced in May 2007, with the first of the six units of the power plant planned for first power by the end of 2014. Once complete, the coal-fired power plant will represent approximately 12% of South Africa's power generation. It will be the biggest dry-cooled power station in the world (ESKOM, 2014b).

In an effort to improve efficiency of the station, supercritical boilers and turbines will be installed. These operate at higher temperatures and pressures than Eskom's other stations. This base load station will also use direct dry-cooling due to the water scarcity in the area (ESKOM, 2014b).

2.3.2. Kusile

Kusile is a coal-fired power station close to the existing Kendal Power Station in the Nkangala District of the Mpumalanga Province. The power station is essentially a carbon copy of its sister station, Medupi, and will be the first power station in South Africa to have Flue Gas Desulphurization (FGD) installed as an atmospheric emission abatement technology. FGD is the current state-of-the art technology used to remove oxides of sulphur (SOx), such as sulphur dioxide (SO_2), from the exhaust flue gases (ESKOM, 2014b).

2.3.3. Ingula

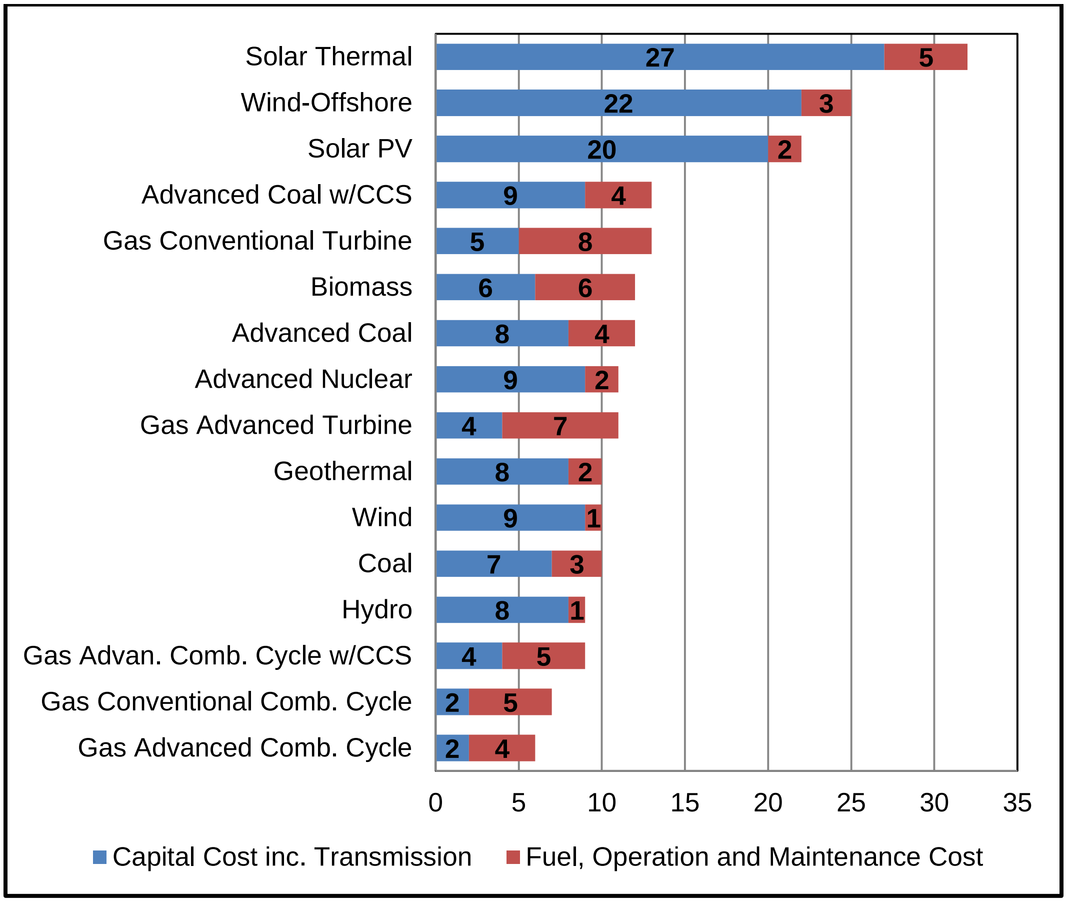
Contributing further to the national utility's challenges have been the delays in construction of two new coal fired power stations, Medupi and Kusile. Medupi has been at the middle of great controversy as South Africans have argued the need for another coal fired station amidst the abundant renewable resources the country has to offer. A third of Eskom's current investment and build programme is the Ingula pumped storage scheme. With an output of 1 332MW, mostly used during peak-demand periods, it is foreseen that the station will be fully operational at the end of 2015. This will assist Eskom in reducing its primary energy costs as the load factor of the OCGT fleet will be significantly reduced (ESKOM, 2014b).

2.4. ALTERNATIVE TECHNOLOGIES

The United States alternative Energy administration compared the costs of different technologies by calculating the cost of generating a kilowatt hour of electricity by adding the cost of building a facility, operating it, and paying for the fuel it consumes, then amortizing all this across all the electricity it is expected to produce in its lifetime. Interestingly the study highlights how expensive solar energy is compared to the other technologies and that coal is still a low cost base load technology. Considering that the study was conducted with United States economic factors, the numbers could look different in a South African context with different fuel, labour and financing costs. Nevertheless, the study provides some insight into the selection of the appropriate technology and that renewable technologies such as biomass, geothermal, wind and hydro are comparable and even cheaper than the advanced coal technologies Eskom's new building programme is based on (Conti, 2014: IF41). However, Eskom argues that the country is in need of base load technology and that coal fired power stations are still the most cost effective to supply the country's future energy needs with a long-term focus on nuclear power.

(Note: All values in US cents per kilowatt hour)

Figure 2.7: Estimated levelised cost of new generation resources, 2016



Source: Adapted from (Conti, 2014:MT33)

2.5. INDEPENDENT POWER PRODUCERS

South Africa has a high level of renewable energy potential and presently has put in place a target of 10 000 GWh to be generated from renewable energy sources. The Minister has determined that 3 725 megawatts (MW) is required from renewables to ensure the continued uninterrupted supply of electricity. This IPP Procurement Programme was initially designed to contribute towards the target of 3 725 megawatts and towards socio-economic and environmentally sustainable growth in order to start and stimulate the renewable industry in South Africa. The procurement of renewable energy takes place in five bid windows known as the renewable energy bidding programme (REBID). Ceiling prices or price caps are listed for the different technologies namely; biogas, landfill gas, biomass, concentrated solar power (CSP), small hydro power (< 40 MW), solar photovoltaic (PV) and onshore wind. Different bidders submit their projects which are evaluated on price (70%), economic development (30%) and against their competitors should there be more projects than the allocation per technology. Pursuant to the Ministerial determination in December 2012, the Minister determined that a further 3200MW of renewable generation capacity was to be procured from the REBID programme. Of the further Ministerial determination, an additional allocation of 308MW was made available for bidding in the third bid window (CSP 200MW, Biomass 47,5MW and Small Hydro 60MW) (Department of Energy, 2013a).

Under bid window one, the Department entered into 28 agreements on 5 November 2012. Under the second bid window, the Department entered into 19 agreements on 9 May 2013. With competitive bidding, the Department has seen prices decline during the progression of the programme and with the announcement of the preferred bidders under bid window three on the 4th of November 2013; it was evident that South Africa is ready to enter a new era of electricity generation (Department of Energy, 2013b).

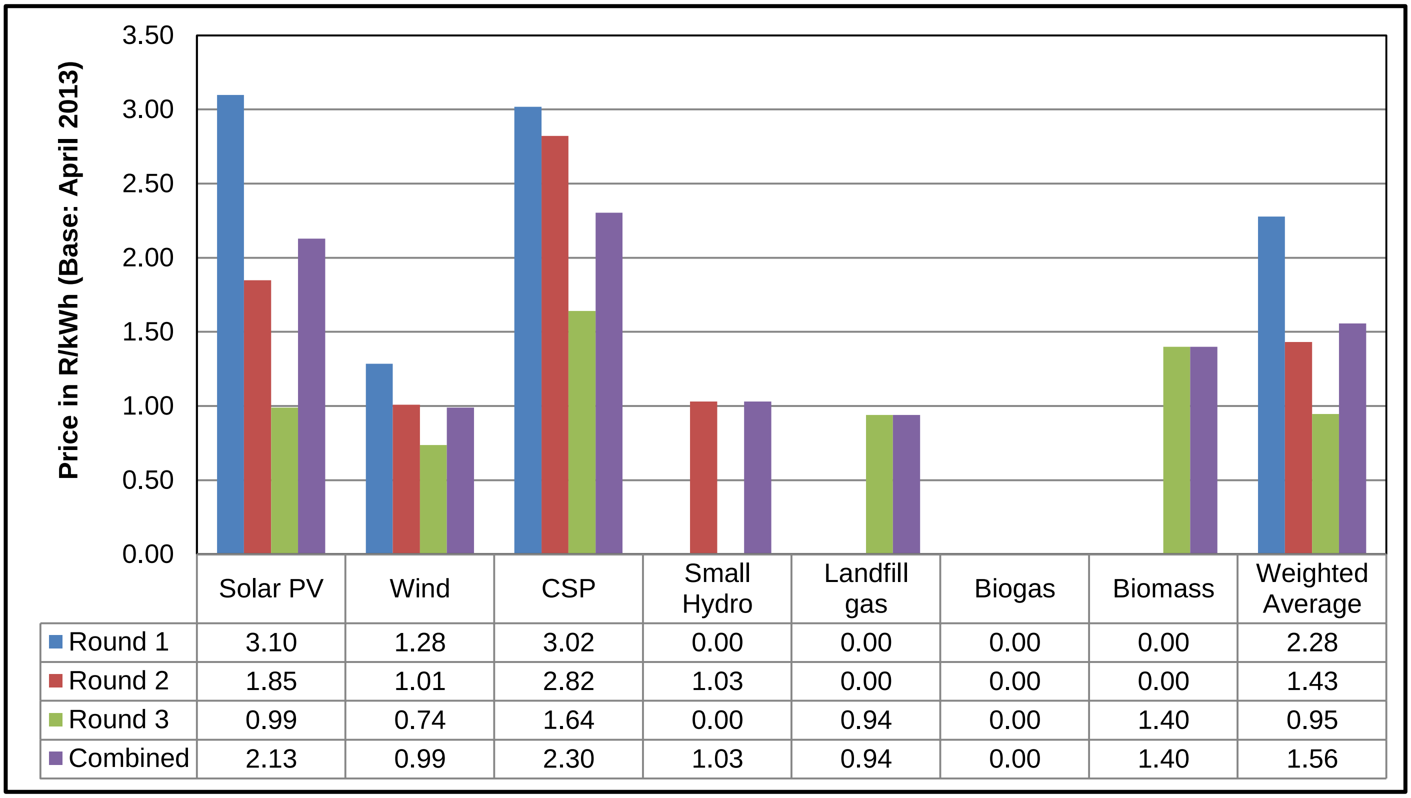
The results of bid window three are summarized below (Department of Energy, 2013b):

Table 2.1: Summary of preferred bidders under window 3

Technology	**Number of Bids**	**MW taken by preferred bidders**	**Maximum MW allocated for Bid Window 3**
Solar photovoltaic	6	435	401
Wind	7	787	654
Concentrated Solar	2	200	200
Small Hydro	0	0	121
Landfill Gas	1	18	25
Biomass	1	16	60
Biogas	0	0	12
TOTAL	**17**	**1 456**	**1 473**

The decline in electricity prices of the contracted bidders is evident from the figure below:

Figure 2.8: Decline in electricity prices from competitive bidding in the REIPPPP



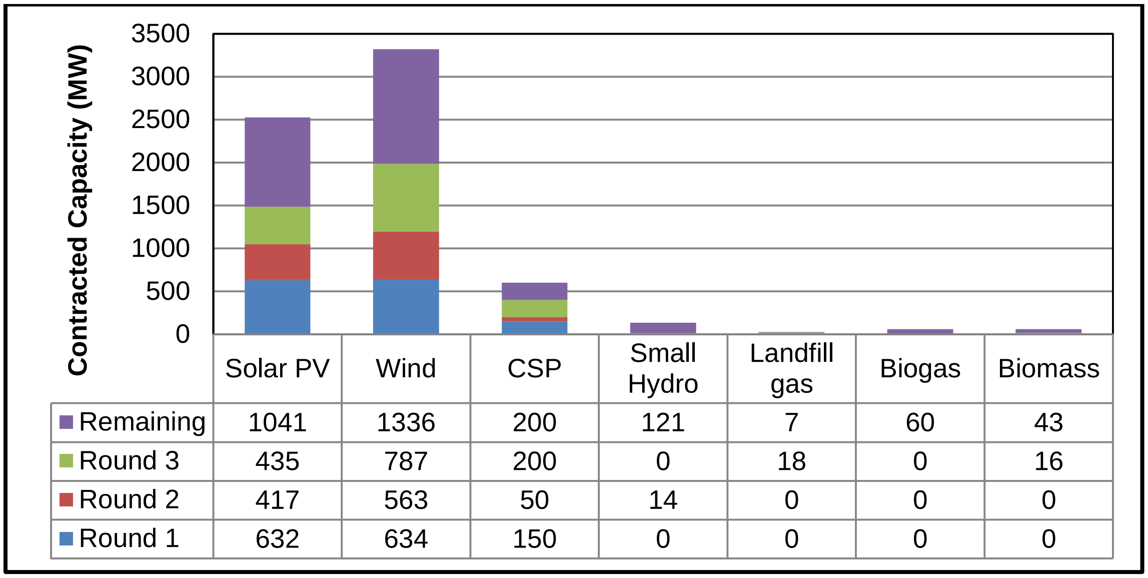
	Solar PV	Wind	CSP	Small Hydro	Landfill gas	Biogas	Biomass	Weighted Average
🟦 Round 1	3.10	1.28	3.02	0.00	0.00	0.00	0.00	2.28
🟥 Round 2	1.85	1.01	2.82	1.03	0.00	0.00	0.00	1.43
🟩 Round 3	0.99	0.74	1.64	0.00	0.94	0.00	1.40	0.95
🟪 Combined	2.13	0.99	2.30	1.03	0.94	0.00	1.40	1.56

Source: Adapted from (Department of Energy, 2012) & (Department of Energy, 2013b)

From the graph it is noticeable how the weighted average cost of renewable energy in the procurement programme has declined rapidly from R2.28 per kWh in the first window to R1.43 in the second window and then even further to below R1.00 per kWh in the third bid window. The combined cost of procuring renewable energy under the REIPPPP, based on April 2013 pricing, is R1.56 per kWh. It is remarkable how the cost of wind energy has reduced to R0.74 per kWh under bid window three due to the fierce competitive bidding process (Department of Energy, 2012) & (Department of Energy, 2013b).

A summary of the total capacity procured from the three bid windows, per technology, is illustrated below:

Figure 2.9: REIPPPP technology share in MW for first three bidding windows



	Solar PV	Wind	CSP	Small Hydro	Landfill gas	Biogas	Biomass
🟪 Remaining	1041	1336	200	121	7	60	43
🟩 Round 3	435	787	200	0	18	0	16
🟥 Round 2	417	563	50	14	0	0	0
🟦 Round 1	632	634	150	0	0	0	0

Source: Adapted from (Department of Energy, 2012; (Department of Energy, 2013b)

From the information, the total allocation for the five bid windows is 6725 MW which leaves a balance of 200 MW in fulfilling the total allocation of 6925 MW (3725 + 3200) from the ministerial determination.

In the same ministerial determination, 200 MW was allocated to the procurement of small projects which individually have a maximum contracted capacity of 5 MW. The projects with a generation capacity of not less than 1MW and not more than 5MW utilising the following technologies shall be considered as qualifying technologies for selection under the Small Projects IPP Procurement Programme (SPIPPPP), with the respective price caps indicate below (Department of Energy, 2013c):

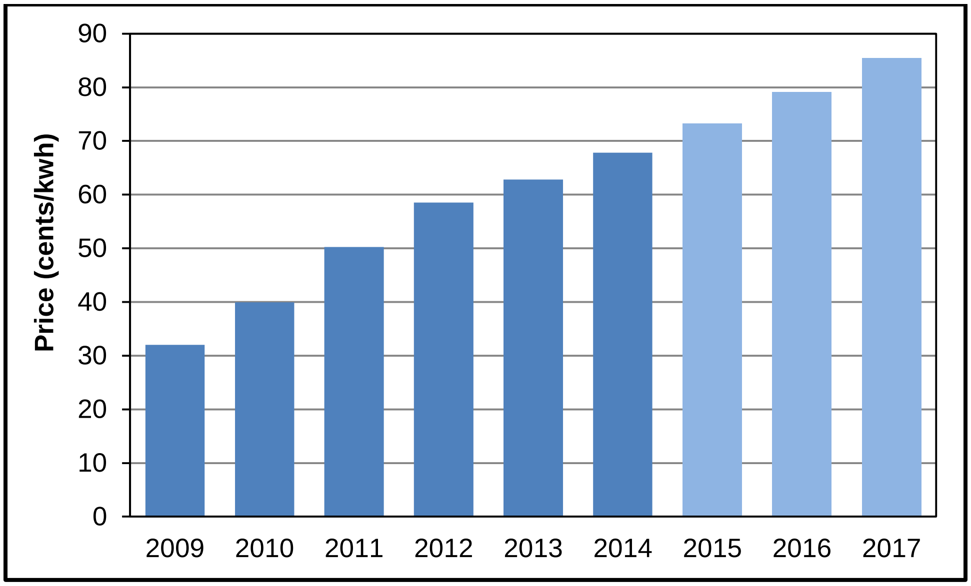
Table 2.2: Price caps per technology for the SPIPPPP

Technology	Price Cap (R/kWh)
Onshore wind	1.00
Solar photovoltaic	1.40
Biomass	1.40
Biogas	0.90
Landfill gas	0.94

2.6. ELECTRICITY PRICE INCREASES AND GLOBAL COMPARISON

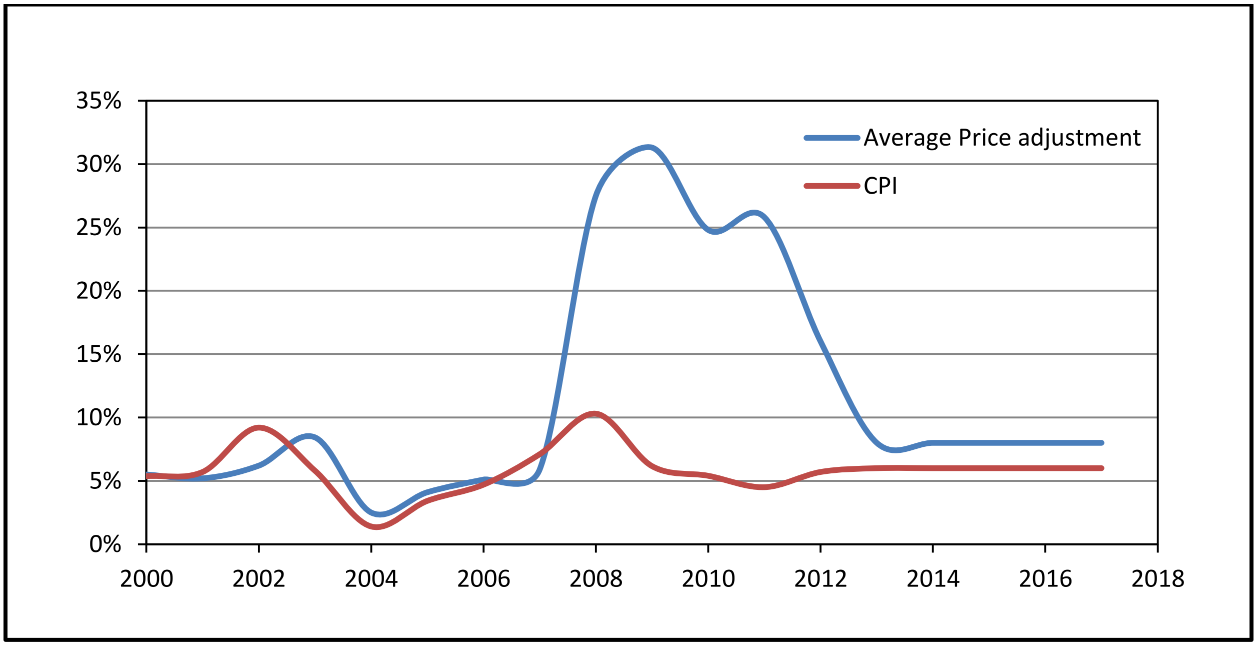
In 1990 a kilowatt-hour (kWh) of electricity had cost merely 8 cents, by 2007 the average price had risen to just less than 20 cents. Now, seven years later, the average electricity selling price is 68 cents/kWh. Eskom was proposing an increase in electricity prices to R1.28/kWh by 2018 with five 16% increases, year-on-year, as part of its third multi-year price determination (MYPD3). However, the National Energy Regulator of South Africa (NERSA) granted the power utility an 8% average increase per annum over the next five years (ESKOM, 2014a). South Africa's electricity prices had rocketed by more than 170% over the past five years, whilst administered prices in other countries had decreased by more than 36% in the past decade (Seccombe, 2013).

Figure 2.10: Eskom's average electricity price history and forecast



Source: Adapted from (ESKOM, 2014c:58)

Figure 2.11: Eskom's average tariff adjustment for the past 15 years

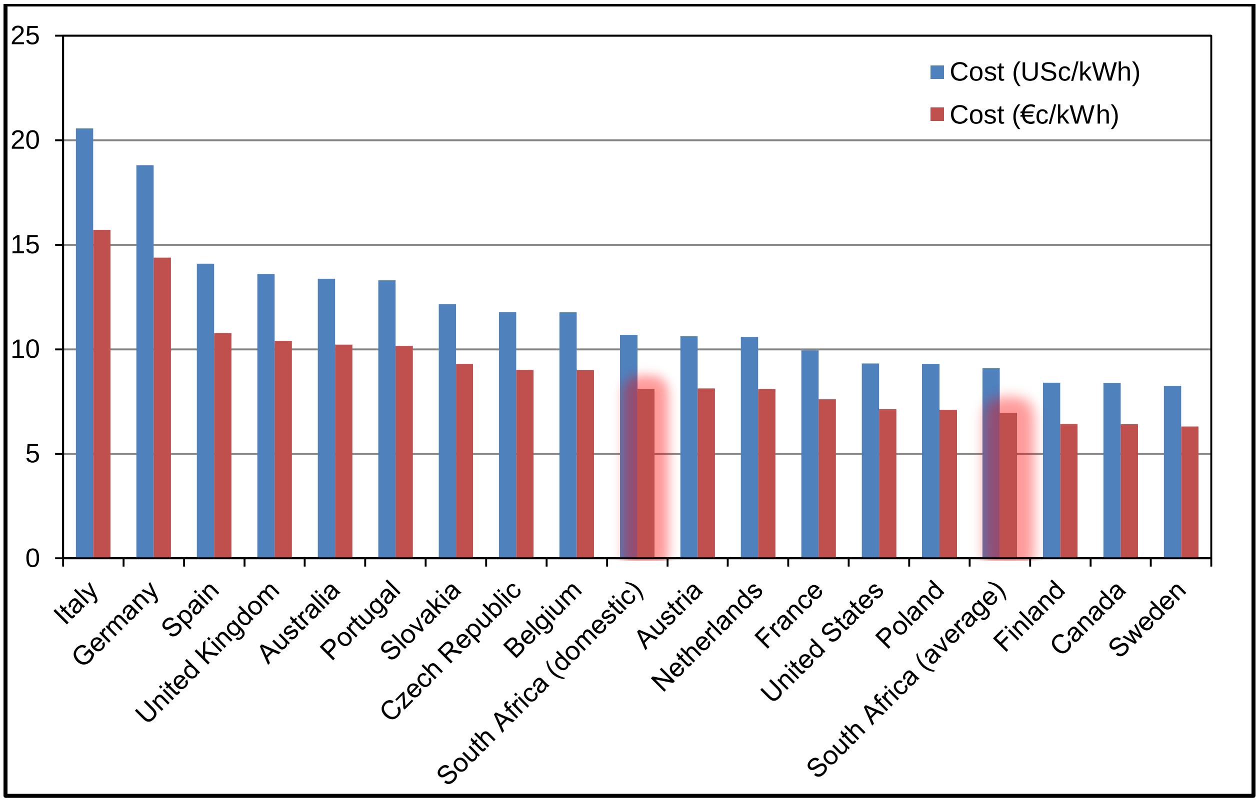


Source: Adapted from (ESKOM, 2014c:58)

With the abundance of coal, South Africa's cost of electricity has historically been among the lowest in the world, but a lack of infrastructure planning and recent increases far exceeding inflation has led to the question of where South Africa ranks currently with other countries. In addition, the majority of the state owned utility's sales (41.9%) are to municipalities. These local authorities are responsible for the upgrading and maintenance of their own distribution networks and sell the electricity onto smaller industries and domestic users at an inflated rate. A residential owner residing in Ekurhuleni (Gauteng) is currently paying R1.27 per kWh which is 187% more than the weighted average tariff that Eskom is selling the electricity to its clients (Ekurhuleni, 2014a).

A recent study done by the NUS consulting group compares South Africa's electricity price with other countries, internationally (GSGF, 2014):

Figure 2.12: International Electricity delivered price table of 2013



Source: Adapted from (GSGF, 2014)

South Africa showed the second highest change in year-on-year tariff increases while most of the other countries' tariffs decreased. From the study it is evident that the days of "cheap electricity" are long gone and with more increases to come, the South African consumer is set to pay among the highest for electricity in the world. In the same survey, NUS found that South Africa's natural gas prices are the highest of the eighteen countries at 12.55 US cents per kWh (GSGF, 2014). This provides some insight into why the costs to operate the OCGT fleet are so exorbitant.

South-Africa needs to raise its electricity supply significantly to enhance energy access for its growing population and provide the necessary energy for economic growth. Currently, many Southern African nations suffer from unreliable power supply, and the economic cost of power outages is high (Eberhard *et al*., 2011). South-Africa has great domestic renewable energy potential, which could be used to provide much needed energy in an affordable and secure manner, and to contribute to universal access to modern energy while avoiding negative environmental impacts. A long-term vision is needed to make optimal use of available domestic resources, given the long-lasting nature of energy infrastructure. Since different power supply technologies have different operational characteristics that could complement each other, the deployment of renewable technologies cannot be planned in isolation from the rest of the power system, but rather needs to be looked at from the perspective of their integration into the system (IRENA, 2013:13).

2.7. ENERGY OUTLOOK AND CHALLENGES

South Africa's renewable energy resources could be able to supply 94% of the country's electricity demand by 2050 according to the South African energy revolution (Teske *et al.*, 2011:41). Yet, there is a common misconception that renewable energy resources are unable to supply the country with much needed base load capacity. Base load is commonly described as the minimum level of power required over 24 hours by the collective users also known as the minimum demand. Graphically, it is illustrated as a band below the peaks and troughs of demand fluctuations. It is the level that remains unchanged for that day whereas above the line the demand varies as the day progresses. The variances are commonly found as residences draw more power, referred to as peak periods of the day, and as large factories start-up their operations. These demand fluctuations have to be balanced by the supply feeding the grid which is the primary role of the distribution centre (Gets & Mhlanga, 2013:15).

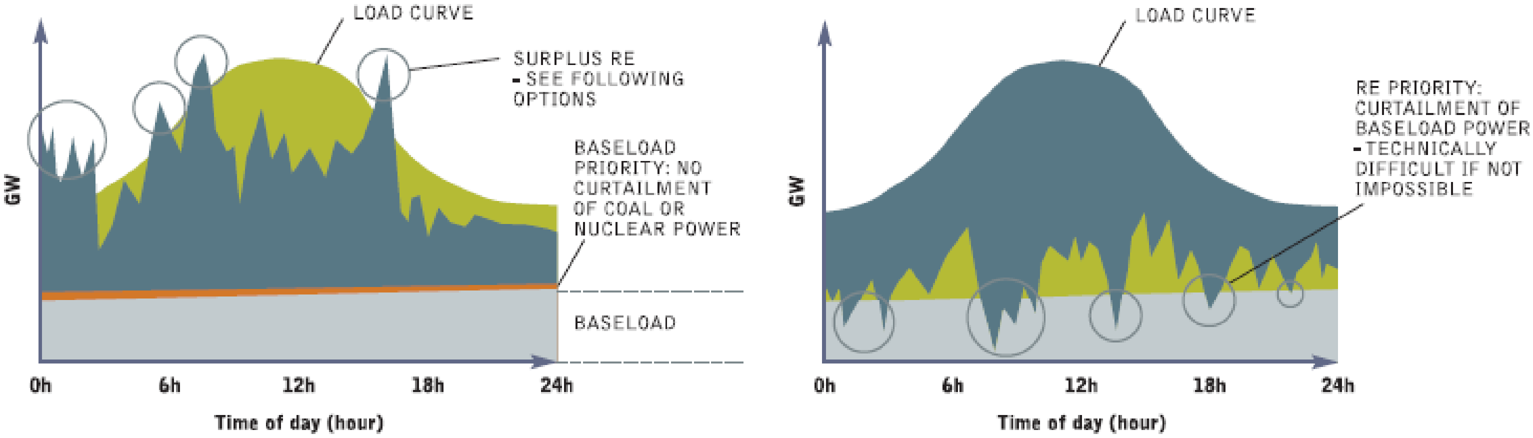
The base load is usually very constant which is used as a justification to install coal and nuclear power stations. Coal stations require 8 hours from cold start-up to full load so switching off and restarting in less than 8 hours cannot be easily met by a coal station (Eskom Fact Sheet GX 0003, 2012). This is the reason why big coal and nuclear stations run continuously for long periods of time and are only switched off for planned maintenance intervals. This makes it difficult for the grid operators to follow the peaks when only coal or nuclear stations are available and is the main reason for the OCGT fleet and pumped storage schemes.

South Africa still relies on the same centralized grid system which is inflexible and difficult to follow demand fluctuations (Short & Van De Putte, 2011:5). The primary concern is that the business case for large coal and nuclear power stations are only justified with a high load factor and as renewable energy increase, coal and nuclear will have less room to operate in the base load mode. Historically, renewable energy plants have had to adapt to the conditions of the grid and even be shut down during periods of excess supply to ensure that base load station run continuously. If, however, renewable energy takes priority and base load stations follow the remaining demand requirements, the load factor will decrease which will fundamentally change the economics of coal and nuclear power stations (Short & Van De Putte, 2011:26).

The traditional grid is also exposed to failures of big centralized power stations which could result in power outages and instability of the grid whereas a distributed grid is more robust as smaller stations have an insignificant impact on the entire grid (Diesendorf, 2010:7). A combination of renewable energy resources is available most of the time and a smart grid system is able to follow demand through the day. Therefore a system based on continuous renewable energy is technically and economically viable through decentralized stations combined with cogeneration but requires the right policy from government and a smart grid system interconnected over a large decentralized area (Ackerman *et al.*, 2009:46).

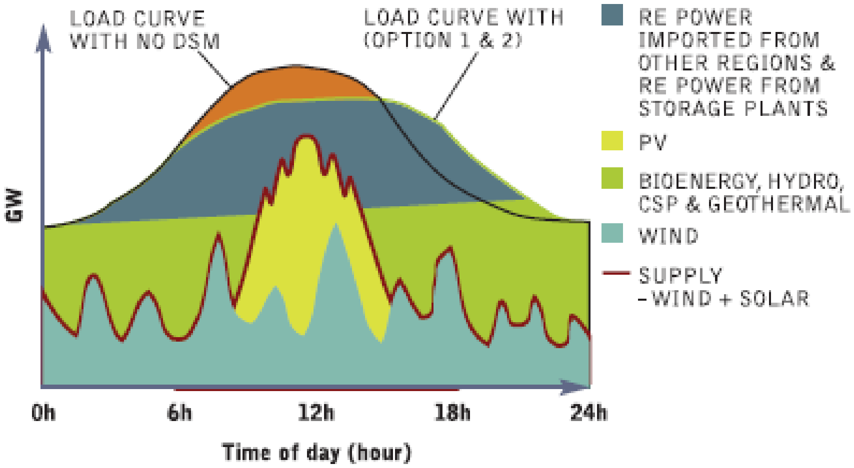
Currently the South African policy, built on coal and nuclear, allows for 25% renewable energy integration. However, more than 25% of renewable energy is required to meaningfully contribute to climate change (Teske *et al.*, 2012:31-32). If base load power stations still have priority and renewable energy exceed 25%, it would mean that there will be excess supply of electricity during certain periods of the day which could be overcome by shifting power to different regions, shifting demand or shutting down the renewable stations. When renewable energy exceeds 50%, the system can no longer accommodate for the supply-demand imbalances. However, if the roles are reversed and renewable energy, more than 25%, take priority it would necessitate large coal and nuclear stations to follow demand fluctuations which is difficult if not impossible to do. However, a fully optimized smart grid system with more than 90% renewables, operating with transmission, storage and demand management is viable and a solution to decrease carbon emissions, increase job creation and promote sustainable energy.

Figure 2.13: System with > 25% RE: a) base load priority (left). b) RE priority (right)



Source: (Teske *et al*., 2012)

Figure 2.14: Optimised system with 90% renewable supply



Source: (Teske *et al*., 2012)

The figure illustrates the ability of some renewable technologies to store energy that can be produced during peak periods of demand. For example, biomass plants can store fuel which can be loaded when required and the biogas from anaerobic digestion plants can also be stored in gas holding vessels. Solar thermal plants, such as the concentrated solar powered plants, can store energy in the form of molten salt which can be released long after the sun has set to produce electricity. Renewable energy thus has the capability to smooth out production often underlined as the reason for not moving towards a renewable energy system. Several wind farms distributed across various regions will also fall in different wind regimes which will further lower the intermittency (Gets & Mhlanga, 2013:17).

Even with this positive outlook, renewable energy is not the technology of choice. The following barriers affect the uptake of renewable energy in South Africa and hamper low carbon development which will need to be addressed if the country is to change into a greener economy (Gets & Mhlanga, 2013:21):

2.7.1. Political

South Africa’s coal dependence and vested interests in the fossil and mineral sector is a major barrier halting the development of renewable energy. The heavy economic weight of the fossil fuel industry and sector battling to sustain coal and nuclear power generation along with a lack of expertise in smart energy technology is preventing renewable energy from reaching its true potential (Amerasinghe, 2011).

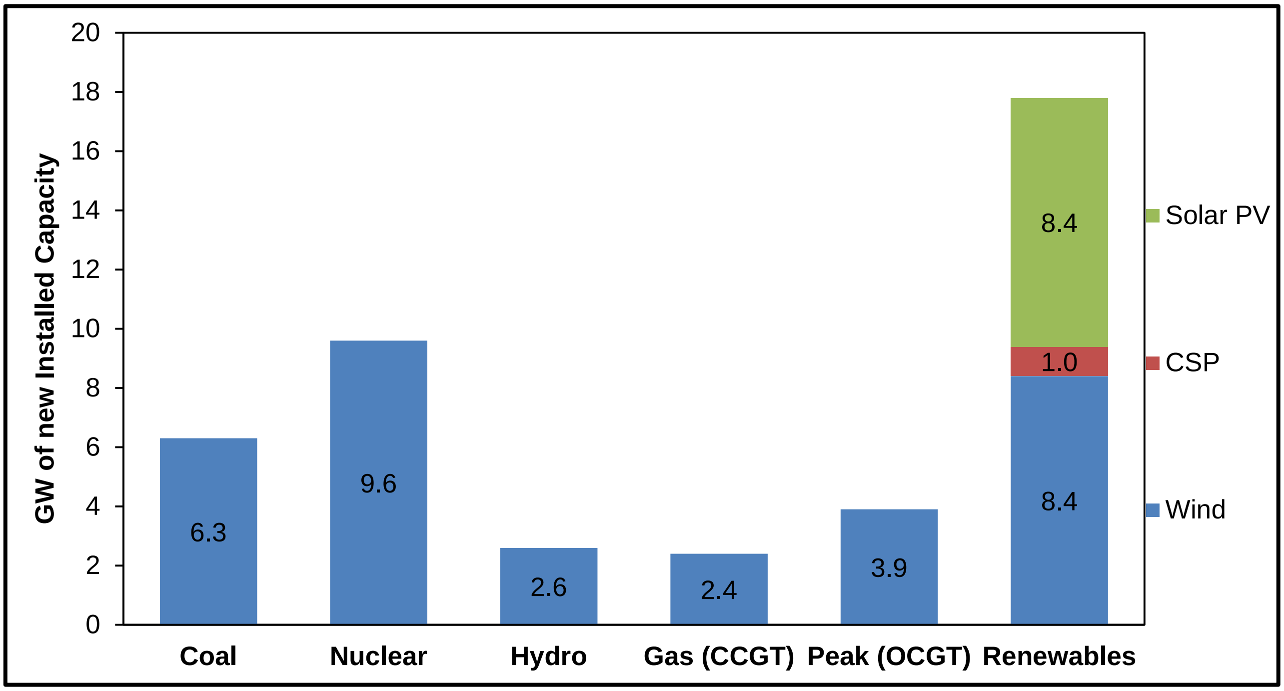
South Africa’s Integrated Resource Plan (IRP) of 2010 targets 17.8 GW of renewable energy by 2030 (South Africa, 2011:15). However, to date only 6925 MW of renewable energy have been allocated to the REIPPPP and SPIPPPP as discussed in section 2.5. If the set target of the IRP is to be reached, the country needs to urgently shift its focus from coal and nuclear towards renewable energy on a large scale.

2.7.2. Legislative

The IRP 2010 policy-adjusted plan after consultation indicates that 42% of all new build generation will be from renewable resources, equal to 17.8GW and 38% (15.9GW) from coal and nuclear. However, even with this in place, the energy mix is still dominated by coal and nuclear power as indicated in Figure 2.16 (South Africa, 2011:15).

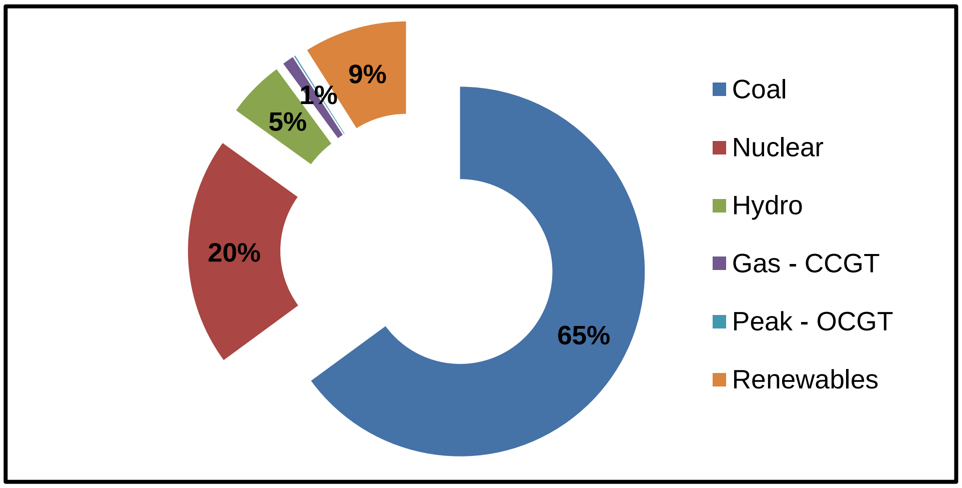
In addition, obtaining environmental authorisation and permitting is a long and cumbersome process that delays the implementation of a renewable project, aimed at improving environmental impacts. Trading agreements, licencing, power purchase agreements and land access are all legislative processes that need to be streamlined in order to prevent these from becoming barriers to the development of renewable energy in South Africa (Gets & Mhlanga, 2013:21).

Figure 2.15: Total additional new capacity until 2030 according to adjusted IRP 2010



Source: Adapted from (South Africa, 2011)

Figure 2.16: Total annual contribution by technology in 2030



Source: Adapted from (South Africa, 2011)

2.7.3. Economics and finance

Historically, coal and nuclear projects have received favourable government funding and subsidies. Aversion to taking risk in the initial development of renewable energy projects is also a barrier to entry as many projects fail to reach financial closure (Department of Environmental Affairs, 2011:47). One type of funding mechanism that has proven to be very successful in Europe, particularly Germany, is the use of a Feed in Tariff System (FITS). This means that renewable energy projects are paid a fixed tariff for every kWh fed into the grid and any additional costs of the system is carried by the taxpayer and electricity users. As this increases and more renewable power is sold into the grid, the additional system costs decrease (Teske *et al*., 2011:44).

In South Africa, FITS will encourage renewable energy and the establishment of a decentralised grid as more and more small generators will be able to sell electricity. This mechanism would also help to level the financial playing field for renewable energy projects versus conventional technologies and aid the development of smart grid technology.

2.7.4. Renewable industry development and the grid

Part of the conditions of the REIPPPP and SPIPPPP is that 30% of the bid scoring is allocated to economic development which includes local content contributions, black economic empowerment and the promotion of small to medium enterprise participation. Due to the lack of a clear roadmap for renewable energy after the 5 REBID windows and the small allocation of megawatts to technologies such as CSP, biomass, biogas and hydro, the current status of the industry does not justify a large enough pipeline for local industry to invest capital in establishing manufacturing facilities for the core components of these technologies (Gets & Mhlanga, 2013:22).

More ambitious policies from government are required to promote local manufacture and the development of renewable energy, which is at current a barrier to the industry. In addition, the current large centralised grid does not cater for the uptake of small renewable projects and feed in of electricity as discussed in 2.7.3. These barriers along with the lack of awareness and expertise from public and private sector, on renewable technologies, are preventing the industry from reaching its full potential (Gets & Mhlanga, 2013:22).

2.8. OVERVIEW OF RENEWABLE TECHNOLOGIES

Renewable energy is energy derived from resources such as sunlight, wind, rain, tides, waves and geothermal heat which are naturally replenished within a human time scale (Maczulak, 2010:8). Currently, a third of South Africa's population does not have energy access and those that do, often cannot afford it. The South African government is attempting to meet the electricity demands of a growing industrial sector, along with creating universal electrification. South Africa has the opportunity to leapfrog fossil-fuelled development by embarking on a world-leading ambitious renewable energy and energy efficiency programme where clean, sustainable, secure, stable, employment-supporting and accessible energy is achieved (Foster-Pedley & Hertzog, 2006:61). This would enable true long-term socio-economic development with reduced emissions but requires strong commitment from government to move towards a clean energy future. This section provides an overview and concise technical information on the various forms of renewable energy relevant to the study.

2.8.1. Biogas

Biogas is produced from anaerobic digestion, a biological process in which micro-organisms break down biodegradable material through a series of reactions in the absence of oxygen. The gas consists primarily of methane (CH_4) and carbon dioxide (CO_2) and may have small amounts of hydrogen sulphide (H_2S), water vapour (H_2O), nitrogen (N_2), carbon monoxide (CO) and siloxanes (Jarvis & Schnürer, 2010:19)

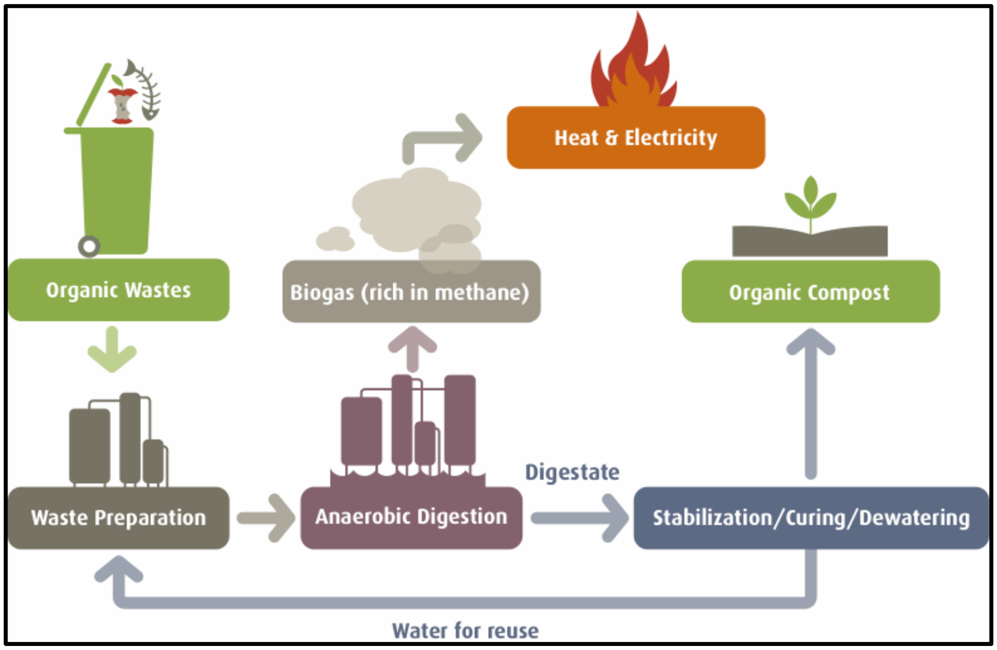
A simplified generic chemical equation for the overall processes is given below:

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4 \tag{1}$$

Biogas can be produced from regionally available raw materials such as manure, sewage, municipal waste, green waste, plant material, and crops. It is a renewable energy source and in many cases exerts a very small carbon footprint. The gases; methane, hydrogen, and carbon monoxide (CO) can be combusted or oxidized with oxygen. This energy release allows biogas to be used as a fuel for heating purposes as well as in a gas engine to convert the thermal energy in the gas into electricity (Clarke Energy, 2014).

As a source of alternative, sustainable energy biogas fulfils all the criteria relating to environmental sustainability, requires relative low technological input and, under certain conditions, may be cost effective to implement. Biogas is one of the most untapped sources of natural and sustainable energy available. Although biogas is used all over the world (India for instance has more than 12 million digesters), biogas in South Africa is practically unknown. In comparison a very a small number of small scale digesters (less than 100) have successfully been built and commissioned in South Africa. Most of these are small scale domestic digesters, with only a handful of larger commercial size plants (Energy Web, 2014). There is a trend to construct larger and larger biogas plants to take advantage of the economies of scale. The choice of anaerobic digestion technology and full scale design is critical to ensure long-term production and sustainability (Smith, 2011:7). A simplified schematic of a biogas plant is given below:

Figure 2.17: Overall flow schematic of a biogas plant



Source: (Iona Capital, 2014)

The organic waste stream is first prepared and typically homogenised before being diluted to the correct solids concentration. The substrate is then fed into an anaerobic digester where it is heated, mixed and retained for a minimum period of time to ensure complete digestion (Banks & Zhang, 2010:3). This period of time is known as the hydraulic retention time and is calculated by dividing the reactor volume by the feed flow rate. The time required for efficient digestion is highly dependent on the type and putrescibility of the waste stream which also determines the gas yield potential. The digested stream flowing out of the reactor is known as digestate and is a stabilised waste stream that can be used as fertiliser in agricultural practices. The digestate is stable as all volatile organic matter has been converted into biogas and any pathogens and other harmful bacteria are destroyed in the anaerobic process (Baskar *et al*., 2012:111-112,114).

In typical continuous stirred tank reactor systems, the digestate is first dewatered in a screw press, belt filter or centrifuge and then applied to land as fertiliser. The liquid portion from the dewatering step is recycled for dilution or alternatively applied to land through irrigation as a liquid fertiliser. The biogas, rich in methane gas (typically 50% to 70% of the biogas by volume) is a renewable fuel source that can be used to generate electricity or replace fossil fuels in traditional thermal heating applications (Ronneltrap *et al.,* 2014:99).

2.8.2. Biomass

Biomass is a carbon, oxygen and hydrogen based biological material from living or previously living organisms. Biomass can either be used directly for the production of energy or converted to energy products such as biofuels and bio char (Biomass Energy Centre, 2014). Biomass (forest residues, wood chips and other woody wastes from industrial process as well as municipal solid waste and refuse derived fuels) is converted to usable energy through thermal, chemical and biochemical processes. Industrial biomass as source of energy can be produced from various crops/grains such as miscanthus, switch grass, sorghum, poplar, maize, sugar cane and a variety of tree species (Darby, 2014).

With the increasing fossil fuel prices it makes sense to look more closely at the use of biomass to provide for some of our energy needs. Forest harvesting residue, or slash, is a resource that should be exploited for this purpose. Sawdust waste from the sawmilling industry is another source of suitable material. Plantation biomass is a carbon neutral source of energy that is ideal for replacing fossil fuels. If developed properly, biomass can and should supply increasing amounts of bio-power (Baskar *et al*., 2012:93).

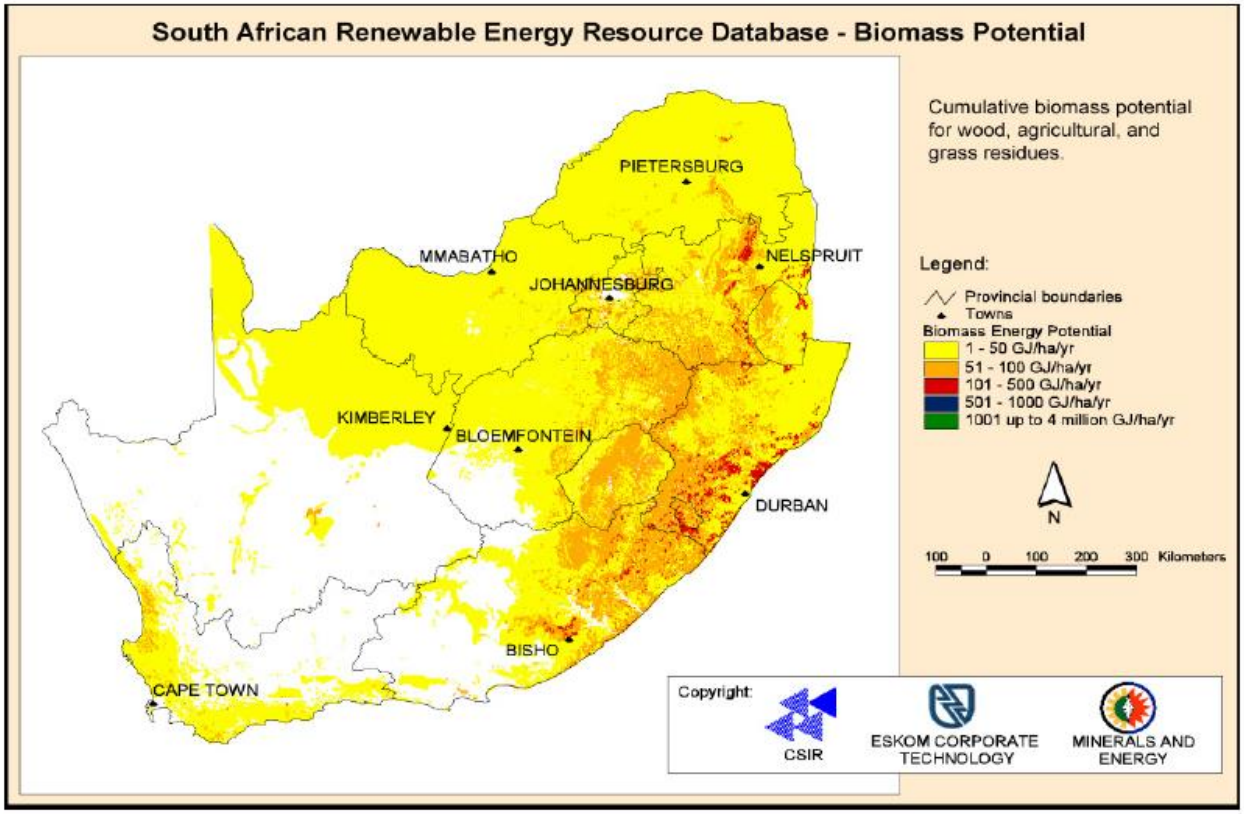
In fact, in numerous analyses, it is shown that sustainable biomass is a critical renewable resource. In the United States, already 50 billion kilowatt-hours of electricity is produced from biomass, providing nearly 1.5 percent of the nation's total electric sales. Biomass was the largest source of renewable electricity in the United States until 2009 (EIA, 2010).

South Africa has tremendous biofuel potential when considering the capacity to grow total plant biomass. According to conservative estimates, South Africa produces about 18 million tonnes of agricultural and forestry residues every year (Cleantech Solutions, 2014). The growth of bio-power will depend on the availability of resources, land-use and harvesting practices, and the amount of biomass used to make fuel for transportation and other uses. Viewed broadly, biomass could replace about 1 million tons of coal in South Africa (Dobson, 2008). Analysts have produced widely varying estimates of the potential for electricity from biomass. For example, a 2005 DOE study found that the nation has the technical potential to produce more than a billion tons of biomass for energy use (Perlack *et al*., 2005:59).

Sustainable, low-carbon biomass can provide a significant fraction of the new renewable energy we need to reduce our emissions of greenhouse gases like carbon dioxide to levels that scientists say will avoid the worst impacts of global warming. Without sustainable, low-carbon bio-power, it will likely be more expensive and take longer to transform to a clean energy economy (Cleetus *et al*., 2009).

With the current trends in energy pricing and pressure to reduce reliance on fossil fuels it make sense, where possible, to switch to a neutral forest biomass. Of the various biomass collection methods the slash bundling option appears the most viable. It not only allows the operator to render the biomass more dense but the creation of the bundles makes it possible to slot the harvesting operation in with the conventional forwarding/long haul arrangements that exist in the industry. Care must be taken when collecting forest biomass to ensure that enough nutrients are left on site to maintain long-term site productivity (Dobson, 2008).

Figure 2.18: Biomass potential in South Africa



Source: (GENI, 2014)

Thermal conversion involves processes driven by heat as dominant mechanism to convert biomass into energy or another chemical form. The basic alternatives of combustion, torrefaction, pyrolysis and gasification are separated principally by the extent of the chemical reactions involved and the conversion of reactants mainly driven by the availability of oxygen and temperature (Sugathapala, 2013:16).

The temperature range and products of the different processes is depicted below (Dahlquist, 2013:6):

Table 2.3: Temperature range and products of different thermal processes

Temp.(C)	80 – 140	~140 – 350	~350 - 650	650 - 900	800 – 900
Process Oxygen	Low	0% O2	Sub-stoichiometric O2	Sub-stoichiometric O2	Excess O2
Volatiles remaining	100%	75% – 90%	0 – 15%	0%	0%
Fixed Carbon remaining	100% FC	100% FC	90 – 100% FC	0 – 10% FC	0% FC
Off-Gas	Water Vapour	Some CO, CO2, Organic Acids	CO/CO2/H2/CxHy	CO/CO2/H2/CxHy	CO2 + H2O
Solids	Dry Product	• Roasted product (smokeless fuel) • Embrittled & hydrophobic	• Char product • Most volatiles driven off • FC and ash remains	• Ash product • Low residual FC	• Ash product

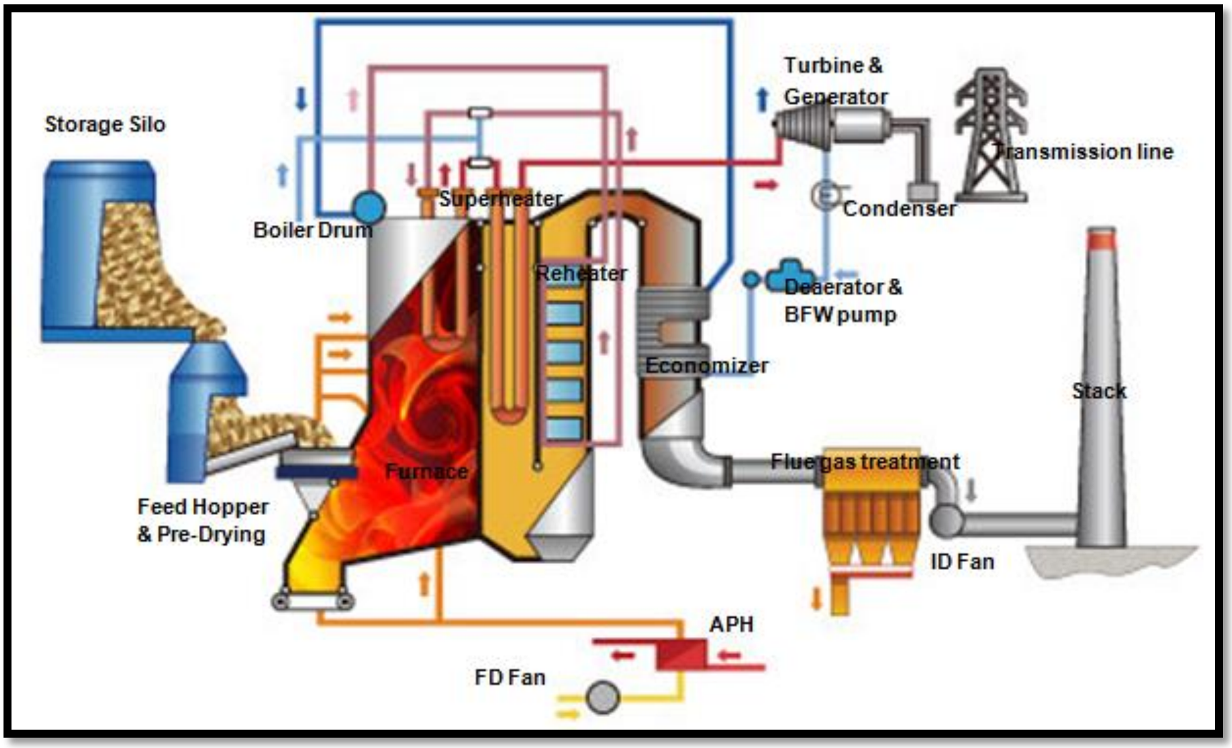
Source: Adapted from (Dahlquist, 2013:6)

Gasification is the process where carbonaceous materials such as coal, petroleum, biofuel or biomass are converted to combustible gases consisting of Carbon monoxide (CO), Hydrogen (H_2) and traces of Methane (CH_4) (Rajvanshi, 2014:2). The raw material is reacted at high temperatures with a controlled amount of oxygen and/or steam. The amount of oxygen used is generally between 20% and 70% of the stoichiometric required amount for complete combustion of the carbonaceous material. Pure oxygen or air may be used. The resulting gas mixture is known as synthesis gas or syngas. The syngas can be burned in an internal combustion engine or be used in highly efficient integrated combined gasification cycle processes for energy production (Laurence & Ashenafi, 2012:96).

The advantages of gasification are that the syngas is potentially more efficient than direct combustion of the original fuel because it can be combusted at elevated temperatures. The high temperature combustion refines out corrosive ash elements such as chloride and potassium, allowing clean gas production from otherwise problematic fuels (Higman & Van der Burgt, 2008:15).

Direct combustion refers to the complete oxidization of a fuel in the presence of excess oxygen (Mitchell & Overend, 2013: 189). An overall process flow diagram of a biomass fired conventional steam Rankine cycle is depicted below:

Figure 2.19: Process flow diagram of a biomass powered steam Rankine cycle



Source: (DP Cleantech, 2014)

The biomass power plant can be divided into the following main operations/areas (Maciejewska *et al*., 2006:24):

- Fuel transport, storage, preparation and feed
- Pre heating and control of combustion air;
- Combustion and flue gas treatment;
- Boiler feed water treatment and recycle; and
- Power generation and cooling.

Depending on the furnace/combustion technology and fuel characteristics, biomass may need to undergo some preparation prior to combustion. The typical size range for a moving grate or step grate furnace is any particle dimension < 80mm. These furnaces are very robust and can be designed to handle up to 25% outside of the specified range. The biomass is first sorted with a vibrating screen and oversize fractions are subsequently chipped or milled to below the size requirement. Biomass is introduced to the feed hopper from the storage silo with a walking floor or scraper chain conveyer. The biomass undergoes pre-drying before being fed from the hopper to the combustion chamber/furnace with screw feeders (Koppejan & Van Loo, 2012:38).

Ambient air is pre-heated with flue gas and partly used for drying biomass in the feed hopper. The forced draft fan introduces hot air into the combustion chamber/furnace at a controlled rate (Koppejan & Van Loo, 2012: 89).

Similar to gasification, the furnace type can be of fluidized nature or a more common moving grate furnace. The moving grate allows for the removal of bottom ash through water cooled, wet ash removal scraper into an ash hopper for disposal or sale to brick manufacturing / road building companies (Koppejan & Van Loo, 2012: 147).

The actual combustion process is exothermic and produces hot flue gas rich in CO_2, and H_2O. The excess O_2 in the flue gas is an indication of the excess air and is used to adjust the air to fuel ratio. The hot flue gas is used to superheat steam before pre-heating and evaporating the boiler feed water. Flue gas is rich in particulate matter and depending on the air emission regulations the flue gas is treated to remove particulates and reduce SOx and NOx concentrations. The choice of flue gas treatment technology is dependent on the extent of particulate removal and emission reduction. Fly ash removal is done by a conventional counter flow cyclone and if need be fabric bag filters or electrostatic precipitators (BERC, 2011:9).

Where required by law, the sulphur and nitrogen oxide pollutants are removed by stack gas scrubbers which use a pulverized limestone or other alkaline wet slurry to remove those pollutants from the exit stack gas. Other devices use catalysts to remove Nitrous Oxide compounds from the flue gas stream. A typical flue gas stack may be 150–180 meters tall to disperse the remaining flue gas components in the atmosphere (BERC, 2011: 10).

The feed water used in a steam boiler is a transport medium for energy from the hot flue gas, produced by heat of combustion from the fuel, to mechanical energy of the rotating blades of a steam turbine. The feed water consists of circulated condensate return after the turbine and purified make up water (Everett *et al.*, 2012:109).

The metallic pressure parts of the boiler are highly prone to corrosion at elevated temperatures and pressures; therefore the make-up water undergoes extensive treatment before use. The water flows through a series of intermediate feed water heaters, heated up at each point with steam extracted from an appropriate duct on the turbines and gaining temperature at each stage. It then flows through a deaerator that removes dissolved air from the water, further purifying and reducing its corrosiveness. Boiler feed water then enters the steam drum after being heated by the flue gas in an economizer/recuperator. The economizer raises the temperature of the feed water to close to the saturation point at the design pressure. The water is then evaporated and superheated at constant pressure before entering the steam turbine (Manivasakam, 2012:83).

The turbine generator consists of a series of steam turbines interconnected to each other and a generator on a common shaft. There is a high pressure turbine at one end, followed by an intermediate pressure turbine, two low pressure turbines, and the generator. As steam moves through the system and loses pressure and thermal energy it expands in volume, requiring increasing diameter and longer blades at each succeeding stage to extract the remaining energy (Manivasakam,2012:85).

The exhaust steam is condensed with a cooling medium and returned to the process as condensate (Hamworthy, 2014). The main methods of cooling are:

- Wet/Evaporative cooling;
- Dry/Air cooling; and
- Closed circuit cooling.

The lower the temperature at which the steam is condensed the higher the cycle efficiency according to Carnot’s theorem. Practically, a colder cooling water temperature will enable the condenser to be designed for a lower vacuum pressure at which the exhaust steam condenses. This means that more energy can be extracted from the steam in the turbine. The air wet bulb temperature can be approached by using evaporative cooling and is therefore the most efficient method of cooling. With air coolers the dry bulb temperature of the air is approached and this method of cooling is operationally very intensive (Tipler & Mosca, 2008).

Water availability is however the limiting factor in deciding which method of cooling to apply. Evaporative losses are significant and if water is scarce; dry cooling or closed circuit cooling where the warm fluid finds application for district heating or low temperature process heat demand, is preferred (Seattle Public Utilities, 2014:3).

2.8.3. Solar

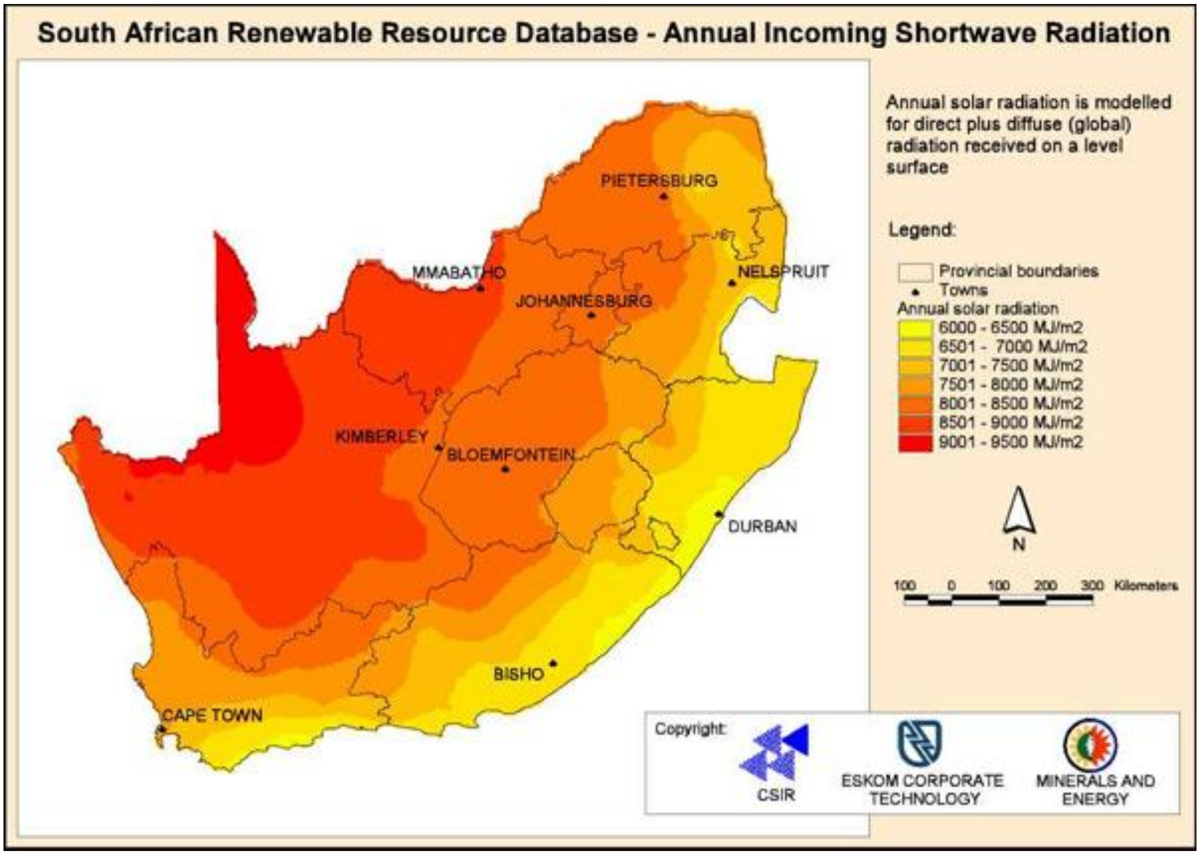
Solar power is the conversion of sunlight into electricity, either directly using photovoltaic (PV), or indirectly using concentrated solar power (CSP). In these systems a working fluid is heated by the concentrated sunlight, and is then used for power generation or energy storage which allows up to 24 hour electricity generation (Power Plant, 2010).

Concentrated solar power systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. The concentrated heat is then used as a heat source for a conventional power plant. Various techniques are used to track the sun and focus light (Kenneth & Skipka, 2014:185). Photovoltaic convert light into electric current using the photovoltaic effect. Photovoltaic were initially, and still are, used to power small and medium-sized applications. They are an important and relatively inexpensive source of electrical energy (Cunningham, 2014:17).

More than 1.5 billion people worldwide live without access to electricity (Gronewold, 2009). For people without access to an electrical grid, solar energy is the most cost-effective source of electricity as it provides clean energy to select regions (Pope, 2012). However, as the cost of solar electricity is falling, solar power is also increasingly being used even in grid-connected situations as a way to feed low-carbon energy into the grid. While the start-up costs of solar equipment can be higher than generators, the long-term operating costs are very small since there is no fuel to buy and little maintenance to carry out. Solar energy can be consumed directly or fed into a public power grid. Solar energy, like all other renewable energies, is very safe and environmentally friendly (Solartech, 2013).

The use of solar energy is the most readily accessible resource in South Africa. Most areas in South Africa average more than 2 500 hours of sunshine per year, and average solar-radiation levels range between 4.5 and 6.5kWh/m^2 in one day, more than double that of Germany which relies on renewable sources to produce 15% of its total electricity demand (Emvelo Energy Renewable Solutions, 2014). The southern African region, and in fact the whole of Africa, has sunshine all year round. The annual 24-hour global solar radiation average is about 220 W/m2 for South Africa (Emvelo Energy Renewable Solutions, 2014). This makes South Africa's local resource one of the highest in the world. Installed capacity of solar power in South Africa is expected to reach 8,400 MW by 2030 according to the Integrated Resource Plan (Energy Matters, 2013).

Figure 2.20: Annual Incoming shortwave radiation for South Africa



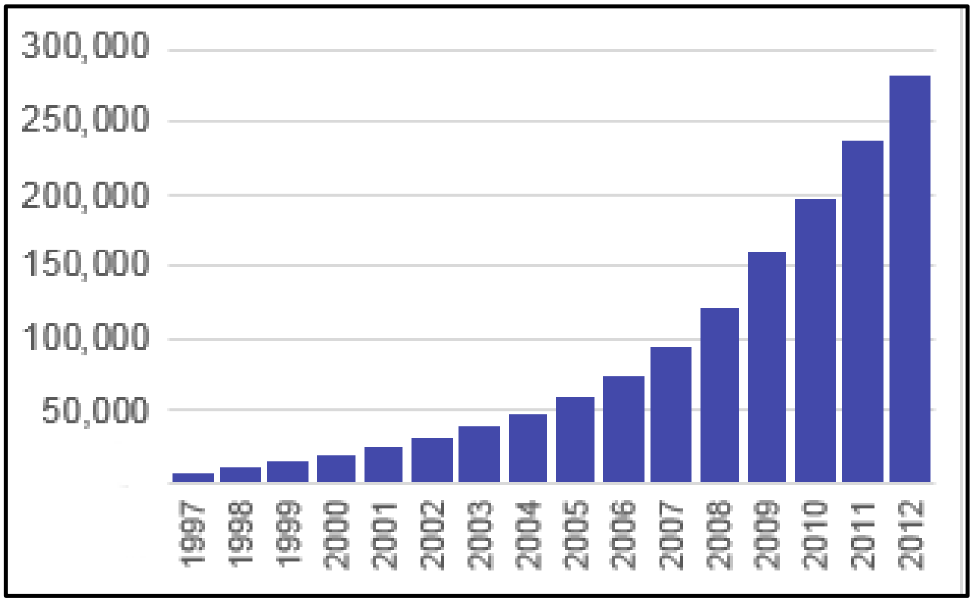
Source: (GENI, 2014)

2.8.4. Wind

Wind power involves converting wind energy into electricity by using wind turbines. A wind turbine is composed of 3 propeller-like blades called a rotor. The rotor is attached to a tall tower that looks like a very tall pole. On average wind towers are about 20m high to take advantage of stronger wind currents higher from ground (Energy Matters, 2013). Wind is produced by atmospheric changes and changes in temperature and pressure makes the air move around the surface of the earth. The wind makes the rotor spin; as the rotor spins, the movement of the blades spinning gives power to a generator which makes energy. The kinetic energy from the motion of the wind turbine turning is then converted into electricity. Because the wind is a source of energy which is non-polluting and renewable, wind turbines create power without using fossil fuels, without producing greenhouse gases, radioactive – or toxic waste and reduce global warming (Bloch, 2008).

As of 2011, Denmark is generating more than a quarter of its electricity from wind and 83 countries around the world are using wind power to supply the electricity grid. In 2010, wind energy production was over 2.5% of the total worldwide electricity usage, and growing rapidly at more than 25% per annum (Green Life, 2014). Worldwide there are now over two hundred thousand wind turbines operating, with a total nameplate capacity of 282,482 MW as of the end of 2012 (Aeris, 2014).

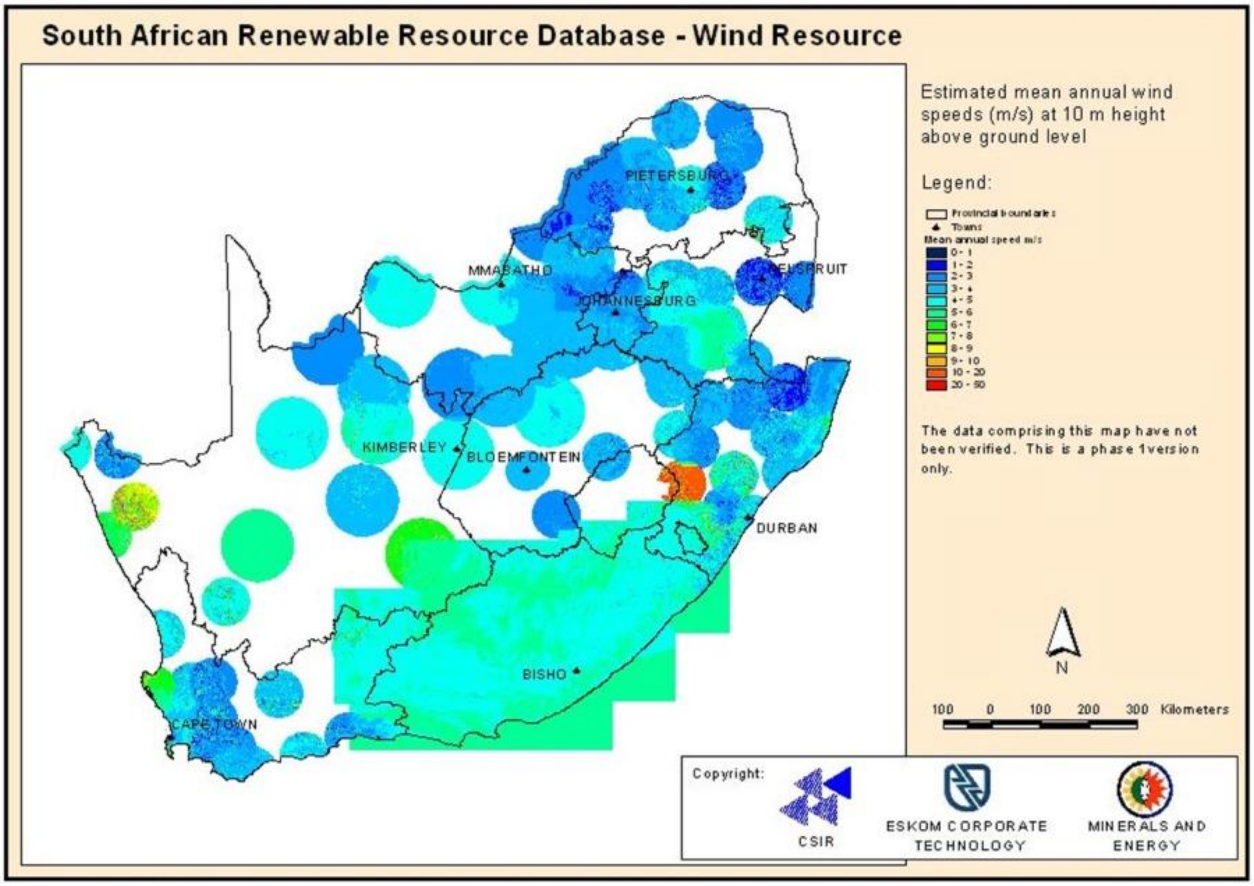
Figure 2.21: Increase in global power production from wind energy



Source: (Aeris, 2014)

Wind as an energy source is only practical in areas that have strong and steady winds. South Africa has fair wind potential, especially along the coastal areas of Western and Eastern Cape. The first large scale wind farm in South Africa became operational in 2014, and others are in planning and construction stages. Eskom has constructed one small scale prototype wind farm at Klipheuwel in the Western Cape and another demonstration plant near Darling. Under the Government's renewable energy programme for independent power producers, a consortium led by British company Globeleq recently constructed a 138 MW wind farm in Jeffrey's Bay, one of the largest in Africa. With 8.4 GW of new build generation to come from wind power by 2030, South Africa is set to become one of the global powerhouses in wind generation over the next two decades (Lenmanciya, 2014).

Figure 2.22: Estimated mean annual wind speeds across South Africa



Source: (GENI, 2014)

2.9. LEVELISED ENERGY COST APPROACH

2.9.1. Formula

Levelised energy cost (LEC) also known as levelised cost of energy (LCOE) is a calculation of the cost of generating electricity at the point of connection to a load or electricity grid. It comprises the initial capital, discount rate, as well as the costs of continuous operation, fuel and maintenance. This type of calculation assists policy makers, researchers and others to guide discussions in strategic decision-making

(Pearce, 2013). LEC is determined by dividing the project's total cost of operation by the energy generated. The total cost of operation should include all costs that the projects incurs and may incorporate any salvage or residual value at the end of the project`s lifetime, if applicable. The formula to calculate the LEC is given below (Taylor, 2013: 82):

$$LEC = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \tag{2}$$

Where:

- LEC = Average lifetime levelised electricity generation cost
- I_t = Investment expenditures in the year t
- M_t = Operations and maintenance expenditures in the year t
- F_t = Fuel expenditures in the year t
- E_t = Electricity generation in the year t
- r = Discount rate
- n = Life of the system

The LEC is calculated over the project lifetime (n) which is typically, 20 to 40 years and is expressed in units of currency per kilowatt-hour, for example R/kWh. It is the constant unit cost of a payment stream that has the same present value as the total cost of building and operating a generating plant over its life (Black & Veatch, 2011:2). Care should be taken when comparing different technologies and the LCE of different studies as the results are highly dependent on the assumptions, financing terms and particularly the capacity factor as this can be as low as 10% for solar PV depending on the location (Branker *et al.*, 2011:3). Therefore, the assumptions of the study should be clearly defined upfront to avoid any ambiguity. Another important factor is defining the same system boundaries for the technologies as this has a substantial impact on the levelised cost. Initial upgrading cost for power lines, distribution and transmission network costs are all factors that should be considered whether or not they are included in the calculation. Other factors to consider are tax calculations, research and development costs, environmental impact studies, costs of government subsidies and impacts on public health.

Another key component is the discount rate used in the formula as this can be the determining factor in swinging the decision from one option to another. The discount rate is used to convert future costs to a present value and is typically based on market interest rates or weighted cost of capital. The use of a specific discount rate should be substantiated and based on industry norms and standards. The discount rate and project lifetime is used to calculate the capital recovery factor (CRF) with the following formula (Black & Veatch, 2011:3):

$$CRF = \frac{r(1+r)^n}{[(1+r)^n]-1} \tag{3}$$

Using the capital recovery factor, equation 2 can then be rewritten into equation 4 below, which is known as the simplified LCOE or SLCOE (Black & Veatch, 2011:4):

$$SLCOE = \sum_{t=1}^{n} \frac{(I_t \times CRF)+M_t+F_t}{E_t} \tag{4}$$

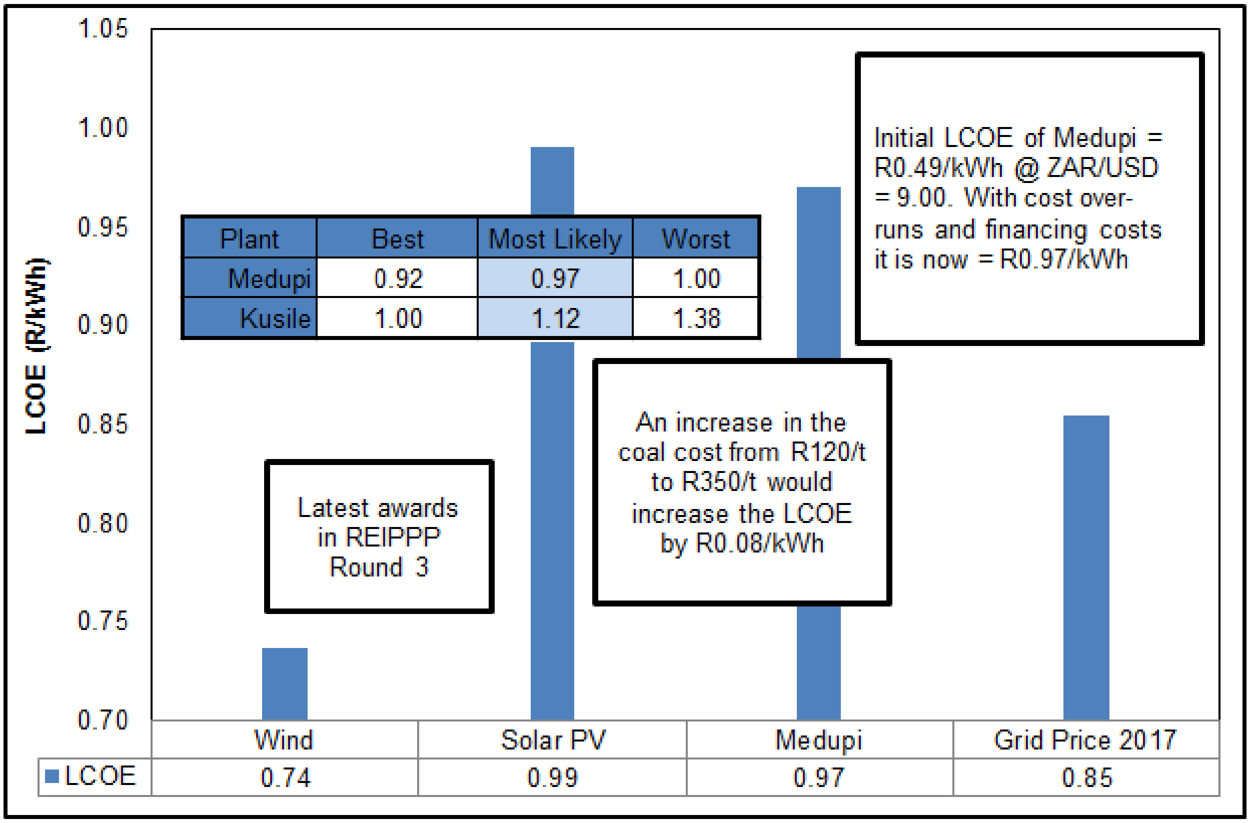
Another way to calculate the levelised cost of energy is the financial model approach, whereby a financial model is constructed that solves for the required revenue to achieve a certain internal rate of return over the project lifetime (Black & Veatch, 2011:5). The revenue is determined by the electricity price as input which is the levelised cost of energy. The reason that the financial model is preferred over the SLCOE is because it captures the impacts of tax incentives and depreciation as well as more complex financing assumptions and revenue requirements for an independent power producer such as the research and development costs mentioned above. In the empirical study to follow, the SLCOE as well as the financial model approach is used for comparison purposes.

2.9.2. Cost of Medupi

The power station is currently expected to cost R105 Billion excluding capitalised borrowing costs (ESKOM, 2014a). In July 2013 Eskom said that the plant start-up would be delayed until 2014, and fully commissioned by 2017, due to rising costs and labour unrest. The power utility told parliamentarians that finance charges on its new power station would be an estimated R25-billion for Medupi in Limpopo in 2013. When all interest and finance costs are included up to completion, the current price of Medupi is expected to be R170 billion (Donnelly, 2012). The estimates for nominal new Eskom coal power range from NERSA's 97c/kWh to Standard Bank's estimate that Kusile will cost R1.38/kWh in 2019, when it is commissioned. These revelations that electricity from Medupi could come in at an estimated 97c/kWh suggest South Africa could have got better value from renewable technologies such as wind (Gets & Mhlanga, 2013:18).

To further add to this, the LCE for Medupi does not include Carbon Tax as discussed in section 2.2, and its sensitivity to the coal price is illustrated below as viewed by the Energy Intensive User Group of Southern Africa (EIUG) (Collins, 2013:55):

Figure 2.23: Levelised cost comparison of Medupi and renewable sources



Plant	Best	Most Likely	Worst
Medupi	0.92	0.97	1.00
Kusile	1.00	1.12	1.38

Latest awards in REIPPP Round 3

An increase in the coal cost from R120/t to R350/t would increase the LCOE by R0.08/kWh

Initial LCOE of Medupi = R0.49/kWh @ ZAR/USD = 9.00. With cost over-runs and financing costs it is now = R0.97/kWh

Source: Adapted from (Collins, 2013:55)

2.10. SUMMARY

From Figure 2.23 it is clear that wind and solar are competitive with the levelised cost of Eskom’s new build coal power plants and that wind, in particular, is even more cost effective than the grid price in 2017.

The empirical study will evaluate these technologies along with biomass and biogas on a smaller scale of 1 MW to 5 MW with specific focus on the price caps per technology for the SPIPPPP (Table 2.2). The information obtained from the empirical study will be used to calculate the simplified levelised cost of energy and by constructing a financial model to determine the LCOE for each of the four technologies. These results (on a smaller scale) can then be used to determine the viability of renewable independent power production in its entirety.

CHAPTER 3

EMPIRICAL STUDY

3.1. INTRODUCTION

In this study quantitative research that can be described as the systematic empirical investigation of social phenomena via statistical, mathematical or numerical data or computational techniques will be discussed. In quantitative research the investigator relies on numerical data to test the relationship between the variables (Charles & Mertler, 2002). A typical type of research study that employs quantitative research would be an experiment or a survey study. To develop knowledge a researcher relies on a post-positivist approach to knowledge, which implies the existence of one objective reality (Teddlie & Tashakkori, 2009). The quantitative researcher tests the theories about reality, looks for cause and effect and uses quantitative measures to gather data to test the hypothesis or research questions. The researcher relates the variables to determine the magnitude and frequency of relationships. This means that the quantitative researcher asks a specific, narrow question and collects a sample of numerical data from participants to answer the question. The researcher analysed the data with the aid of statistical methods software. Thus, quantitative research provides the fundamental connection between empirical observation and mathematical expression of quantitative relationships (Charles & Mertler, 2002).

To effectively evaluate the different technologies using the levelised energy cost comparison, technical and commercial data will be collected from international leading renewable energy technology providers and project developers in South Africa. Specific data sets will be collected from these participants by completing data sheets and questionnaires for each technology namely (biogas, biomass, solar photo voltaic and wind power). The data was also collected through quotations from the participants for different outputs to determine the scalability and effect of economies of scale on economic viability for each of the four major renewable energy technologies.

This data was then be used in a financial model developed in Microsoft Excel. Basic model requirements such as climatic data, fuel specifications and energy values were collected from trusted (by financiers) and supported engineering databases to determine energy yield potential.

The data sets will be limited to five participants for each technology and the scale from 1 MW electrical output to 5 MW per technology. For solar, Johannesburg, Gauteng, was be selected and for wind the focus was on Port Elizabeth, Eastern Cape, as a basis for installation. Biogas and biomass technologies are not so dependent on location to the extent of wind and solar powered installations and will therefore not be limited to a specific area but for accuracy, Johannesburg, Gauteng was also selected as location.

Data collected through data sheets and questionnaires were scanned and stored in electronic format to ensure safekeeping of information. All data captured from technology providers and participants was backed-up on a virtual drive for future use and validation. Each participant was given a reference number. All data used in the Excel model were linked to the relevant data sheet for audit and verification purposes and all calculations were reported in an annexure to ensure accurate representation of the findings.

To prepare the data for analysis the researcher assigned a numeric value to each response category and variable. Then the data is entered into a computer program for further analysis (Microsoft Excel). The data-analysis consists of describing trends, comparing groups, and relating variables and is conducted at two levels: (1) descriptive statistics that indicate general tendencies in the data and (2) inferential statistics that analyse the data from the sample to draw conclusions about the unknown population. The researcher interprets the results to light of initial predictions and prior research on the same topic. The research report reflects a standardised, fixed structure and excludes personal reactions of the study results.

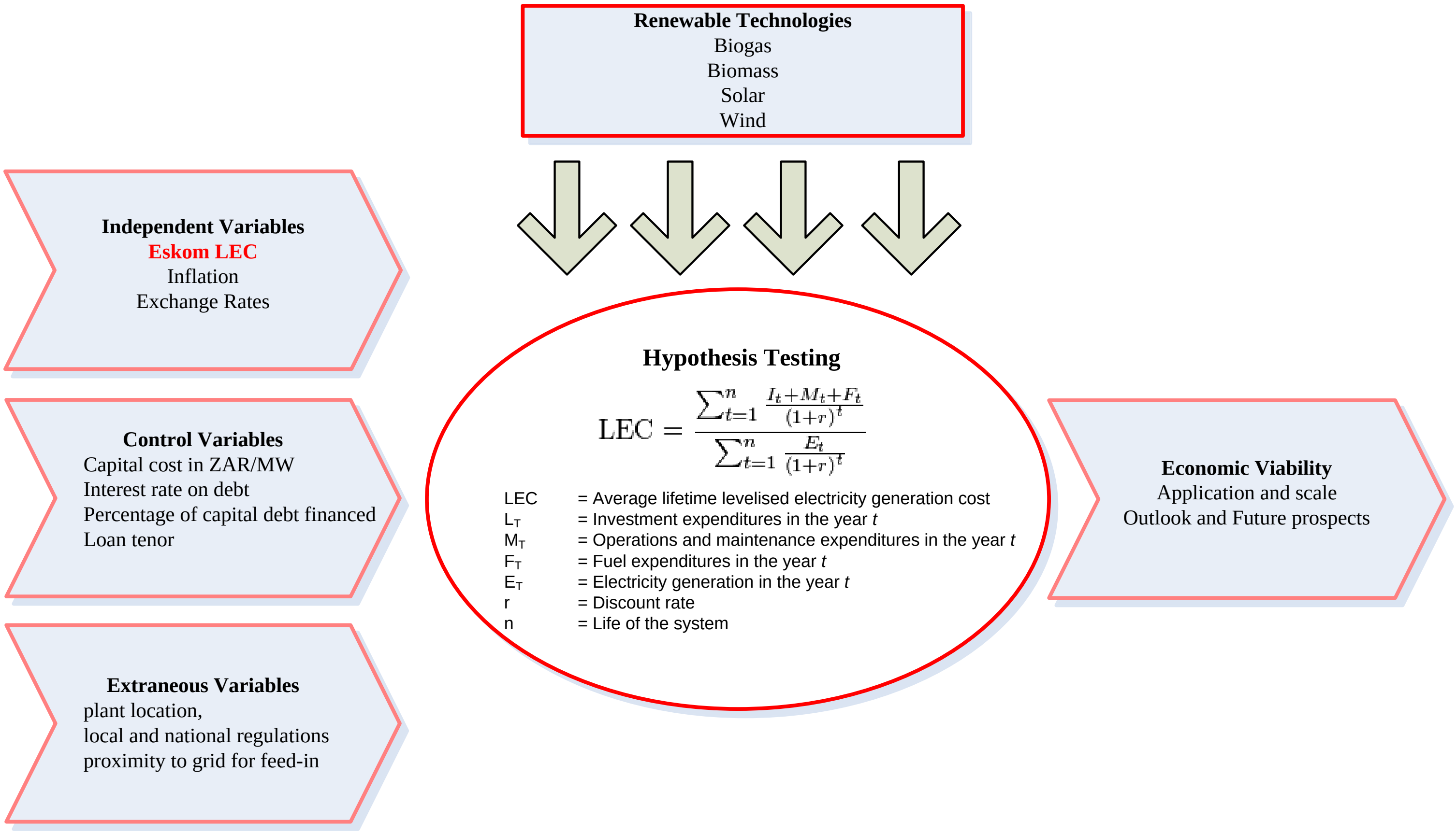
The reporting has a strong technical setting and follows a quantitative writing style intended to focus on the findings, mathematical representations and statistical validity of the data. The report will, however, aim to stimulate the reader by not deviating from the objective of making a meaningful contribution to the understanding and interpretation of renewable energy technologies in South Africa.

Ethics has become a cornerstone for conducting effective and meaningful research. Throughout the research there was a focused drive on obtaining letters of consent, obtain permission to interview participants and voluntary participation. During the entire study, the participant’s privacy and protection are ensured. Integrity will play a major role during execution and publishing of the research findings.

The ethical issues can definitely arise during the research study; it is better to prevent any potential conflicts by familiarizing oneself with the intellectual property and ethics policy of the relevant institutions to present and disclose the information in an ethical manner.

An overall layout of the empirical study is given by the figure below:

Figure 3.1: Overall layout of empirical study



3.2. MEASURING INSTRUMENTS

Four different measuring instruments or questionnaires were developed for each technology namely; biogas, biomass, solar and wind. Each technology has its own unique technical characteristics and different workings as described in section 2.8 and it is therefore important to capture the important parameters of each technology consistently for accurate evaluation. The selection of system boundaries and assumptions regarding energy yield characteristics were carefully considered and selected for each of the technologies.

A purposeful sample of international industry leaders in the technology supply and installation of the technologies, well-established project developers and independent power producers in South Africa were selected to complete the questionnaires. Five different participants were requested to complete the questionnaire for each technology resulting in a total of twenty participants for the study. Careful consideration was given to ensuring their confidentiality and the purpose of the evaluation is to calculate the LCOE for each technology and not to compare the different technology providers to each other.

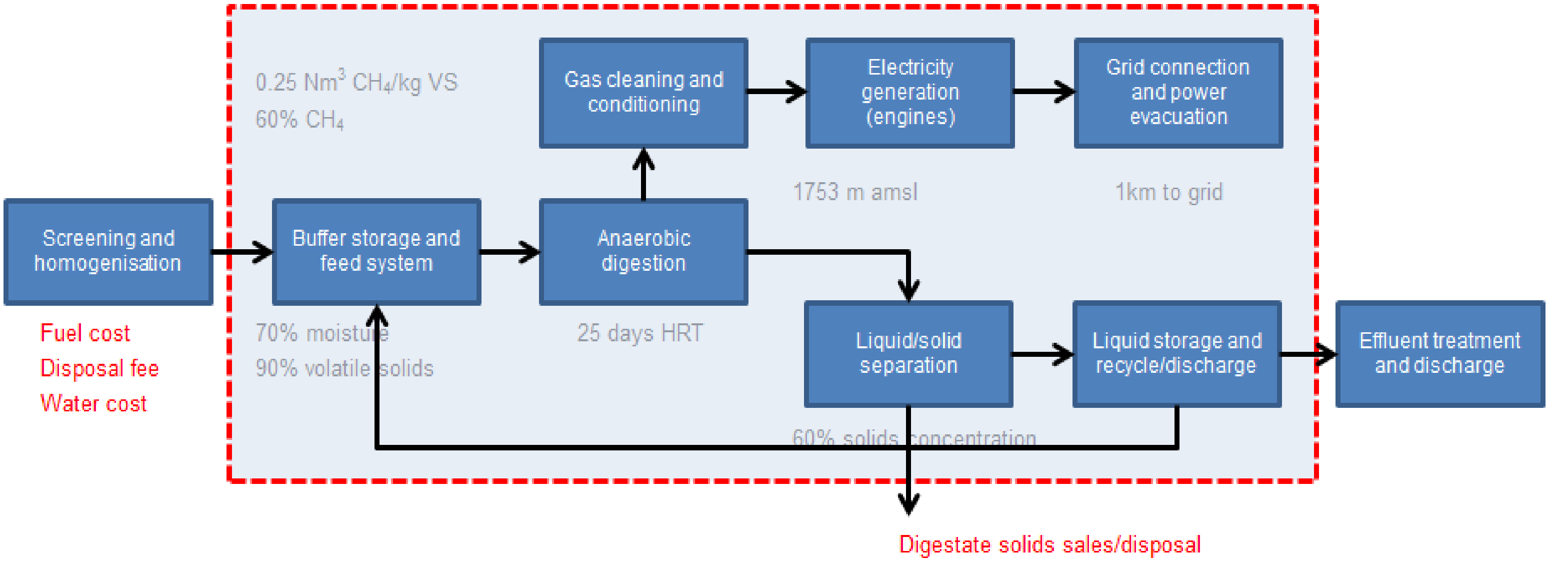
Each questionnaire consists of a list of technical, commercial and timing inputs required from the participant for different sized installations ranging from 1MW to 5MW in scale. Each questionnaire will therefore yield a different output and LCOE for 1-, 2-, 3-, 4- and 5 MW resulting in a total of one hundred LCOE results for the entire study. The technical component is specific to the technology; however, the commercial and timing components are kept the same for all four technologies as the inputs required from the participants in terms of capital cost, operations and maintenance costs and drawdown of capital during the construction period are generic.

The purpose is therefore to evaluate the viability of renewable independent power production in South Africa and economies of scale within the 1-5 MW limits of the Small Projects Independent Power Producer Procurement Programme (SPIPPPP) and to compare these results to the results of the larger Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) as discussed extensively in the research study. The construct of the questionnaires for the different technologies is further described below:

3.2.1. Biogas

The system boundaries for the biogas measuring instrument are illustrated in the figure below.

Figure 3.2: System boundaries for biogas technology questionnaire



The variables highlighted in red, outside of the system boundaries, are control variables that will be further discussed under the financial model section. The variables inside the system boundaries are the parameters supplied to the technology provider in the questionnaire in order to size the plant for the specific output. These parameters (assumptions of the study) are summarised as follows (Browne & Murphy, 2012:174-175):

- Fuel input is a putrescible solid waste - typically food waste
- Fuel is already homogenised and free of any contaminants
- Fuel average moisture content is 70% on a wet basis
- Fuel average Volatile Solids is 90% of the Total Solids on a dry matter basis
- Biomethane potential is 0.25 Nm^3/ton VS at 25 days hydraulic retention time
- Average methane concentration is 60% of the biogas on a volume basis

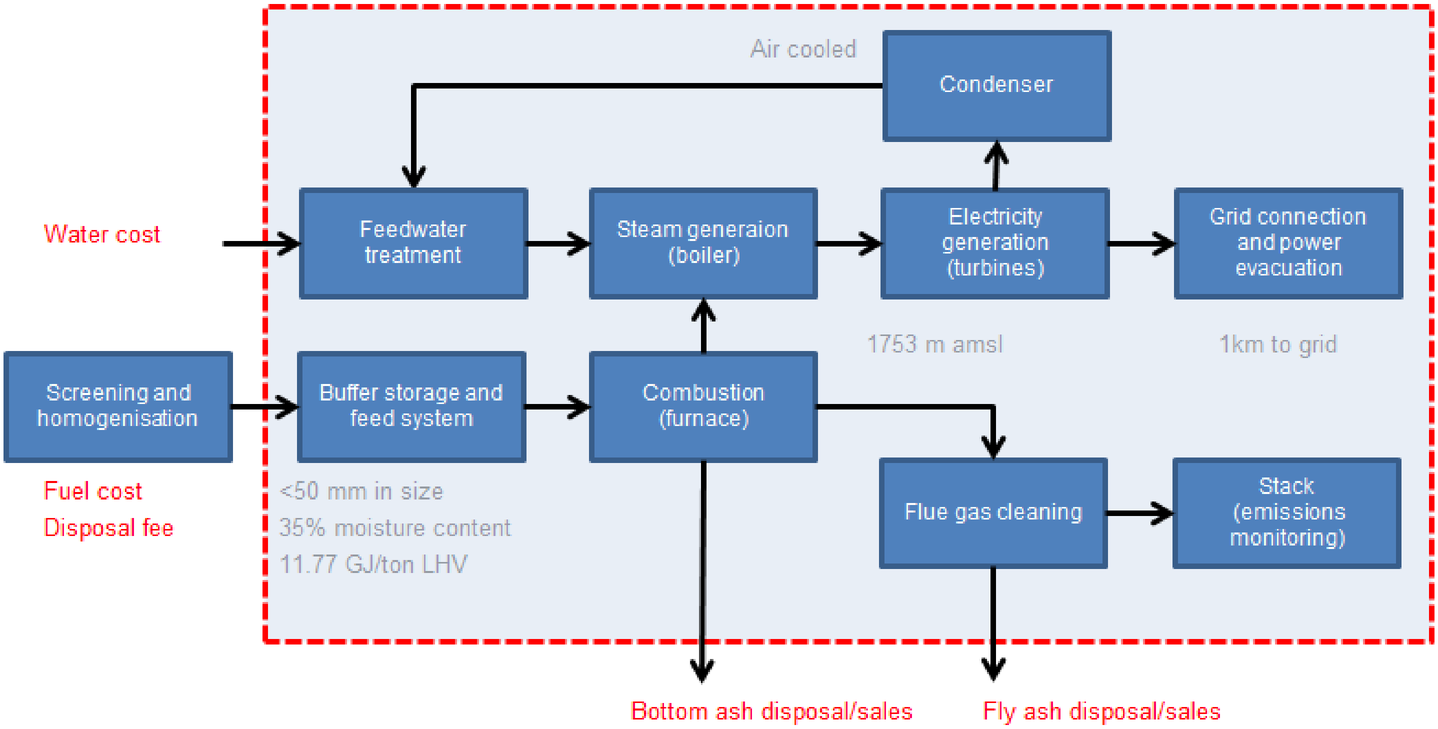
- Project elevation is 1753 meters above mean sea level (Johannesburg, South Africa)
- Grid connection point is a distance of 1km from the generation point

These parameters are discussed on the cover page of the technology questionnaire to ensure that there is no ambiguity in the inputs used by each provider to calculate energy potential and electrical output. As can be seen from Figure 3.2, any initial screening or homogenisation of the substrate prior to digestion and treatment of the effluent (liquid after separation) prior to discharge is excluded from the study. The inclusion of these unit processes is highly dependent on the project location and regulations pertaining to the specific site and can therefore not be evaluated on a generic basis. For complete accuracy, each project's site specific conditions will need to be established to ensure that these processes are included, if required, which will have an impact on the LCOE as investment and operations and maintenance costs will increase as a result.

3.2.2. Biomass

The system boundaries for the biomass measuring instrument are illustrated in the figure below.

Figure 3.3: System boundaries for biomass technology questionnaire



The variables highlighted in red, outside of the system boundaries, are control variables that will be further discussed under the financial model section. The variables inside the system boundaries are the parameters supplied to the technology provider in the questionnaire in order to size the plant for the specific output. These parameters (assumptions of the study) are summarised as follows (Boundy *et al.*, 2011:205):

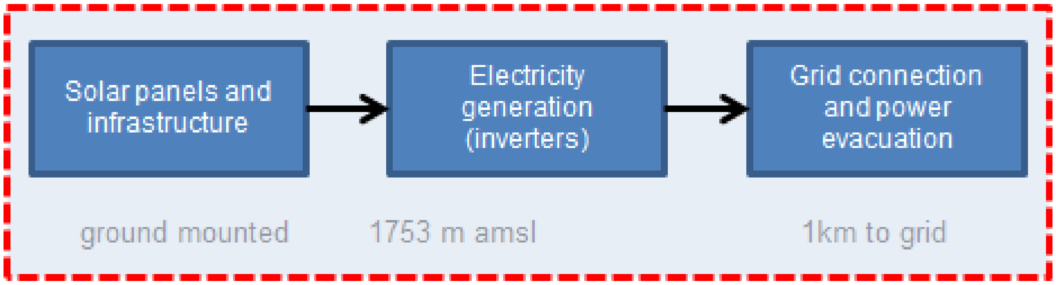
- Fuel input is a woody biomass - typically pine or wattle;
- Fuel is already conditioned and is less than 50mm in size;
- Fuel average moisture content is 35% on a wet basis;
- Fuel average lower heat value is 11.77 GJ/ton;
- Project elevation is 1753 meters above mean sea level (Johannesburg, South Africa);
- Grid connection point is a distance of 1km from the generation point; and
- The technology is a conventional steam Rankine cycle with air-cooled condenser.

The same as biogas, any initial screening or homogenisation of the fuel prior to combustion is excluded from the study and assumed to form part of the fuel cost that will be charged to the project. The power plant therefore pays for conditioned fuel.

3.2.3. Solar

The system boundaries for the solar measuring instrument are illustrated in the figure below.

Figure 3.4: System boundaries for solar technology questionnaire



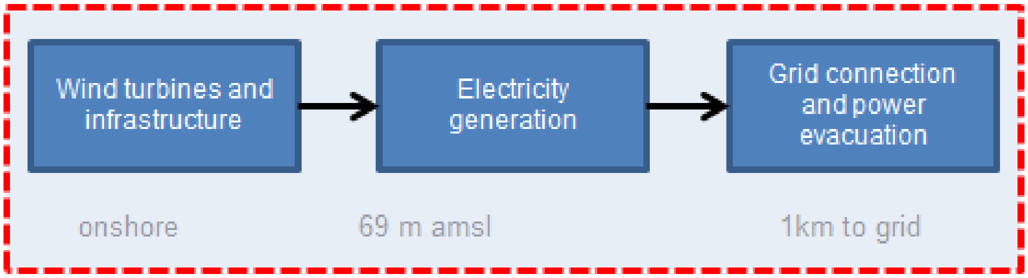
The variables inside the system boundaries are the parameters supplied to the technology provider in the questionnaire in order to size the plant for the specific output. These parameters (assumptions of the study) are summarised as follows (NASA, 2014):

- Project elevation is 1753 meters above mean sea level (Johannesburg, South Africa)
- Average annual solar radiation is 1960 kwh/m^2/year
- Solar panels should be ground mounted
- Grid connection point is a distance of 1km from the generation point

3.2.4. Wind

The system boundaries for the onshore wind measuring instrument are illustrated in the figure below.

Figure 3.5: System boundaries for onshore wind technology questionnaire



The variables inside the system boundaries are the parameters supplied to the technology provider in the questionnaire in order to size the plant for the specific output. These parameters (assumptions of the study) are summarised as follows (Ayodele *et al*., 2012: 35):

- Project elevation is 69 meters above mean sea level (Port Elizabeth, South Africa)
- Annual mean wind velocity = 5.099 m/s
- Annual variance in wind velocity = 10.585 m/s
- Most probable wind speed = 3.176 m/s
- Maximum wind speed = 9.314 m/s

- Wind power density = 196.625 W/m^2
- Grid connection point is a distance of 1km from the generation point

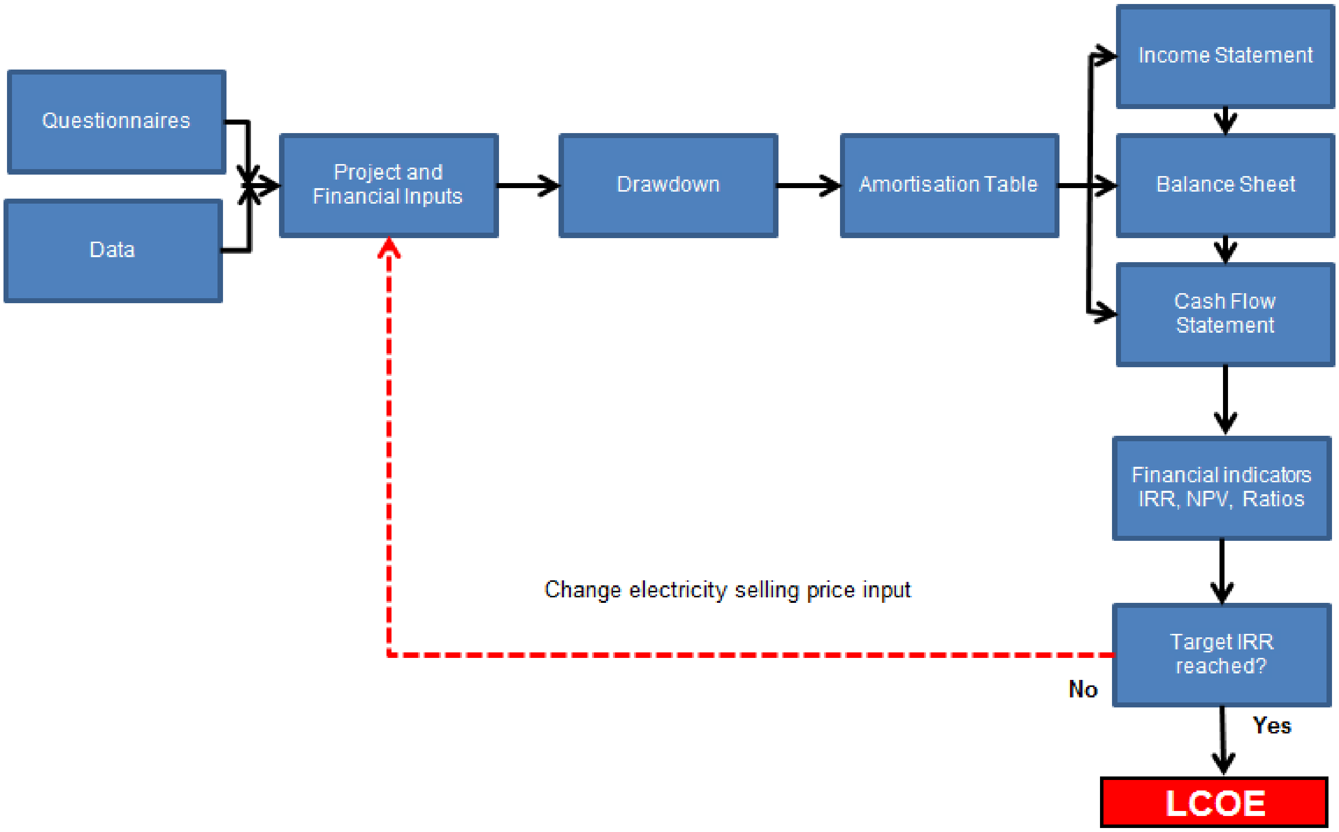
Wind speed characteristics and Weibull parameters for the shape factor (k) and scale factor (c) in Port Elizabeth was based on a study conducted by Ayodele *et al* (2012:35).

3.3. FINANCIAL MODEL

A financial model was developed in Microsoft Excel to determine the LCOE taking into consideration more complex financial structures, tax incentives, depreciation calculations and revenues and costs associated with by-products, not considered when calculating the SLCOE.

The overall layout of the financial model is given below:

Figure 3.6: Overall layout of financial model



The technical, commercial and timing information are obtained from the completed questionnaires and fed into the model as inputs. This information along with other inputs, data and control variables are captured in the “Project and Financial inputs” sheet. The total project cost and drawdown schedule from the questionnaire is used to calculate the monthly drawdown of capital funds during the construction period. The drawdown and interest on the debt portion is given in the “Drawdown” sheet. All construction interest is then capitalised as part of the total capital and the debt repayments are then calculated in the “Amortisation Table”. All revenues and costs are pulled into an annual income statement which takes into consideration all tax calculations and depreciation of the assets. The working capital assumptions and income is then fed into the annual balance sheet and all cash flows are calculated using the indirect method. After the annual cash flow is determined, the free cash flows are calculated, after all repayments, in the “Financial indicators” sheet which then calculates the project and investor internal rate of return over the project period. Finally, a Goal seek function is used to change the electricity selling price input (control variable) in order to achieve the required investor return. Once the investor return is reached, the electricity selling price is captured which is the levelised cost of energy for the scenario.

3.3.1. Discount rate

The discount rate (r) used in the financial model to calculate the SLCOE and LCOE is equal to the weighted average cost of capital (WACC) as given in the table below:

Table 3.1: Weighted average cost of capital

Description	Unit	Value
Debt	% of Total project cost	70%
Equity	% of Total project cost	30%
Interest Rate Paid	%/annum	11%
Required rate of return from Equity Investor(s)	%	18%
Income Tax	%	28%
Weighted Average Cost of Capital	%	**10.94%**

The WACC is calculated, using the formula given below (Megginson *et al*., 2010:143):

$$WACC = (\%Equity \times Cost\ of\ Equity) + [(\%Debt \times Cost\ of\ Debt) \times (1 - Corporate\ Tax\ rate)] \tag{5}$$

With the WACC known the CRF is calculated with equation 4 and equal to 0.1251.

Note that the discount rate is nominal and all expenses and revenues in the model are escalated separately with the Consumer Price Index (CPI) taken as 6% but with the option to change their growth rate independently for sensitivity analysis (Investec, 2014:3).

3.3.2. Total project cost

The total capital expenditure (Capex) is calculated by adding the total plant equipment cost and civil works and grid connection, taken from the completed questionnaires. All development costs and premia earned by the project developer for conducting any initial studies and environmental impact assessments as well as all costs associated in obtaining the necessary permits are accounted for as 6% of Capex, allowed by the Department of Energy in the SPIPPPP General Requirements (Department of Energy. 2013c). Additionally, and because of the nature of the information obtained from the questionnaires, a 5% contingency is added as a percentage of Capex. The Capex, development costs + premia and contingency are summated to give the total project cost which is used as the investment expenditure (I) in the SLCOE formula.

3.3.3. Tax and accounting depreciation

The depreciation of project costs used in calculating the annual tax payment by the project is taken as the accelerated wear and tear allowance or depreciation deduction for renewable projects as granted under section 11B of the Income Tax Act (58 of 1962) (SA, 1962). This is equal to 50:30:20 during the first three years as depreciation on the total project costs.

The accounting depreciation of all capitalised assets in the financial model is taken over the project lifetime equal to twenty years which matches the maximum off-take agreement for the electricity produced under the SPIPPPP (Department of Energy. 2013c).

3.3.4. Working capital

Working capital adjustments are made for accurate cash flow representation by setting the accounts receivable and accounts payable (debtor and creditor days) on 30 day terms, equal to 1 month. Provision is also made for a maintenance reserve, as required by the senior debt financiers, equal to 10% of the operations and maintenance costs taken from the questionnaires (Wärnelid, 2009). Additional provision is made for spares and consumables as 3% of the operations and maintenance costs. These provisions are recorded as current assets in the statement of financial position.

3.3.5. Revenue streams

Biogas and biomass technologies offer additional revenue streams as discussed in the overview of renewable technologies. The financial model was therefore constructed to allow for additional revenue streams in the form of digestate sales and a disposal fee for accepting and treating a waste stream for biogas that would normally be disposed of at a cost to the waste generator, typically in a landfill. For biomass, potential revenue streams other than electricity are disposal fees and ash sales. For all four technologies, the model also makes allowance for revenue from carbon credit sales either as carbon emission reduction credits or carbon tax credits, discussed in section 2.2. Another potential revenue stream applicable to all technologies is the sale of plant at the end of the contract period; however, the equipment salvage value was set to 0 as per the requirements of the SPIPPPP (Department of Energy, 2013c). Interest earned on deposits, specifically equity contributions, was set to 5% per annum (Standard Bank, 2014).

3.3.6. Cost of sales

The cost of sales is only relevant to biogas and biomass technologies and is in the form of water costs and fuel costs. For water, a purchase price of R12 per m^3 was used (Ekurhuleni, 2014b).

3.3.7. Operating expenses

The operations and maintenance (O&M) costs are taken from the completed questionnaires and added to a provision for administrative costs not accounted for by the participants in completing the questionnaires. The administrative costs are assumed to be 10% of the operations and maintenance costs. All inputs are summarised in the table under Annexure 2: Inputs and assumptions of financial model.

3.4. RESULTS AND DISCUSSION

The completed questionnaires for all four technologies are provided in Annexure 1. The simplified levelised cost of energy and results of the financial modelling will be discussed for each technology. Given the time consuming nature of running each model and one hundred scenarios with different inputs and controlled variables, a programme was written in Visual Basic for Applications to automate the model simulations and ensure accuracy of data transfer.

3.4.1. Biogas

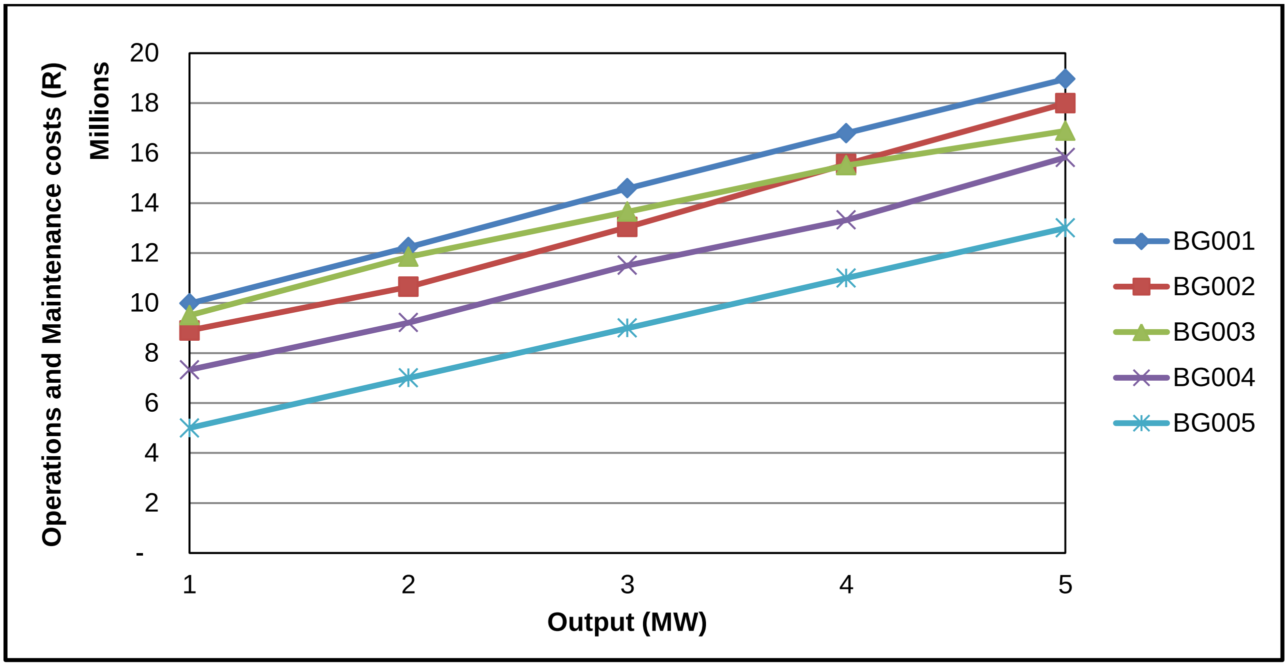
Five biogas questionnaires were completed by different technology providers and their results recorded by assigning each participant a different number starting at BG001 to BG005. From the biogas production and captive consumption supplied by each participant, the engine efficiency was calculated based on the lower heat value of methane gas.

Table 3.2: Engine efficiencies for different biogas participants

MW	BG001	BG002	BG003	BG004	BG005
1	34.9%	32.5%	35.9%	37.2%	38.3%
2	31.9%	32.8%	35.8%	37.2%	38.3%
3	29.0%	32.9%	35.9%	37.2%	38.3%
4	28.9%	32.2%	35.8%	37.2%	38.3%
5	28.8%	32.6%	34.5%	37.2%	38.3%

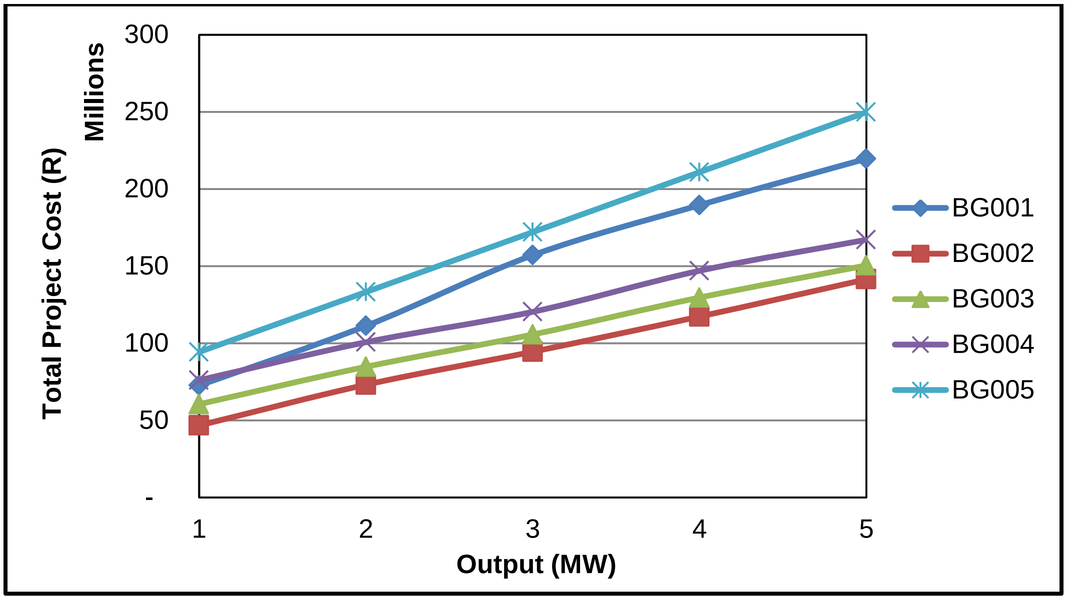
From the table it is apparent that BG005 has provided the most efficient gas engines and that, on average, BG001, the least efficient. The efficiency of different gas engine suppliers can vary significantly which is also evident from these results. The operations and maintenance costs provided by the participants are given in the figure below.

Figure 3.7: Operations and maintenance costs of biogas technologies



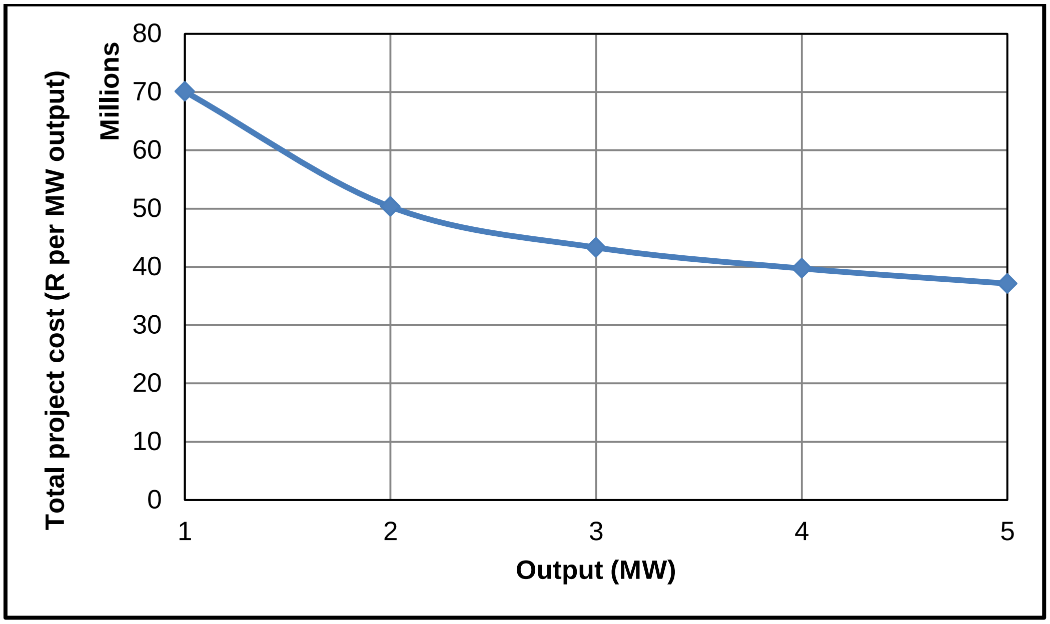
From the results it is evident that BG005 has the lowest O&M costs and BG001, the highest. With the exception of BG003, all the participants show a fairly linear trend in O&M costs over the range of outputs. The total project costs, including development and contingency for the five technology providers are given in the figure below:

Figure 3.8: Total project cost of biogas technologies



From the figure it is interesting to note that BG005 now has the highest project cost per MW output and that BG002, the lowest. The five participants also show a large variance in project cost and resemble a fairly linear trend over the range of outputs. The average total project cost for the five participants are given in Figure 3.9. From the figure it is interesting to note that although each of the technologies displayed fairly linear trends individually, economies of scale are clearly noticeable when plotting the average project cost over the range of outputs. From the figure it is clear that the average total project cost per MW output decreases considerably from R70 million per MW for a 1 MW output to R37 million per MW for a 5 MW installation.

Figure 3.9: Average total project cost of biogas technologies



With all the information provided by the five participants the SLCOE and LCOE was calculated with use of the financial model and the results depicted below:

Table 3.3: SLCOE and LCOE of biogas technologies (Fuel cost = 0)

	SLCOE						LCOE				
MW	**BG001**	**BG002**	**BG003**	**BG004**	**BG005**		**BG001**	**BG002**	**BG003**	**BG004**	**BG005**
1	2.42	1.92	2.20	2.20	2.19		2.31	1.84	2.11	2.06	2.05
2	1.65	1.28	1.44	1.43	1.55		1.56	1.22	1.38	1.33	1.45
3	1.43	1.06	1.15	1.16	1.33		1.34	1.02	1.10	1.08	1.24
4	1.27	0.97	1.02	1.04	1.22		1.19	0.93	0.96	0.97	1.14
5	1.16	0.91	0.91	0.96	1.16		1.09	0.88	0.87	0.90	1.08

From the table it is evident that the LCOE is lower than the SLCOE over the project lifetime, for all scenarios. BG002, BG003 and BG004 at 4 MW and 5 MW are all lower than the LCOE of Medupi according to Figure 2.23. The SLCOE and LCOE for the biogas technologies and a fuel cost of R100/tonne are given below:

Table 3.4: SLCOE and LCOE of biogas technologies (Fuel cost = R100/tonne)

SLCOE						LCOE				
MW	**BG001**	**BG002**	**BG003**	**BG004**	**BG005**	**BG001**	**BG002**	**BG003**	**BG004**	**BG005**
1	2.86	2.54	2.76	2.70	2.65	2.74	2.47	2.67	2.56	2.51
2	2.09	1.83	1.96	1.93	2.00	1.99	1.77	1.90	1.83	1.90
3	1.89	1.60	1.65	1.66	1.79	1.80	1.55	1.59	1.58	1.70
4	1.72	1.50	1.51	1.54	1.68	1.64	1.45	1.45	1.47	1.60
5	1.61	1.43	1.41	1.46	1.61	1.53	1.39	1.37	1.40	1.54

From the tables it is clear that none of the scenarios are able to compete with the LCOE of Medupi power station which highlights the sensitivity of the model to fuel cost. The LCOE for the biogas technologies at a disposal cost of R100/tonne is given as well as the LCOE at a fuel cost of 0 but a digestate selling price of R100/tonne. Note that the SLCOE is not given for these scenarios as the formula remains unchanged when considering revenue streams.

Table 3.5: LCOE of biogas technologies for additional revenue streams

LCOE (Disposal = R100/tonne)						LCOE (Digestate = R100/tonne)				
MW	**BG001**	**BG002**	**BG003**	**BG004**	**BG005**	**BG001**	**BG002**	**BG003**	**BG004**	**BG005**
1	1.87	1.22	1.55	1.56	1.60	2.21	1.67	1.95	1.92	1.93
2	1.12	0.67	0.86	0.83	0.99	1.46	1.07	1.23	1.19	1.32
3	0.88	0.48	0.59	0.58	0.78	1.24	0.87	0.95	0.94	1.11
4	0.74	0.40	0.48	0.46	0.68	1.09	0.78	0.83	0.83	1.01
5	0.65	0.36	0.37	0.40	0.62	0.99	0.73	0.72	0.76	0.95

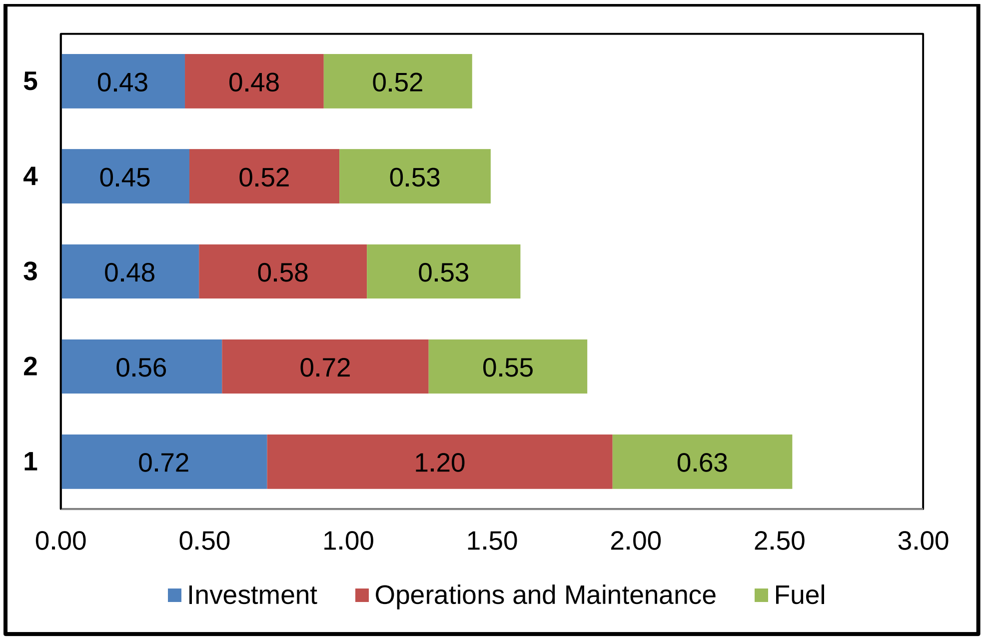
The table clearly indicates the greater sensitivity to disposal fee as revenue because the digestate is only a fraction of the total feed (~30% calculated from financial model). The LCOE for the biogas technologies with a fuel cost of 0 and an additional revenue stream in the form of a carbon tax incentive at R120/tonne CO_2 in 2015 is given in Table 3.6.

Table 3.6: LCOE of biogas technologies including carbon tax incentive

LCOE (Carbon tax of R120/tonne CO_2)					
MW	**BG001**	**BG002**	**BG003**	**BG004**	**BG005**
1	2.18	1.72	1.99	1.93	1.93
2	1.43	1.10	1.26	1.21	1.32
3	1.22	0.89	0.97	0.96	1.12
4	1.06	0.80	0.84	0.84	1.02
5	0.96	0.75	0.74	0.77	0.96

Table 3.6 indicates that carbon tax is able to contribute R0.12/kWh as an incentive to green technologies. From the results, the lowest LCOE was calculated for BG002. The breakdown of the SLCOE into its components of investment costs, O&M costs and fuel costs is given in the figure below:

Figure 3.10: SLCOE of BG002 at a fuel cost of R100/tonne

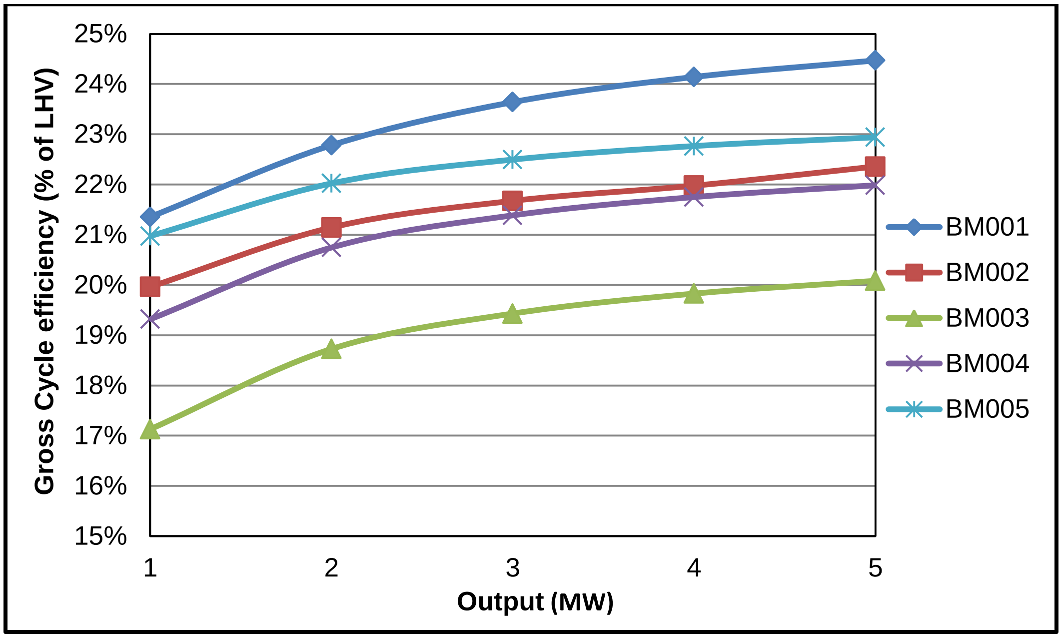


In summary, biogas technologies are able to compete with the LCOE of Medupi and are below the SPIPPPP price cap of R0.90/kWh, provided the fuel cost is 0 or the project is paid a disposal fee for the treatment of the waste stream.

3.4.2. Biomass

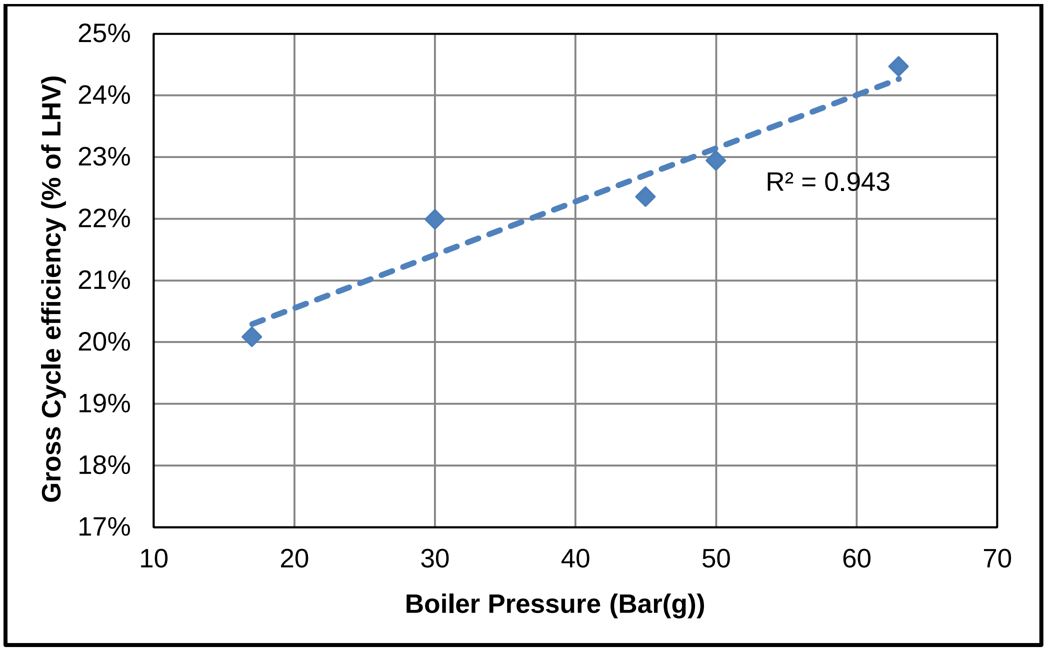
Five biomass questionnaires were completed by different technology providers and their results recorded by assigning each participant a different number starting at BM001 to BM005. From the biogas production and captive consumption supplied by each participant, the gross cycle efficiency was calculated based on the lower heat value of the fuel input. The results from the questionnaires are given in the figure below:

Figure 3.11: Gross cycle efficiencies of different biomass technologies



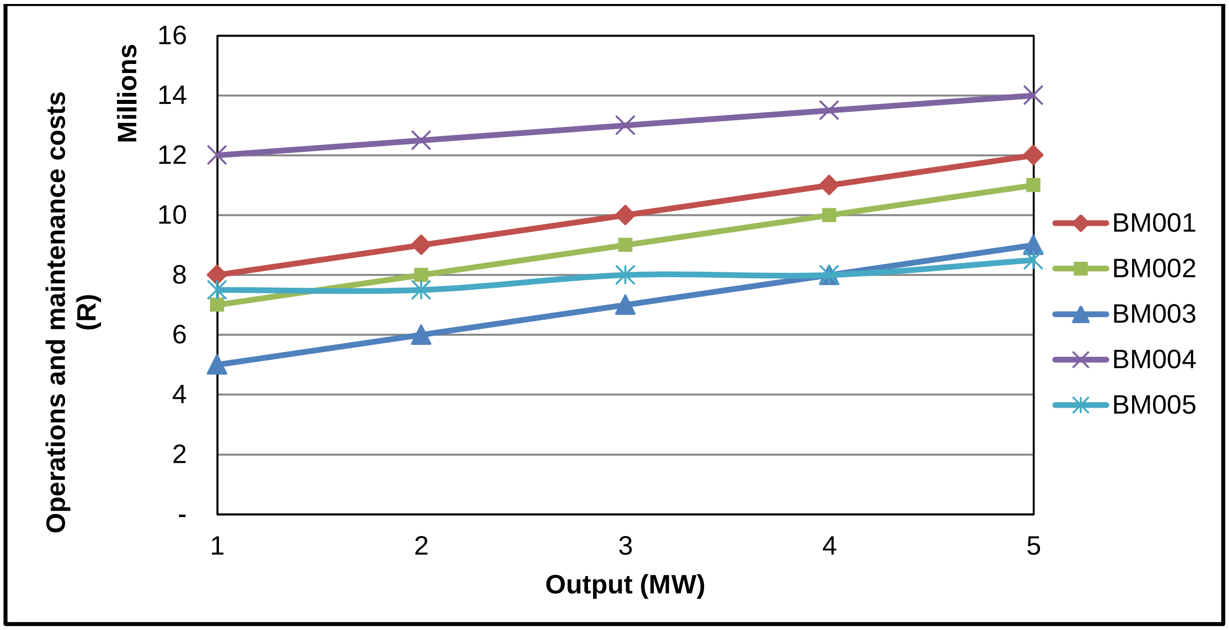
The figure indicates an increase in cycle efficiency with scale for each of the five participants. BM001 produced the highest cycle efficiency and BM003 the lowest. This correlates well with the boiler pressure supplied by the two participants as the boiler pressure for BM001 is 63 Bar(g) and 17 Bar(g) for BM003. The cycle efficiency was then plotted for the five participants at an output of 5 MW as a function of boiler pressure. The result is depicted in the figure below:

Figure 3.12: Gross cycle efficiency as a function of boiler pressure



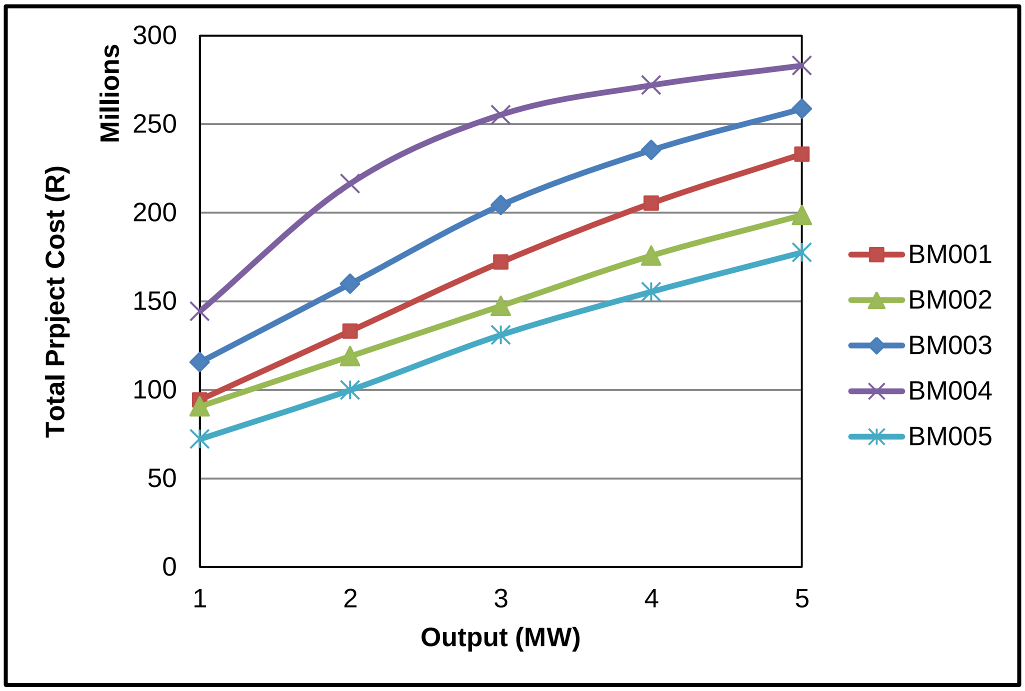
The figure displays a strong positive correlation between boiler pressure and gross cycle efficiency with a correlation coefficient of 0.97. The operations and maintenance costs for the five different biomass technology providers is given in the figure below:

Figure 3.13: Operations and maintenance costs of biomass technologies



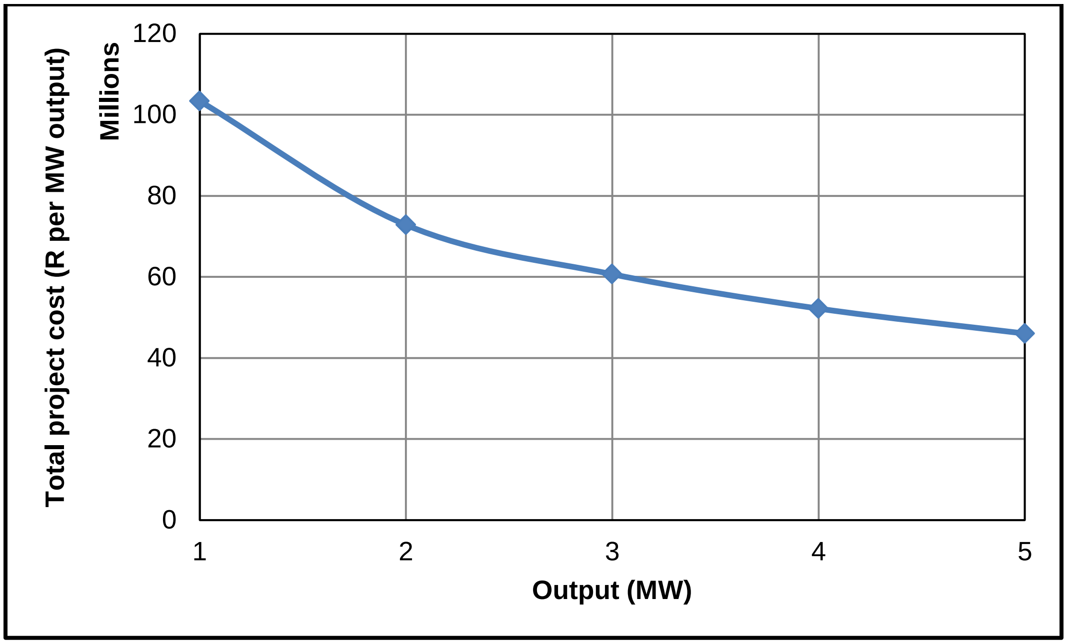
From the figure, BM003 provided the lowest O&M cost on average and BM004, the highest. BM005 showed the least sensitivity to scale as the slope of the curve remained fairly flat over the different outputs. Again, all the participants provided a fairly linear trend over the different set of outputs. The total project costs, including development and contingency for the five technology providers are given in the figure below:

Figure 3.14: Total project cost of biomass technologies



From the figure, BM004 provided the highest project cost for each output and BM005, the lowest. BM001, BM002 and BM005 showed a linear trend over the set of outputs whilst BM003 and BM004 Indicated a lower project cost per MW as the scale increased. The average total project costs for the five participants as a function of output is plotted over the set of outputs in the figure below:

Figure 3.15: Average total project cost of biomass technologies



From the figure economies of scale are clearly noticeable when plotting the average project cost over the range of outputs. From the figure it is clear that the average total project cost per MW output decreases considerably from R103 million per MW for a 1 MW output to R46 million per MW for a 5 MW installation. With all the information provided by the five participants the SLCOE and LCOE was calculated with use of the financial model and the results depicted below:

Table 3.7: SLCOE and LCOE of biomass technologies (Fuel cost = 0)

	SLCOE						**LCOE**			
MW	**BM001**	**BM002**	**BM003**	**BM004**	**BM005**		**BM001**	**BM002**	**BM003**	**BM004**	**BM005**
1	2.53	2.42	2.40	3.91	2.20		2.36	2.24	2.19	3.66	2.09
2	1.63	1.51	1.60	2.55	1.32		1.52	1.40	1.46	2.36	1.25
3	1.33	1.20	1.33	1.93	1.07		1.24	1.12	1.22	1.78	1.00
4	1.16	1.05	1.15	1.53	0.90		1.08	0.98	1.05	1.41	0.84
5	1.04	0.94	1.02	1.27	0.80		0.97	0.88	0.93	1.17	0.75

From the table, none of the biomass technologies is economically viable under the SPIPPPP price cap of R.140/kWh (Table 2.2) at a scale of 1 MW. At a scale of 2 MW, BM002 is viable at the price cap and BM005 at R1.25/kWh. At a scale of 5 MW, all the technologies are viable under the SPIPPPP and only BM004 is higher than the LCOE of Medupi power station. The effect of fuel cost on the LCOE was analysed for the five biomass technology providers is given below:

Table 3.8: SLCOE and LCOE of biomass technologies (Fuel cost = R100/tonne)

SLCOE						LCOE				
MW	**BM001**	**BM002**	**BM003**	**BM004**	**BM005**	**BM001**	**BM002**	**BM003**	**BM004**	**BM005**
1	2.76	2.66	2.65	4.15	2.43	2.59	2.48	2.44	3.90	2.33
2	1.82	1.70	1.80	2.75	1.51	1.70	1.59	1.66	2.56	1.43
3	1.50	1.38	1.52	2.11	1.24	1.40	1.29	1.40	1.96	1.17
4	1.32	1.22	1.33	1.70	1.06	1.23	1.15	1.23	1.58	1.00
5	1.19	1.10	1.19	1.44	0.96	1.12	1.04	1.11	1.34	0.91

From the table, the technologies show a great sensitivity to fuel cost and the increase in LCOE range from R0.15/kWh to R0.25/kWh for the technology providers, depending on the scale. However, even with the fuel cost, all the technologies were viable under the SPIPPPP at 5 MW and BM005 still lower than the LCOE of Medupi. To verify the effect of fuel cost another scenario was run for the five participants at R200/tonne input cost.

Table 3.9: SLCOE and LCOE of biomass technologies (Fuel cost = R200/tonne)

SLCOE						LCOE				
MW	**BM001**	**BM002**	**BM003**	**BM004**	**BM005**	**BM001**	**BM002**	**BM003**	**BM004**	**BM005**
1	2.99	2.89	2.90	4.39	2.66	2.82	2.72	2.69	4.14	2.56
2	2.00	1.89	2.01	2.94	1.69	1.88	1.78	1.86	2.75	1.62
3	1.66	1.55	1.71	2.28	1.41	1.56	1.47	1.59	2.13	1.35
4	1.47	1.39	1.51	1.87	1.23	1.39	1.31	1.41	1.75	1.17
5	1.34	1.27	1.37	1.60	1.12	1.27	1.21	1.29	1.50	1.07

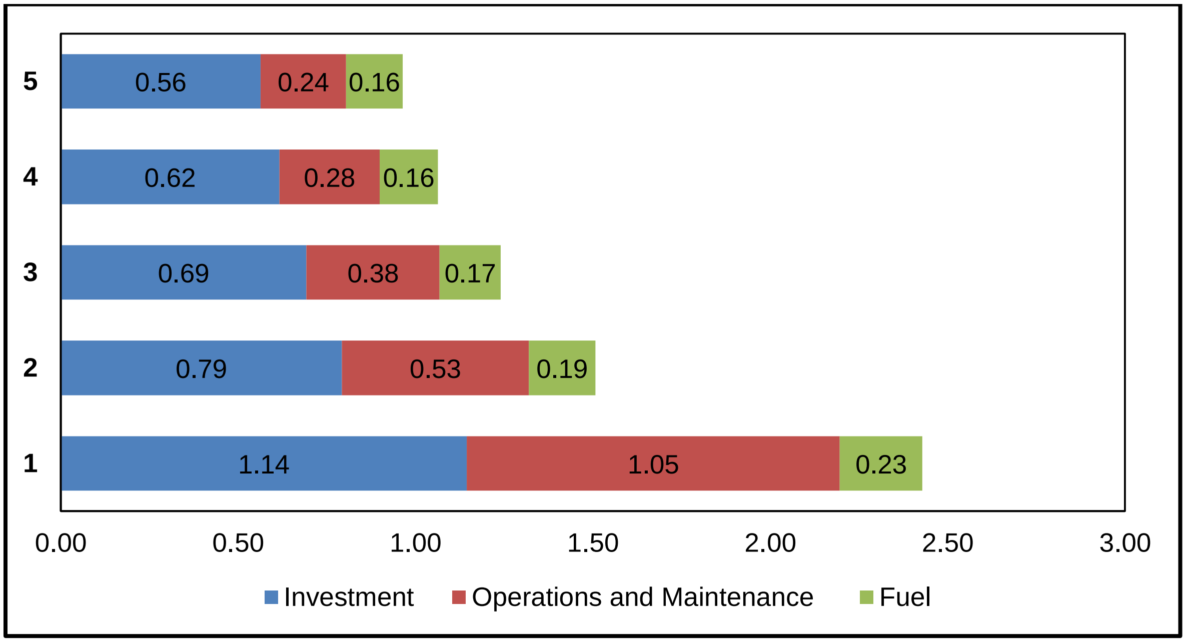
From the figure it is evident that the biomass technologies (excluding BM004) are still below the price cap of R1.40/kWh for the SPIPPPP at a scale of 5 MW. The effect of a carbon tax incentive at R120/tonne CO_2 in 2015 is indicated in the table below:

Table 3.10: LCOE of biomass technologies including carbon tax incentive

LCOE (Carbon tax of R120/tonne CO_2)					
MW	**BM001**	**BM002**	**BM003**	**BM004**	**BM005**
1	2.70	2.59	2.57	4.02	2.43
2	1.76	1.66	1.74	2.62	1.50
3	1.44	1.35	1.47	2.01	1.22
4	1.27	1.19	1.29	1.62	1.05
5	1.15	1.08	1.16	1.38	0.95

Table 3.10 confirms that carbon tax is able to contribute R0.12/kWh as an incentive to green technologies. From the results, the lowest LCOE was calculated for BM005. The breakdown of the SLCOE into its components of investment costs, O&M costs and fuel costs are given in the figure below:

Figure 3.16: SLCOE of BM005 at a fuel cost of R100/tonne



3.4.3. Solar

Five solar questionnaires were completed by different technology providers and those results recorded by assigning each participant a different number starting at PV001 to PV005. From the peak installed output and the power produced in kWh/year, the capacity factor was determined for each of the participants. The results from the questionnaires are given in the table below:

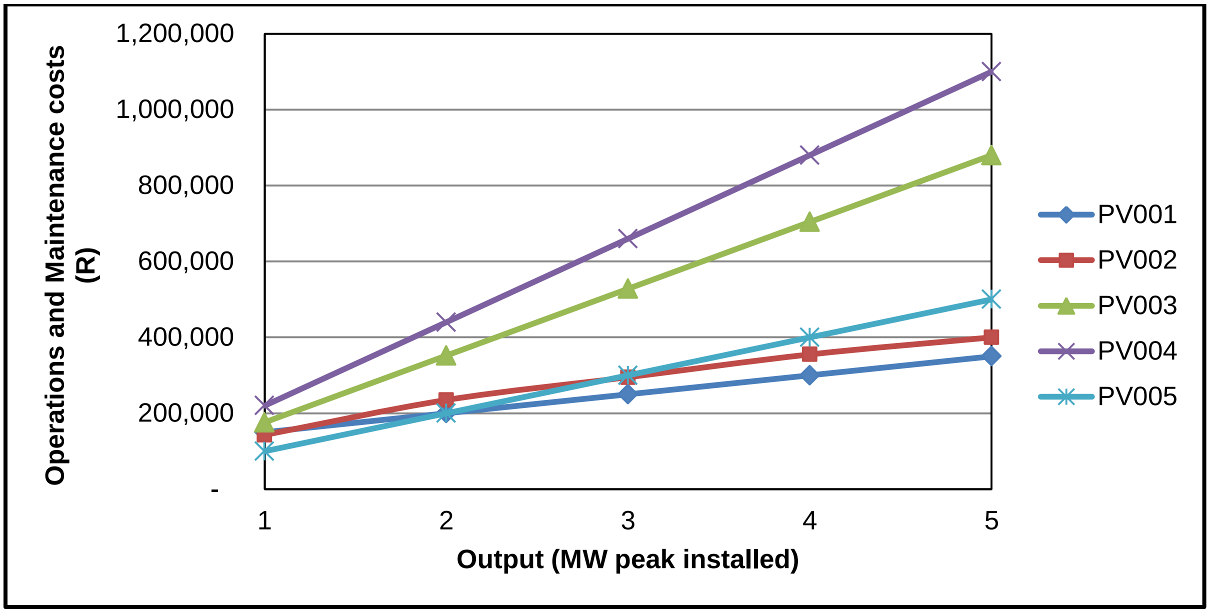
Table 3.11: Capacity factors of solar technologies for Johannesburg

MW	PV001	PV002	PV003	PV004	PV005
1	16.3%	19.6%	17.5%	15.5%	19.0%
2	16.3%	19.6%	17.5%	15.5%	19.0%
3	16.3%	19.6%	17.5%	15.5%	19.0%
4	16.3%	19.6%	17.5%	15.5%	19.0%
5	16.3%	19.6%	17.5%	15.5%	19.0%

The table reveals interesting results regarding the expected capacity factors of solar photovoltaic technologies in Johannesburg, South Africa with an average annual solar radiation of 1960 kwh/m^2/year. It is also interesting to note the range of capacity factors from 15.5% to 19.6%. All the participants supplied a constant value of capacity factor over the set of outputs which confirms the modularity of the technology.

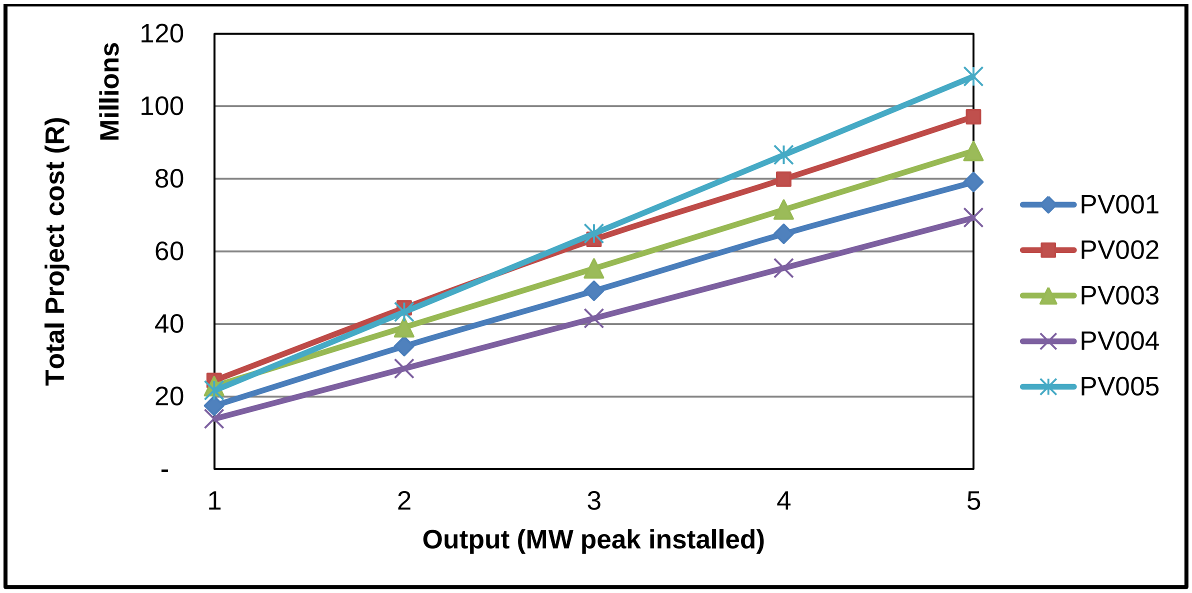
From the questionnaires, the average area per MW peak installed was calculated and found to be 6512 m^2 with the lowest 5991 m^2 and the highest 6926 m^2. The operations and maintenance costs for the five different solar photovoltaic technology providers is given in the figure below:

Figure 3.17: Operations and maintenance costs of solar photovoltaic technologies



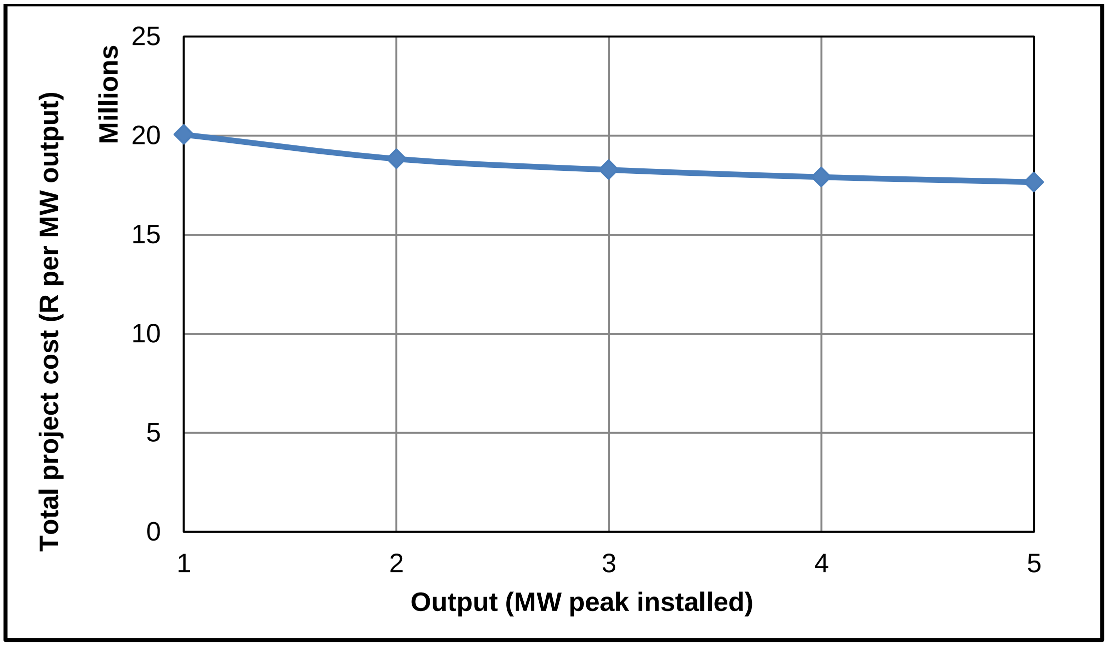
From the figure, PV004 provided the highest O&M cost and PV001, the lowest on average. PV001 and PV002 showed the lowest sensitivity to output and it is also evident that the O&M costs of solar photovoltaic technologies are magnitudes lower than biogas and biomass. The total project costs, including development and contingency for the five technology providers are given in the figure below:

Figure 3.18: Total project cost of solar photovoltaic technologies



From the figure, PV005 provided the highest total project cost and PV004, the lowest. All the participants showed a linear trend over the set of outputs. The average total project costs for the five participants as a function of output is plotted over the set of outputs in the figure below:

Figure 3.19: Average total project cost of solar photovoltaic technologies



From the figure it is noticeable that the average total project cost for solar technologies is not as sensitive to output compared with biogas and biomass and the unit cost only decreases slightly from R20 million a MW to R17.7 million a MW for a 5 MW installation. It can therefore be established that solar technologies display a modular cost per MW installation in contrast with biogas and biomass technologies. With all the information provided by the five participants the SLCOE and LCOE was calculated with use of the financial model and the results depicted below:

Table 3.12: SLCOE and LCOE of solar technologies

	SLCOE					LCOE				
MW	**PV001**	**PV002**	**PV003**	**PV004**	**PV005**	**PV001**	**PV002**	**PV003**	**PV004**	**PV005**
1	1.65	1.88	1.99	1.45	1.69	1.44	1.62	1.73	1.30	1.46
2	1.56	1.70	1.72	1.45	1.69	1.36	1.47	1.50	1.30	1.46
3	1.50	1.60	1.63	1.45	1.69	1.30	1.38	1.43	1.30	1.46
4	1.48	1.52	1.58	1.45	1.69	1.28	1.31	1.40	1.30	1.46
5	1.44	1.47	1.56	1.45	1.69	1.25	1.27	1.39	1.30	1.46

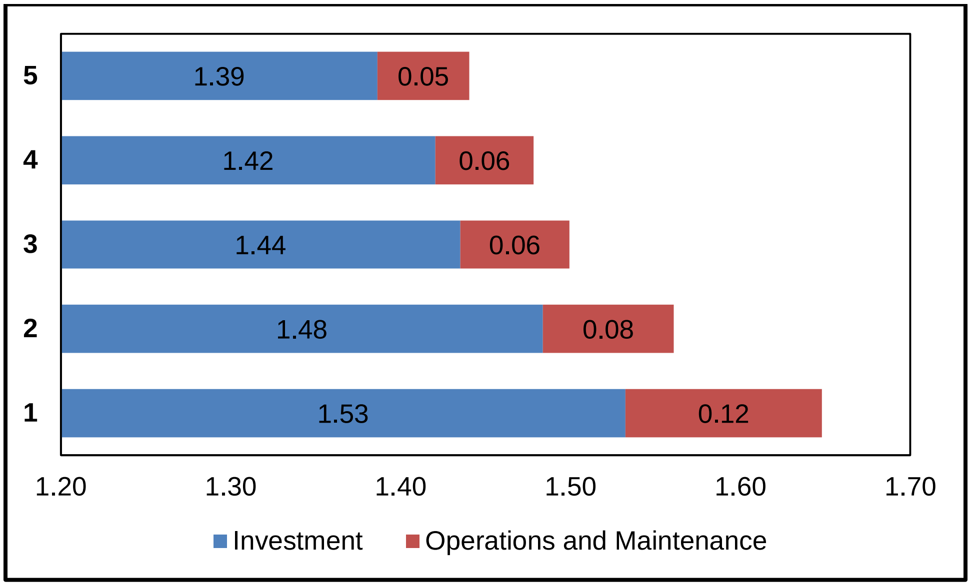
From the table it is evident that PV004 is economically viable under the SPIPPPP for all outputs and PV005 is above the price cap of R1.40/kWh for each scenario. On a 5 MW scale, all participants are below the price cap excluding PV005. The effect of a carbon tax incentive at R120/tonne CO_2 in 2015 is indicated in the table below:

Table 3.13: LCOE of solar technologies including carbon tax incentive

	LCOE (Carbon tax of R120/tonne CO_2)				
MW	**PV001**	**PV002**	**PV003**	**PV004**	**PV005**
1	1.32	1.50	1.61	1.17	1.34
2	1.23	1.35	1.38	1.17	1.34
3	1.18	1.26	1.31	1.17	1.34
4	1.16	1.19	1.28	1.17	1.34
5	1.13	1.15	1.26	1.17	1.34

From the table it is clear that the R0.12/kWh contribution of carbon tax results in only two scenarios that are above the SPIPPPP price cap namely; PV002 and PV003 for 1 MW output. None of the scenarios result in a LCOE that is below the LCOE of Medupi power station. From the results, the lowest LCOE was calculated for PV001. The breakdown of the SLCOE into its components of investment costs and O&M costs is given in the figure below:

Figure 3.20: SLCOE of PV001



3.4.4. Wind

Five wind questionnaires were completed by different technology providers and their results recorded by assigning each participant a different number starting at OW001 to OW005. From the peak installed output and the power produced in kWh/year, the capacity factor was determined for each of the participants. The results from the questionnaires are given in the table below:

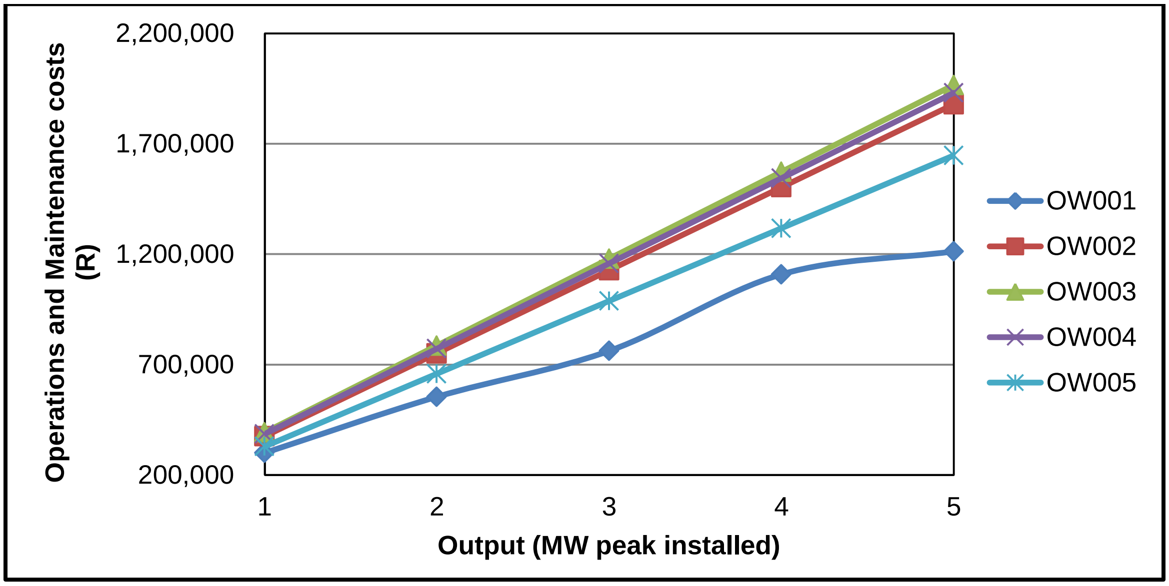
Table 3.14: Capacity factors of onshore wind technologies for Port Elizabeth

MW	OW001	OW002	OW003	OW004	OW005
1	34.2%	39.0%	32.0%	30.0%	37.3%
2	34.2%	39.0%	32.0%	30.0%	37.3%
3	34.0%	39.0%	32.0%	30.0%	37.3%
4	34.2%	39.0%	32.0%	30.0%	37.3%
5	34.0%	39.0%	32.0%	30.0%	37.3%

The table reveals interesting results regarding the expected capacity factors of onshore wind technologies in Port Elizabeth, South Africa, with an annual mean wind velocity of 5.099 m/s. It is also interesting to note the range of capacity factors from 30.0% to 39.0%. All the participants supplied a constant value of capacity factor over the set of outputs which confirms the modularity of the technology. It is also observed that the capacity factors for onshore wind are roughly double that of solar technologies.

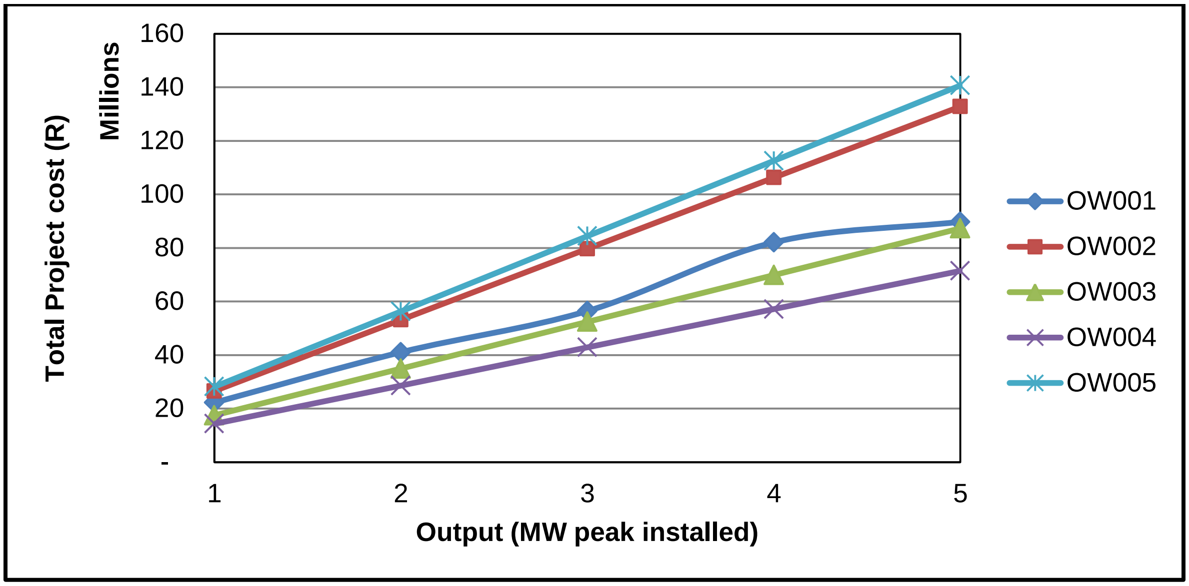
All the participants designed for a hub height of 80m to access the higher wind velocities at elevated heights. Rotor diameters varied depending on the technology provider. The operations and maintenance costs for the five different solar photovoltaic technology providers is given in the figure below:

Figure 3.21: Operations and maintenance costs of onshore wind technologies



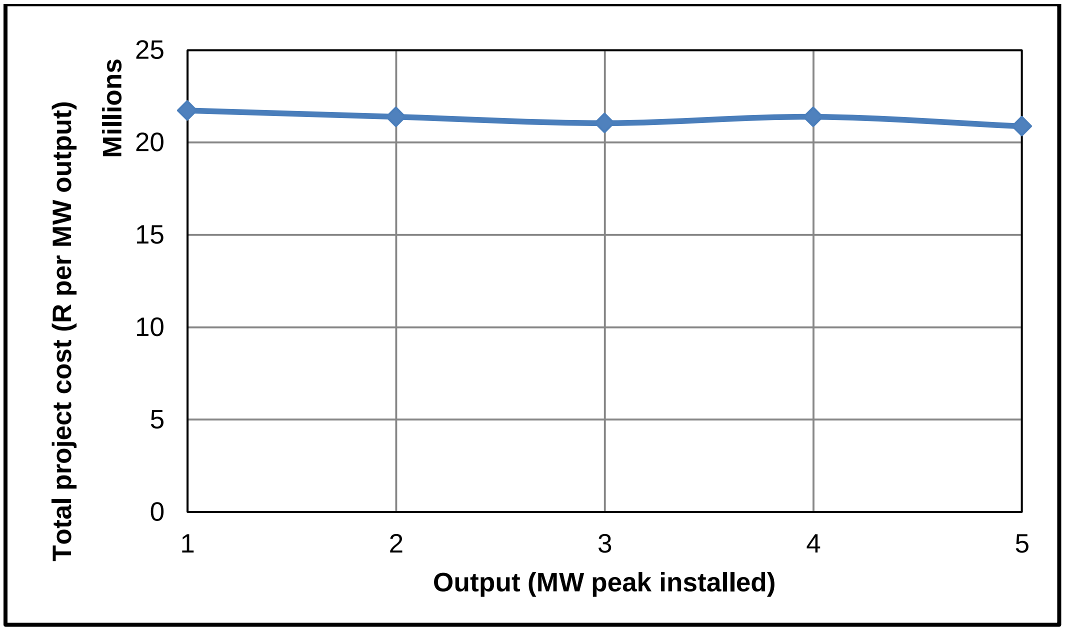
From the figure, OW003 provided the highest O&M cost and OW001 the lowest, on average. It is also evident that the O&M costs of onshore wind technologies are magnitudes lower than biogas and biomass. The total project costs, including development and contingency for the five technology providers are given in the figure below:

Figure 3.22: Total project cost of onshore wind technologies



From the figure, OW005 provided the highest total project cost and OW004, the lowest. All the participants showed a linear trend over the set of outputs. The average total project costs for the five participants as a function of output is plotted over the set of outputs in the figure below:

Figure 3.23: Average total project cost of onshore wind technologies



From the figure it is noticeable that the average total project cost for onshore wind technologies is not as sensitive to output compared with biogas and biomass and the unit cost remain flat, only decreasing slightly from R21.7 million a MW to R20.9 million a MW for a 5 MW installation. It can therefore be established that onshore wind technologies display a modular cost per MW installation in contrast with biogas and biomass technologies. With all the information provided by the five participants the SLCOE and LCOE was calculated with use of the financial model and the results depicted below:

Table 3.15: SLCOE and LCOE of wind technologies

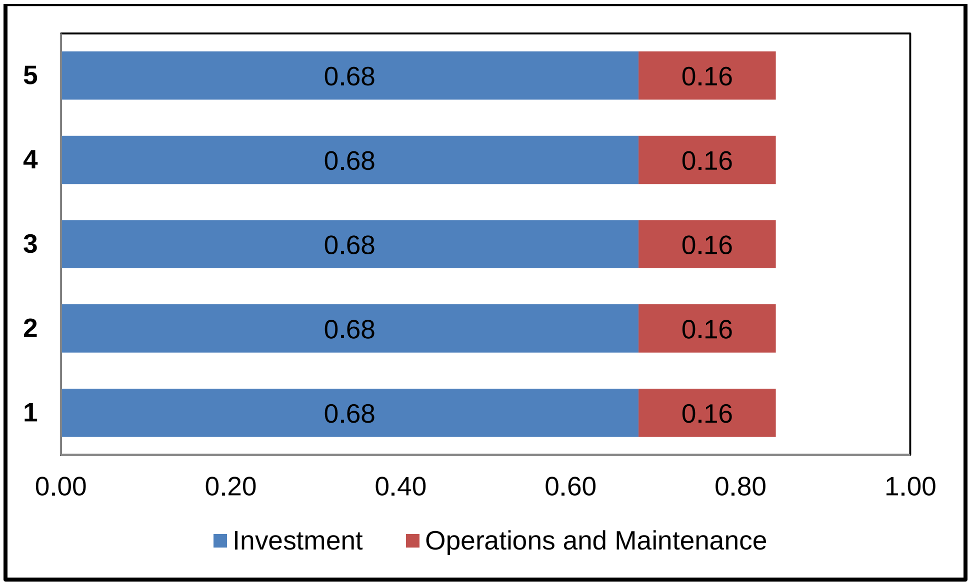
	SLCOE						LCOE				
MW	**OW001**	**OW002**	**OW003**	**OW004**	**OW005**		**OW001**	**OW002**	**OW003**	**OW004**	**OW005**
1	1.04	1.09	0.93	0.84	1.19		0.92	0.97	0.84	0.76	1.06
2	0.96	1.09	0.93	0.84	1.19		0.85	0.97	0.84	0.76	1.06
3	0.88	1.09	0.93	0.84	1.19		0.78	0.97	0.84	0.76	1.06
4	0.96	1.09	0.93	0.84	1.19		0.85	0.97	0.84	0.76	1.06
5	0.84	1.09	0.93	0.84	1.19		0.75	0.97	0.84	0.76	1.06

From the table it is evident that all onshore wind technologies are economically viable under the SPIPPPP for all outputs with the exception of OW005 that is above the price cap of R1.00/kWh as depicted in Table 2.2. Additionally all onshore wind technologies are below the LCOE of Medupi power station with the exception of OW005. The effect of a carbon tax incentive at R120/tonne CO_2 in 2015 is indicated in Table 3.16. From the table it is clear that the R0.12/kWh contribution of carbon tax results in all scenarios falling below the SPIPPPP price cap and all of the scenarios result in a LCOE that is below the LCOE of Medupi power station. From the results, the lowest LCOE was calculated for OW004. The breakdown of the SLCOE into its components of investment costs and O&M costs are given in the figure below:

Table 3.16: LCOE of onshore wind technologies including carbon tax incentive

LCOE (Carbon tax of R120/tonne CO_2)					
MW	**OW001**	**OW002**	**OW003**	**OW004**	**OW005**
1	0.79	0.84	0.72	0.63	0.94
2	0.72	0.84	0.72	0.63	0.94
3	0.66	0.84	0.72	0.63	0.94
4	0.72	0.84	0.72	0.63	0.94
5	0.62	0.84	0.72	0.63	0.94

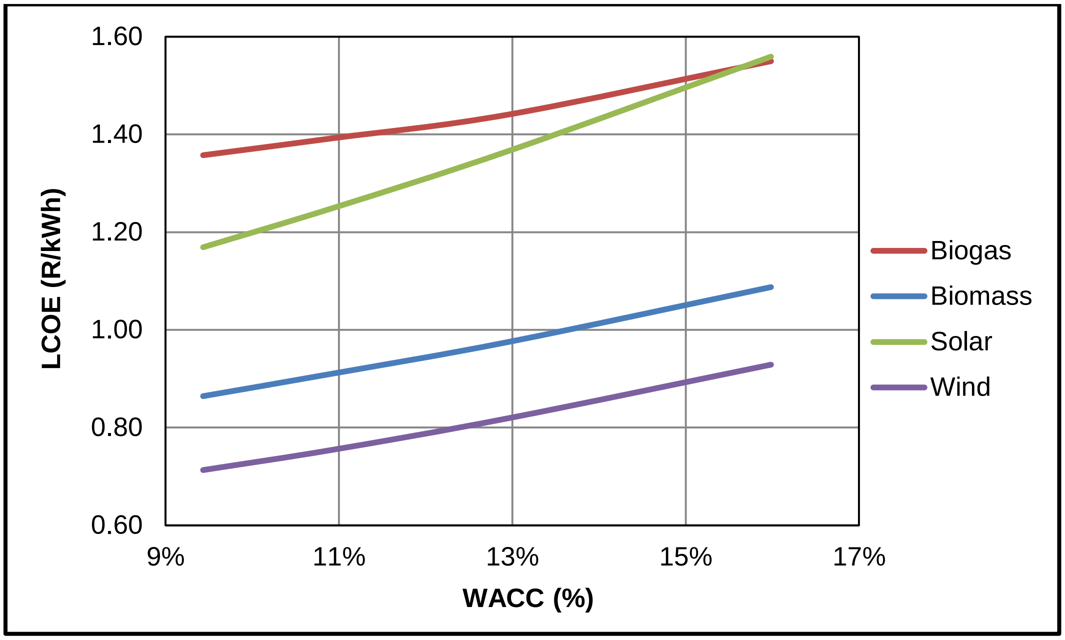
Figure 3.24: SLCOE of OW004



3.5. SENSITIVITY ANALYSIS

A sensitivity analysis was conducted on the LCOE of the four renewable energy technologies by changing the weighted average cost of capital (WACC). This was done by changing the debt to equity ratio or gearing in the financial model. The best scenario for each technology was selected, as discussed above, and compared to its base case. The results of the sensitivity analysis, on a scale of 5 MW, are given below:

Figure 3.25: Sensitivity of the LCOE to WACC on a scale of 5MW



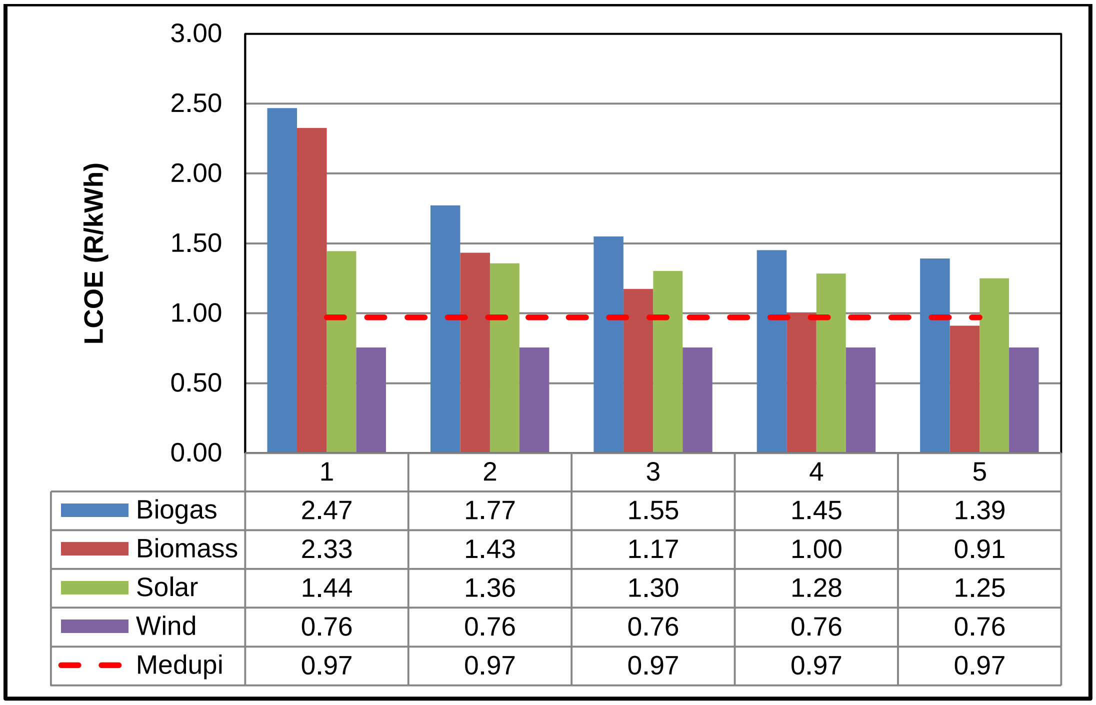
From the figure, solar technology is the most sensitive with the highest gradient per unit change in WACC. The LCOE increased, on average, by the following:

- 3.0 cents/kWh for every percentage increase in WACC for biogas
- 3.4 cents/kWh for every percentage increase in WACC for biomass
- 6.0 cents/kWh for every percentage increase in WACC for solar
- 3.3 cents/kWh for every percentage increase in WACC for wind

3.6. SUMMARY OF RESULTS

To summarise the results obtained in the section, the LCOE of the four main technologies at each output is consolidated in Figure 3.26. The fuel cost of biogas and biomass was at R100/tonne and carbon tax incentives were not considered.

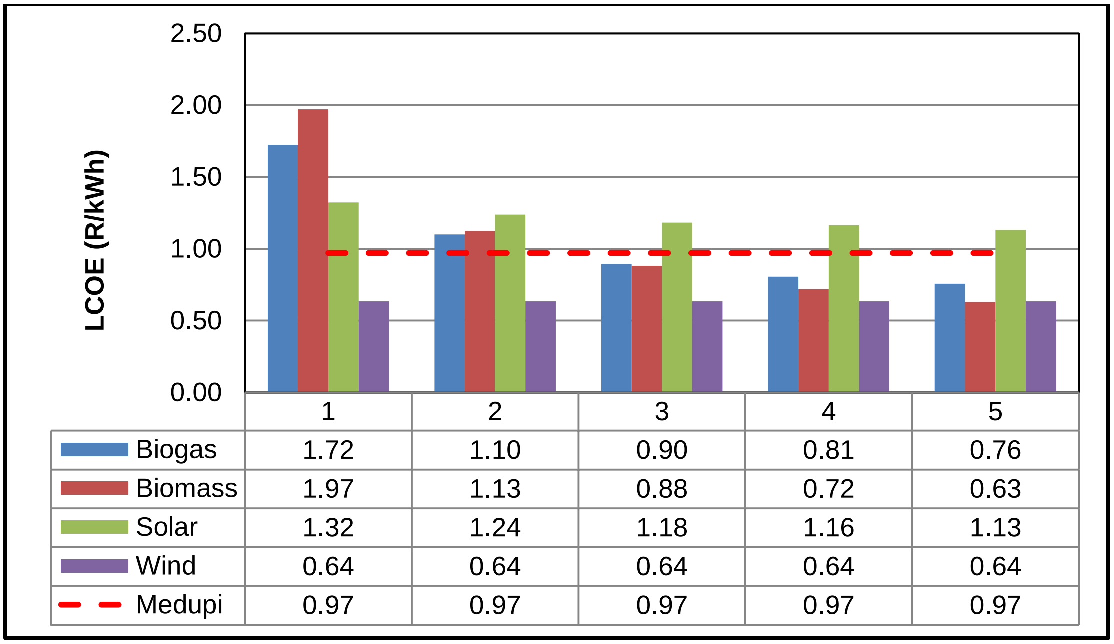
Figure 3.26: Summary of LCOE for renewable technologies



	1	2	3	4	5
🟦 Biogas	2.47	1.77	1.55	1.45	1.39
🟥 Biomass	2.33	1.43	1.17	1.00	0.91
🟩 Solar	1.44	1.36	1.30	1.28	1.25
🟪 Wind	0.76	0.76	0.76	0.76	0.76
– – Medupi	0.97	0.97	0.97	0.97	0.97

The LCOE of the four technologies is given below, including a carbon tax incentive and at no fuel cost to the biogas and biomass technologies.

Figure 3.27: Summary of LCOE with carbon tax and at no fuel cost

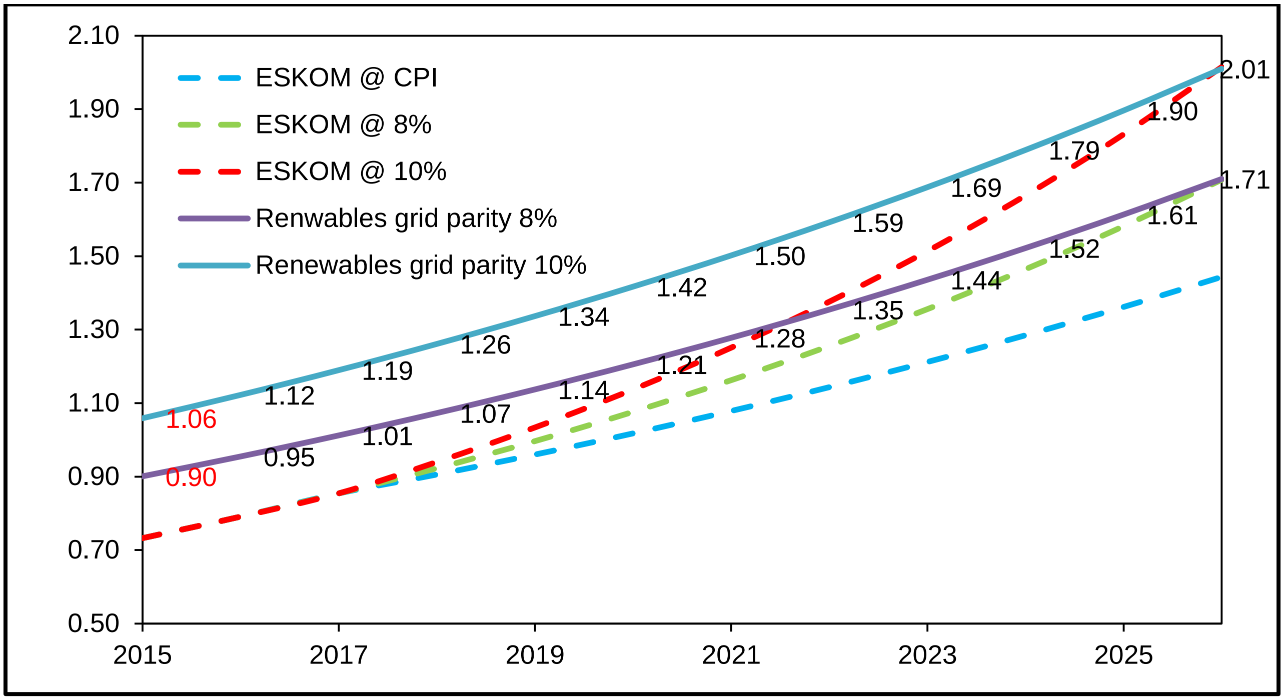


	1	2	3	4	5
🟦 Biogas	1.72	1.10	0.90	0.81	0.76
🟥 Biomass	1.97	1.13	0.88	0.72	0.63
🟩 Solar	1.32	1.24	1.18	1.16	1.13
🟪 Wind	0.64	0.64	0.64	0.64	0.64
– – Medupi	0.97	0.97	0.97	0.97	0.97

From the figures it is clear that, even on a small scale, the LCOE of onshore wind technology is lower than the LCOE of Medupi. Without the inclusion of carbon tax incentives and at a fuel cost of R100/tonne for biogas and biomass, the LCOE of biomass is still lower than that of Medupi on a scale of 5 MW. With the inclusion of carbon tax and at no fuel cost, biogas and biomass technologies are lower than the LCOE of Medupi from a scale of 3 MW. Even with the inclusion of carbon tax, solar photovoltaic technologies are unable to compete with the LCOE of Medupi mainly due to the weak Rand as solar technologies show the greatest sensitivity to an increase in project cost and cost of capital as illustrated in Figure 3.25: Sensitivity of the LCOE to WACC on a scale of 5MW

With the projection of the nominal LCOE fixed at CPI for the project lifetime of twenty years, it is important to understand at which current rate the renewable technologies will be at a grid parity with Eskom in future. With the MYPD3 approved as illustrated in Figure 2.10, three potential scenarios are given in terms of Eskom's increases for the next ten years following the MYPD3 period. The first projection assumes CPI linked increases after the MYPD3; the second assumes ten increases of 8% per annum and the third, ten increases of 10% per annum. The required LCOE of renewable technologies to be on grid parity for the three scenarios are given in Figure 3.28. With the Eskom increases at 8% per annum for ten years after the MYPD3 period, a current LCOE of R0.90/kWh is required to be on grid parity at the end of the period. With reference to Figure 3.27, biogas and biomass are below this rate from a scale of 3 MW and wind is already below the current grid price of R0.68/kWh. With the Eskom increases at 10% per annum for ten years after the MYPD3 period, a current LCOE of R1.06/kWh is required to be on grid parity at the end of the period. With this projection, biomass is below the rate from a scale of 4 MW without the inclusion of carbon tax incentives and at a fuel cost of R100/tonne. If Eskom's increases are to follow CPI after the MYPD3, wind at all outputs regardless of carbon tax incentives, biogas at 5 MW and biomass from a scale of 4 MW fall below the grid price provided there are no fuel cost and a carbon tax benefit for the two base load technologies.

Figure 3.28: Grid parity price of renewable technologies



In conclusion, the empirical research study has proven the validity of arguments in favour of renewable technologies on a small scale to promote a decentralised grid. The study has proven, even on a small scale applicable to the SPIPPPP, that wind energy is a more cost effective resource of new power than coal and in some instances, the base load technologies of biogas and biomass are also able to challenge the LCOE of Medupi coal fired power station.

With the three price projections for Eskom given in Figure 3.28, it is evident that renewable technologies will be in a position to reach grid parity and even fall below the grid price in the next ten years following Eskom's MYPD3 period.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1. SUMMARY OF FINDINGS

During the past financial year, Eskom faced great challenges in keeping the lights on and suffered higher than expected increases in operational expenditure due to the significant reliance placed on the OCGT fleet at a cost of R2.92 per kWh generated. The load factor for the OCGT fleet was 17.16% in 2014 against a budgeted load factor of 6.08% which contributed to 64% of its total 14.2% increase in primary energy costs (ESKOM, 2014a:107).

In strong contrast, the weighted average cost of renewable energy in the procurement programme has declined rapidly from R2.28 per kWh in the first window to R1.43 in the second window and then even further to below R1.00 per kWh in the third bid window. The combined cost of procuring renewable energy under the REIPPPP, based on April 2013 pricing, is R1.56 per kWh and it is remarkable how the cost of wind energy has reduced to R0.74 per kWh under bid window three due to the fierce competitive bidding process.

With the abundance of coal, South Africa’s cost of electricity has historically been among the lowest in the world, but a lack of infrastructure planning has led to recent increases far exceeding inflation. In addition, the majority of the state owned utility’s sales (41.9%) are to municipalities who sell the electricity onto smaller industries and domestic users at an inflated rate. Domestic users residing in Ekurhuleni are currently paying R1.27 per kWh which is 187% more than the weighted average tariff that Eskom is selling the electricity to its clients (Ekurhuleni, 2014a).

The estimates for nominal new Eskom coal power range from NERSA’s 97c/kWh to Standard Bank’s estimate that Kusile will cost R1.38/kWh in 2019, when it is commissioned. These revelations that electricity from Medupi could come in at an estimated 97c/kWh suggest South Africa could have gotten better value from renewable technologies such as wind (Gets & Mhlanga, 2013:18). To further add to this, the LCE for Medupi does not include Carbon Tax set to contribute another R0.12/kWh as from 1 January, 2016 (SAIT, 2014).

From the literature study it is clear that wind (R0.74/kWh) and solar (R0.99/kWh) under the REIPPPP are competitive with the levelised cost of Eskom's new build coal power plants and that wind, in particular, is even more cost effective than the grid price in 2017.

The empirical study evaluated these technologies along with biomass and biogas on a smaller scale of 1 MW to 5 MW with specific focus on the price caps per technology for the SPIPPPP. The information obtained from the empirical study (on a smaller scale) can then be used to determine the viability of renewable independent power production in its entirety.

From the empirical study the following key findings were made:

4.1.1. Biogas

- The efficiency of the different gas engine suppliers varied significantly from 28.8% to 38.3% based on the lower heat value of methane gas. The efficiency had a significant impact on the quantity of substrate feed required to produce the set of outputs.
- Economies of scale are clearly noticeable when plotting the average project cost over the range of outputs. The average total project cost per MW output for the five biogas participants decreased considerably from R70 million per MW for a 1 MW output to R37 million per MW for a 5 MW installation.
- Biogas technology offers the opportunity to earn additional revenue from a disposal cost for treating the waste stream as most of the organic waste streams, ideal for anaerobic digestion, are landfilled at a transport and disposal cost to the waste generator. Additionally, the excess heat and digestate can also be sold to supplement the electricity income.
- At fuel cost of zero, biogas technology at a scale of 4 MW and 5 MW are all lower than the LCOE of Medupi; however, at a fuel cost of R100/tonne, none of the scenarios were below the LCOE of Medupi or the price cap of R0.90/kWh under

the SPIPPPP. Even at a fuel cost of zero (assuming no alternative revenue), biogas technology was below the price cap only at a scale of 5 MW which indicates an aggressive price model from the DOE or the assumption that alternative revenue streams are part and parcel of biogas technology.

- With revenue from disposal at R100/tonne, the biogas technologies were below the price cap of the SPIPPPP at a scale of 2 MW and the LCOE was as low as R0.36/kWh at a scale of 5 MW which is far below the current grid price of R0.68/kWh. Biogas technology was below the LCOE of Medupi from a scale of 3 MW for this scenario which excluded the sale of digestate as fertiliser.
- At a revenue for digestate sales of R100/tonne (assuming no cost or revenue on the substrate), the LCOE was below Medupi from a scale of 3 MW and equal to R0.72/kWh on a scale of 5 MW. The results confirm a greater sensitivity to disposal fee as revenue because the digestate constitutes roughly 30% of the total feed, depending on the putrescibility of the waste.
- Biogas technologies are therefore able to compete with the LCOE of Medupi and are below the SPIPPPP price cap of R0.90/kWh, provided the fuel cost is 0 or the project is paid a disposal fee for the treatment of the waste stream.
- A combination of additional revenue streams from the disposal fee and sale of digestate makes biogas a very attractive technology in waste management practices as the net result of electricity sales could be regarded as supplementary and not the primary objective on which the business case is established.

4.1.2. Biomass

- An increase in cycle efficiency with scale for each of the five participants was observed with the efficiency being a function of boiler pressure. A strong positive correlation between boiler pressure and gross cycle efficiency was found with a correlation coefficient of 0.97.
- Economies of scale are clearly noticeable when plotting the average project cost over the range of outputs. The average total project cost per MW output for the

five biomass participants decreased considerably from R103 million per MW for a 1 MW output to R46 million per MW for a 5 MW installation.

- At a fuel cost of zero, none of the biomass technologies is economically viable under the SPIPPPP price cap of R.140/kWh on a scale of 1 MW. On a scale of 5 MW, all the technologies are viable under the SPIPPPP and only BM004 was higher than the LCOE of Medupi power station.
- An increase in fuel cost of R100/tonne resulted in an increase of the LCOE ranging from R0.15/kWh to R0.25/kWh, depending on the scale. However, even with the fuel cost taken into consideration, all the technologies were viable under the SPIPPPP at 5 MW and BM005 still lower than the LCOE of Medupi. With a fuel cost of R200/tonne, biomass was still below the price cap of R1.40/kWh for the SPIPPPP at a scale of 5 MW.

4.1.3. Solar

- The expected capacity factors of solar photovoltaic technologies in Johannesburg, with an average annual solar radiation of 1960 kwh/m^2/year, were between 15.5% and 19.6%. All the participants supplied a constant value of capacity factor over the set of outputs which confirms the modularity of the technology.
- From the questionnaires, the average area per MW peak installed was calculated and found to be 6512 m^2 with the lowest 5991 m^2 and the highest 6926 m^2.
- The average total project cost for solar technologies is not as sensitive to output compared with biogas and biomass and the unit cost only decreased slightly from R20 million a MW to R17.7 million a MW for a 5 MW installation. It can therefore be established that solar technologies display a modular cost per MW installation in contrast to biogas and biomass technologies.
- From the results, PV004 is economically viable under the SPIPPPP for all outputs and PV005 is above the price cap of R1.40/kWh for each scenario. On a 5 MW scale, all participants are below the price cap excluding PV005.
- The R0.12/kWh contribution of carbon tax results in only two scenarios that are above the SPIPPPP price cap namely; PV002 and PV003 for a 1 MW output.

None of the scenarios results in a LCOE that is below the LCOE of Medupi power station.

- The breakdown of the SLCOE for PV001 into its constituents shows that although the total project cost did not provide evidence of economies of scale, the decrease in SLCOE at higher outputs demonstrates that there are benefits of scale for solar technologies pertaining to the O&M costs.

4.1.4. Wind

- The expected capacity factors of onshore wind technologies in Port Elizabeth, with an annual mean wind velocity of 5.099 m/s, ranged between 30.0% and 39.0%. All the participants supplied a constant value of capacity factor over the set of outputs which confirms the modularity of the technology.
- The capacity factors for onshore wind are roughly double that of solar technologies taking into consideration the geographical locations.
- All the participants designed for a hub height of 80m to access the higher wind velocities at elevated heights.
- The average total project cost for onshore wind technologies is not as sensitive to output compared to biogas and biomass and the unit cost remain flat, only decreasing slightly from R21.7 million a MW to R20.9 million a MW for a 5 MW installation. It can therefore be established that onshore wind technologies display a modular cost per MW installation in contrast to biogas and biomass technologies.
- All onshore wind technologies are economically viable under the SPIPPPP for all outputs with the exception of OW005 that is above the price cap of R1.00/kWh.
- All onshore wind technologies are below the LCOE of Medupi power station with the exception of OW005. The effect of a carbon tax incentive results in all scenarios falling below the SPIPPPP price cap and all of the scenarios result in a LCOE that is below the LCOE of Medupi power station.
- The lowest LCOE was calculated for OW004 at R0.76/kWh with a SLCOE of R0.84/kWh. The constant LCOE for OW004 proves the modularity of the technology and did not indicate any benefits of scale.

4.1.5. Combined results

- Solar technology is the most sensitive to the weighted average cost of capital showing an increase of 6.0 cents/kWh for every percentage increase in WACC; roughly double that of the other technologies.
- Onshore wind yields the lowest LCOE of the four main renewable energy technologies and is lower than the LCOE of Medupi.
- Without the inclusion of carbon tax incentives and at a fuel cost of R100/tonne for biogas and biomass, the LCOE of biomass is still lower than that of Medupi on a scale of 5 MW.
- With the inclusion of carbon tax and at no fuel cost, biogas and biomass technologies are lower than the LCOE of Medupi from a scale of 3 MW.
- On average, solar yields the highest LCOE of the four technologies. Even with the inclusion of carbon tax, solar photovoltaic technologies are unable to compete with the LCOE of Medupi mainly due to the weak Rand as these technologies show the greatest sensitivity to an increase in project cost and cost of capital.
- With Eskom projected increases at 8% per annum for ten years after the MYPD3 period, a current LCOE of R0.90/kWh is required for renewable energy to be on grid parity at the end of the period. Biogas and biomass are below this rate from a scale of 3 MW and wind is already below the current grid price of R0.68/kWh.
- With the Eskom increases at 10% per annum for ten years after the MYPD3 period, a current LCOE of R1.06/kWh is required to be on grid parity at the end of the period. With this projection, biomass is below the rate from a scale of 4 MW without the inclusion of carbon tax incentives and at a fuel cost of R100/tonne.
- If Eskom's increases are to follow CPI after the MYPD3, wind at all outputs regardless of carbon tax incentives, biogas at 5 MW and biomass from a scale of 4 MW fall below the grid price provided there are no fuel cost and a carbon tax benefit for the two base load technologies.

4.2. RECOMMENDATIONS

Alternative solutions should be explored to decrease the load factor of Eskom's open cycle gas turbine fleet in the short to medium term. Biogas lends itself as a fossil fuel replacement and cost effective source of energy if integrated with waste management practices. Additionally, biogas technology offers flexibility in output and production as an energy storage facility. Government should therefore implement regulations to avoid organic, putrescible materials from being landfilled and implement strategies for the development of biogas facilities and storage of biogas to be used for power generation during periods of peak demand. If integrated correctly, the by-products from a biogas plant can subsidise the electricity to the extent that the tariff will be far lower than the current grid price.

South Africa's abundance of renewable energy resources is currently untapped and even with the revised IRP 2010; the future energy mix is still dominated by coal and nuclear. Complete feasibility studies should be conducted into the viability and sustainability of implementing the correct combination of different renewable technologies so that the contribution will decrease the country's dependence on large centralised power stations. In order for renewable energy to be truly meaningful and sustainable, base load technologies such as biomass and biogas will have to be integrated with solar and wind which has dominated the first three rounds of the REIPPPP in terms of MW contributions. Energy storage in the form of CSP and biogas will also be important to ensure a stable grid even when renewable energy contributions exceed 25% of the total energy supply. Future wind farms should be selected based on their locality in different wind regimes of the country in order to increase the overall load factor of wind energy across the country. This will also assist the role of the distribution centre as demand fluctuations have to be balanced by the supply feeding the grid. The allocation of renewable energy for wind, solar and CSP should therefore be revised in the IRP 2010 according to the sustainability of the grid to avoid renewable power stations from becoming redundant when large coal power stations take priority.

The empirical study has clearly proven the viability of renewable energy on a small scale between 1 and 5 MW. The current allocation of 200 MW under the SPIPPPP should therefore be reconsidered as it is too small to justify development of manufacturing facilities in order to increase the local content of such renewable facilities. If a meaningful allocation can be made it would incentivise local investment into the manufacturing of solar panels and wind turbines and decrease the risk and exposure to foreign exchange. Solar photovoltaic technology's high sensitivity to capital cost can be decreased as a result.

The average tariff for a domestic user far exceeds Eskom's weighted average cost and grid price. Local municipalities in large urbanised areas should evaluate the viability of implementing a smart grid system with FITS on a domestic and small to medium industrial scale. This will decrease each region's dependence on large coal fired power stations and fast track the country's evolution towards a decentralised grid.

The current legislation pertaining to environmental authorisation and obtaining the necessary permits for the implementation of renewable energy projects is a barrier to growth. These permits are costly and take a long time to obtain. The development of renewable projects, from an investor's perspective, is costly and at risk for a long period of time which results in fewer players entering the marketplace. Government can assist project developers in establishing a framework of specific environmental regulations for renewable projects to fast track development. Furthermore, grant funding and the implementation of Carbon tax policies will push industry towards change and result in more competition which will ultimately benefit the country through lower energy prices.

The finance of renewable energy projects is another barrier to the growth of the industry. Better financial instruments and funding mechanisms, driven by government, will decrease the WACC and hence lower the LCOE of renewable technologies even further.

4.3. ACHIEVEMENT OF THE STUDY'S OBJECTIVES

The primary objective of the study was to determine whether renewable energy is price competitive with the current state owned utility, Eskom, by not only analysing the current scenario but also the future price projection and point where renewable energy is on a parity with the grid price.

The study has successfully concluded that renewable energy is able to compete with the Eskom New Build Programme by comparing the LCOE of the four main technologies namely, biogas, biomass, solar and wind with the LCOE of Medupi coal fired power station. The literature study found that wind under the REIPPPP was below the LCOE of Medupi. From the study it is clear that wind and solar are competitive with the levelised cost of Eskom's new build coal power plants and that wind, in particular, is even more cost effective than the grid price in 2017. The empirical study focused on the SPIPPPP and concluded that the LCOE of wind energy is lower than Medupi, even on a smaller scale. The study also determined that biogas and biomass, under certain conditions relating to feedstock costs, are able to compete with Medupi and offer real and sustainable benefits in long-term energy supply. The study determined that solar was unable to compete with the LCOE of Medupi on the smaller scale. The future electricity price of Eskom was projected with three different increases for the ten years after the MYPD3 period. The study successfully concluded that under all three scenarios, biogas, biomass and wind are able to compete with the grid price within this period of time.

The secondary objectives were to evaluate the financial viability of renewable energy technologies, determine the scale where these technologies could be applied and address the outlook of renewable energy in South Africa. The study successfully evaluated the scale where the four renewable technologies was able to compete with the price caps as set out for the SPIPPPP and found the technologies to be financially viable under these conditions. Furthermore, the study determined the benefits of scale for each of the technologies and made key recommendations to be considered by policy makers and government in ensuring the successful implementation and long-term sustainability of renewable energy as viable solution to the country's energy requirements.

4.4. RECOMMENDATIONS FOR FUTURE RESEARCH

The foundation of the empirical research was the construct of a dynamic financial model to determine the viability and calculate the LCOE for each of the four technologies. This model can serve as a basis for future research and enable researchers to build on the results. The model can be upgraded to account for more complex financial structures and detailed project costs, in addition, the model allows for the sensitivity analysis of key technical inputs that were used to determine the energy yield for each technology. With more detailed technical and geographical information, the researcher can map where in South Africa solar and wind technology will be viable which will not limit the study to a specific location.

Given the time constraints of the study, it was unpractical to request detailed proposals from the technology providers. It is recommended that the study be continued by evaluating the capital cost and total project cost specific to imported equipment. With this information, the sensitivity of the technologies to the exchange rate can be understood and the potential for local manufacture determined by the extent of local content in the pricing of the different power plants.

It will greatly benefit the study and verify the inputs of the empirical research by comparing the findings with a case study on an actual project under the SPIPPPP, once implemented.

Studies that will further assist the current research are:

- Evaluating the viability of implementing, or upgrading to, a smart grid in large urbanised areas; and
- The viability of micro generation.

These studies will be able to evaluate the practicality of moving towards decentralised power generation. In conjunction with the proposed study it will be very important to evaluate the financial viability of power generation on a domestic level, known as micro generation. The outcome and feasibility of micro generation has the potential to change the way the consumer will consider energy and electricity production in South Africa.

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Annexure 1: Completed questionnaires

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Biogas Measuring Instrument

The following questionnaire is for research purposes only and is not aimed at evaluating or selecting a technology provider for a specific project.

The information is strictly confidential and will only be used for academic purposes.

Technical and Commercial information to be supplied in the questionnaire should be rough order of magnitude only and from the technology provider's experience, it is not expected to provide great technical detail or any further breakdown and calculations to substantiate answers.

The technology provider is not held responsible for the accuracy of the data or bound by the commercial items in any way.

The questionnaire is based on the following assumptions:

1 Fuel input is a putrescible solid waste - typically food waste
2 Fuel is already homogenised and free of any contaminants
3 Fuel average moisture content is 70% on a wet basis
4 Fuel average Volatile Solids is 90% of the Total Solids on a dry matter basis
5 Biomethane potential is 0.25 Nm^3/ton VS at 25 days hydraulic retention time
6 Average methane concentration is 60% of the biogas on a volume basis
7 Project elevation is 1753 meters above mean sea level (Johannesburg, South Africa)
8 Grid connection point is a distance of 1km from the generation point

It is requested to complete the questionnaire for each size plant ranging from 1MW - 5MW export power.

Technical inputs from participant:
1 Substrate (Fuel) feed required in Ton/day
2 Biogas production in m^3/day
3 Captive consumption of the plant equipment during normal operations in MW

Commercial inputs from participant:
4 Total plant equipment cost in currency of preference
5 Civil works and Grid Connection cost
6 Annual Operations and Maintenance cost

Timing inputs from participant:
7 Total construction period in months
8 Drawdown of capital required per month as % of Total Capex
9 Plant availability or total production as a % of total annual hours

Biogas powered renewable energy plant

Output (Net)	MW	1	2	3	4	5
Technical						
Project Elevation	m amsl	1753	1753	1753	1753	1753
Distance to grid connection point	km	1	1	1	1	1
Average Moisture content	%	70%	70%	70%	70%	70%
Volatile Solids (VS)	%	90%	90%	90%	90%	90%
Biomethane Potential	Nm^3/kg VS	0.25	0.25	0.25	0.25	0.25
Hydraulic Retention Time	Days	25	25	25	25	25
Methane Concentration	% v/v	60%	60%	60%	60%	60%
Substrate Feed required	Ton/day	105	210	330	430	530
Biogas Production	m^3/day	15028	30225	47576	62220	76774
Captive Consumption (operational)	MW	0.336	0.456	0.519	0.582	0.645
Commercial						
Total Plant Equipment Cost	currency	30,767,000	47,718,000	68,706,000	83,699,000	97,394,000
Civil works and Grid connection	currency	34,672,000	52,503,000	72,798,000	87,043,000	100,452,000
Total Capex	currency			*CALCULATED*		
Operations and Maintenance	/annum	9,982,379	12,235,067	14,590,607	16,792,417	18,961,778
Timing						
Construction period	months	14	14	14	14	14
Drawdown of capital	% / Capex	100%	100%	100%	100%	100%
month 1		10%	10%	10%	10%	10%
month 2		5%	5%	5%	5%	5%
month 3		5%	5%	5%	5%	5%
month 4		5%	5%	5%	5%	5%
month 5		20%	20%	20%	20%	20%
month 6		5%	5%	5%	5%	5%
month 7		5%	5%	5%	5%	5%
month 8		5%	5%	5%	5%	5%
month 9		5%	5%	5%	5%	5%
month 10		5%	5%	5%	5%	5%
month 11		5%	5%	5%	5%	5%
month 12		5%	5%	5%	5%	5%
month 13		0%	0%	0%	0%	0%
month 14		20%	20%	20%	20%	20%
month 15						
month 16						
month 17						
month 18						
month 19						
month 20						
month 21						
month 22						
month 23						
month 24						
Plant Availability	% / annum	94.5%	94.7%	94.8%	94.8%	94.8%

Biogas powered renewable energy plant

Output (Net)	MW	1	2	3	4	5
Technical						
Project Elevation	m amsl	1753	1753	1753	1753	1753
Distance to grid connection point	km	1	1	1	1	1
Average Moisture content	%	70%	70%	70%	70%	70%
Volatile Solids (VS)	%	90%	90%	90%	90%	90%
Biomethane Potential	Nm^3/kg VS	0.25	0.25	0.25	0.25	0.25
Hydraulic Retention Time	Days	25	25	25	25	25
Methane Concentration	% v/v	60%	60%	60%	60%	60%
Substrate Feed required	Ton/day	150	265	385	505	620
Biogas Production	m^3/day	16875	29813	43313	56813	69750
Captive Consumption (operational)	MW	0.40	0.49	0.63	0.67	0.79
Commercial						
Total Plant Equipment Cost	currency	30,874,473	51,469,473	67,075,473	83,692,473	101,294,473
Civil works and Grid connection	currency	11,231,000	14,408,000	18,082,000	21,999,000	26,154,000
Total Capex	currency			*CALCULATED*		
Operations and Maintenance	/annum	8,901,347	10,644,635	13,037,295	15,556,631	17,991,463
Timing						
Construction period	months	12	14	16	18	20
Drawdown of capital	% / Capex	100%	100%	100%	100%	100%
month 1		10%	10%	10%	10%	10%
month 2		10%	10%	10%	5%	5.0%
month 3		10%	10%	5%	5%	5.0%
month 4		10%	10%	5%	5%	5.0%
month 5		10%	5%	5%	5%	5.0%
month 6		10%	5%	5%	5%	5.0%
month 7		5%	5%	5%	5%	5.0%
month 8		5%	5%	5%	5%	5.0%
month 9		5%	5%	5%	5%	5.0%
month 10		5%	5%	5%	5%	5.0%
month 11		5%	5%	5%	5%	5.0%
month 12		15%	5%	5%	5%	5.0%
month 13			5%	5%	5%	5.0%
month 14			15%	5%	5%	2.5%
month 15				5%	5%	2.5%
month 16				15%	5%	2.5%
month 17					0%	2.5%
month 18					15%	2.5%
month 19						2.5%
month 20						15%
month 21						
month 22						
month 23						
month 24						
Plant Availability	% / annum	93.0%	93.0%	93.5%	93.6%	93.6%

Biogas powered renewable energy plant

Output (Net)	MW	1	2	3	4	5
Technical						
Project Elevation	m amsl	1753	1753	1753	1753	1753
Distance to grid connection point	km	1	1	1	1	1
Average Moisture content	%	70%	70%	70%	70%	70%
Volatile Solids (VS)	%	90%	90%	90%	90%	90%
Biomethane Potential	Nm^3/kg VS	0.25	0.25	0.25	0.25	0.25
Hydraulic Retention Time	Days	25	25	25	25	25
Methane Concentration	% v/v	60%	60%	60%	60%	60%
Substrate Feed required	Ton/day	135	250	360	470	600
Biogas Production	m^3/day	15188	28125	40500	52875	67500
Captive Consumption (operational)	MW	0.39	0.57	0.71	0.83	0.94
Commercial						
Total Plant Equipment Cost	currency	32,217,473	49,882,473	65,127,473	82,591,473	97,766,473
Civil works and Grid connection	currency	22,304,000	26,475,000	30,068,000	34,193,000	37,758,000
Total Capex	currency			*CALCULATED*		
Operations and Maintenance	/annum	9,505,825	11,849,804	13,653,845	15,507,319	16,887,459
Timing						
Construction period	months	16	16	16	16	16
Drawdown of capital	% / Capex	100%	100%	100%	100%	100%
month 1		10%	10%	10%	10%	10%
month 2		5%	5%	5%	5%	5%
month 3		5%	5%	5%	5%	5%
month 4		5%	5%	5%	5%	5%
month 5		5%	5%	5%	5%	5%
month 6		5%	5%	5%	5%	5%
month 7		5%	5%	5%	5%	5%
month 8		20%	20%	20%	20%	20%
month 9		5%	5%	5%	5%	5%
month 10		5%	5%	5%	5%	5%
month 11		5%	5%	5%	5%	5%
month 12		5%	5%	5%	5%	5%
month 13		5%	5%	5%	5%	5%
month 14		5%	5%	5%	5%	5%
month 15		0%	0%	0%	0%	0%
month 16		10%	10%	10%	10%	10%
month 17						
month 18						
month 19						
month 20						
month 21						
month 22						
month 23						
month 24						
Plant Availability	% / annum	93.5%	93.5%	93.5%	93.5%	93.5%

Biogas powered renewable energy plant

Output (Net)	MW	1	2	3	4	5
Technical						
Project Elevation	m amsl	1753	1753	1753	1753	1753
Distance to grid connection point	km	1	1	1	1	1
Average Moisture content	%	70%	70%	70%	70%	70%
Volatile Solids (VS)	%	90%	90%	90%	90%	90%
Biomethane Potential	Nm^3/kg VS	0.25	0.25	0.25	0.25	0.25
Hydraulic Retention Time	Days	25	25	25	25	25
Methane Concentration	% v/v	60%	60%	60%	60%	60%
Substrate Feed required	Ton/day	120	240	360	480	600
Biogas Production	m^3/day	13500	27000	40500	54000	67500
Captive Consumption (operational)	MW	0.28	0.56	0.84	1.12	1.40
Commercial						
Total Plant Equipment Cost	currency	31,399,473	49,361,473	63,715,473	83,111,473	97,766,473
Civil works and Grid connection	currency	37,116,000	41,355,000	44,729,000	49,312,000	52,758,000
Total Capex	currency			*CALCULATED*		
Operations and Maintenance	/annum	7,325,539	9,214,820	11,506,728	13,323,669	15,821,199
Timing						
Construction period	months	12	12	12	12	12
Drawdown of capital	% / Capex	100%	100%	100%	100%	100%
month 1		10%	10%	10%	10%	10%
month 2		8%	8%	8%	8%	8%
month 3		8%	8%	8%	8%	8%
month 4		8%	8%	8%	8%	8%
month 5		8%	8%	8%	8%	8%
month 6		8%	8%	8%	8%	8%
month 7		8%	8%	8%	8%	8%
month 8		8%	8%	8%	8%	8%
month 9		8%	8%	8%	8%	8%
month 10		8%	8%	8%	8%	8%
month 11		8%	8%	8%	8%	8%
month 12		10%	10%	10%	10%	10%
month 13						
month 14						
month 15						
month 16						
month 17						
month 18						
month 19						
month 20						
month 21						
month 22						
month 23						
month 24						
Plant Availability	% / annum	91%	91%	91%	91%	91%

Biogas powered renewable energy plant

Output (Net)	MW	1	2	3	4	5
Technical						
Project Elevation	m amsl	1753	1753	1753	1753	1753
Distance to grid connection point	km	1	1	1	1	1
Average Moisture content	%	70%	70%	70%	70%	70%
Volatile Solids (VS)	%	90%	90%	90%	90%	90%
Biomethane Potential	Nm^3/kg VS	0.25	0.25	0.25	0.25	0.25
Hydraulic Retention Time	Days	25	25	25	25	25
Methane Concentration	% v/v	60%	60%	60%	60%	60%
Substrate Feed required	Ton/day	110	220	330	440	550
Biogas Production	m^3/day	12375	24750	37125	49500	61875
Captive Consumption (operational)	MW	0.21	0.42	0.63	0.84	1.05
Commercial						
Total Plant Equipment Cost	currency	60,000,000	85,000,000	110,000,000	135,000,000	160,000,000
Civil works and Grid connection	currency	25,000,000	35,000,000	45,000,000	55,000,000	65,000,000
Total Capex	currency			*CALCULATED*		
Operations and Maintenance	/annum	5,000,000	7,000,000	9,000,000	11,000,000	13,000,000
Timing						
Construction period	months	20	20	20	20	20
Drawdown of capital	% / Capex	100%	100%	100%	100%	100%
month 1		30%	30%	30%	30%	30%
month 2		0%	0%	0%	0%	0%
month 3		0%	0%	0%	0%	0%
month 4		0%	0%	0%	0%	0%
month 5		0%	0%	0%	0%	0%
month 6		20%	20%	20%	20%	20%
month 7		0%	0%	0%	0%	0%
month 8		0%	0%	0%	0%	0%
month 9		5%	5%	5%	5%	5%
month 10		0%	0%	0%	0%	0%
month 11		0%	0%	0%	0%	0%
month 12		15%	15%	15%	15%	15%
month 13		0%	0%	0%	0%	0%
month 14		0%	0%	0%	0%	0%
month 15		0%	0%	0%	0%	0%
month 16		20%	20%	20%	20%	20%
month 17		0%	0%	0%	0%	0%
month 18		0%	0%	0%	0%	0%
month 19		0%	0%	0%	0%	0%
month 20		10%	10%	10%	10%	10%
month 21						
month 22						
month 23						
month 24						
Plant Availability	% / annum	90%	90%	90%	90%	90%

23862327

Biomass Measuring Instrument

The following questionnaire is for research purposes only and is not aimed at evaluating or selecting a technology provider for a specific project.

The information is strictly confidential and will only be used for academic purposes.

Technical and Commercial information to be supplied in the questionnaire should be rough order of magnitude only and from the technology provider's experience, it is not expected to provide great technical detail or any further breakdown and calculations to substantiate answers.

The technology provider is not held responsible for the accuracy of the data or bound by the commercial items in any way.

The questionnaire is based on the following assumptions:

1 Fuel input is a woody biomass - typically pine or wattle
2 Fuel is already conditioned and is less than 50mm in size
3 Fuel average moisture content is 35% on a wet basis
4 Fuel average lower heat value is 11.77 GJ/ton
5 Project elevation is 1753 meters above mean sea level (Johannesburg, South Africa)
6 Grid connection point is a distance of 1km from the generation point
7 The technology is a conventional steam Rankine cycle with air cooled condenser

It is requested to complete the questionnaire for each size plant ranging from 1MW - 5MW export power.

Technical inputs from participant:

1 Biomass (Fuel) feed required in Ton/day
2 Boiler Pressure in Bar gauge
3 Steam Temperature to turbine in degrees Celsius
4 Water consumption in m^3/day
5 Captive consumption of the plant equipment during normal operations in MW

Commercial inputs from participant:

6 Total plant equipment cost in currency of preference
7 Civil works and Grid Connection cost
8 Annual Operations and Maintenance cost

Timing inputs from participant:

9 Total construction period in months
10 Drawdown of capital required per month as % of Total Capex
11 Plant availability or total production as a % of total annual hours

Biomass powered renewable energy plant

Output (Net)	**MW**	**1**	**2**	**3**	**4**	**5**
Technical						
Project Elevation	m amsl	1753	1753	1753	1753	1753
Distance to grid connection point	km	1	1	1	1	1
Lower Heat Value	GJ/ton	11.77	11.77	11.77	11.77	11.77
Average Moisture content	%	35%	35%	35%	35%	35%
Biomass Feed required	Ton/day	55.0	87.0	118.0	149.0	180.0
Boiler Pressure	Bar(g)	63	63	63	63	63
Steam Temperature	°C	483	483	483	483	483
Water Consumption (air cooled)	m^3/day	8.5	13.5	18.5	23.5	28.5
Captive Consumption (operational)	MW	0.6	0.7	0.8	0.9	1.0
Commercial						
Total Plant Equipment Cost	ZAR	60,000,000	90,000,000	120,000,000	145,000,000	165,000,000
Civil works and Grid connection	ZAR	25,000,000	30,000,000	35,000,000	40,000,000	45,000,000
Total Capex	ZAR			*CALCULATED*		
Operations and Maintenance	ZAR/annum	8,000,000	9,000,000	10,000,000	11,000,000	12,000,000
Timing						
Construction period	months	13	14	15	17	18
Drawdown of capital	% / Capex	100%	100%	100%	100%	100%
month 1		10%	10%	5%	5%	5%
month 2		10%	10%	5%	5%	5%
month 3		10%	10%	10%	10%	10%
month 4		10%	10%	10%	10%	10%
month 5		10%	10%	10%	10%	10%
month 6		10%	10%	10%	10%	10%
month 7		4%	4%	10%	10%	10%
month 8		2%	2%	10%	10%	5%
month 9		2%	2%	10%	0%	0%
month 10		2%	2%	0%	0%	0%
month 11		10%	10%	5%	5%	5%
month 12		10%	10%	5%	5%	5%
month 13		10%	0%	0%	0%	0%
month 14			10%	0%	5%	5%
month 15				10%	5%	5%
month 16					0%	5%
month 17					10%	0%
month 18						10%
month 19						
month 20						
month 21						
month 22						
month 23						
month 24						
Plant Availability	% / annum	93%	93%	93%	93%	93%

Biomass powered renewable energy plant

Output (Net)	MW	1	2	3	4	5
Technical						
Project Elevation	m amsl	1753	1753	1753	1753	1753
Distance to grid connection point	km	1	1	1	1	1
Lower Heat Value	GJ/ton	11.77	11.77	11.77	11.77	11.77
Average Moisture content	%	35%	35%	35%	35%	35%
Biomass Feed required	Ton/day	57.0	92.0	127.0	162.0	197.0
Boiler Pressure	Bar(g)	45	45	45	45	45
Steam Temperature	°C	400	400	400	400	400
Water Consumption (air cooled)	m^3/day	9.3	15.0	20.7	26.4	32.1
Captive Consumption (operational)	MW	0.55	0.65	0.75	0.85	1.00
Commercial						
Total Plant Equipment Cost	ZAR	61,644,000	82,214,000	102,784,000	123,354,000	143,924,000
Civil works and Grid connection	ZAR	20,000,000	25,000,000	30,000,000	35,000,000	35,000,000
Total Capex	ZAR			*CALCULATED*		
Operations and Maintenance	ZAR/annum	7,000,000	8,000,000	9,000,000	10,000,000	11,000,000
Timing						
Construction period	months	12	14	16	18	20
Drawdown of capital	% / Capex	100%	100%	100%	100%	100%
month 1		10%	10%	10%	10%	10%
month 2		8%	8%	10%	10%	5%
month 3		8%	8%	10%	5%	5%
month 4		8%	8%	5%	5%	5%
month 5		8%	8%	5%	5%	5%
month 6		8%	8%	5%	5%	5%
month 7		8%	8%	5%	5%	5%
month 8		8%	8%	5%	5%	5%
month 9		8%	8%	5%	5%	5%
month 10		8%	8%	5%	5%	5%
month 11		8%	8%	5%	5%	5%
month 12		10%	0%	5%	5%	5%
month 13			0%	5%	5%	5%
month 14			10%	5%	5%	5%
month 15				5%	5%	5%
month 16				10%	5%	5%
month 17					0%	5%
month 18					10%	0%
month 19						0%
month 20						10%
month 21						
month 22						
month 23						
month 24						
Plant Availability	% / annum	90%	90%	90%	90%	90%

BM003

Biomass powered renewable energy plant

Output (Net)	**MW**	**1**	**2**	**3**	**4**	**5**
Technical						
Project Elevation	m amsl	1753	1753	1753	1753	1753
Distance to grid connection point	km	1	1	1	1	1
Lower Heat Value	GJ/ton	11.77	11.77	11.77	11.77	11.77
Average Moisture content	%	35%	35%	35%	35%	35%
Biomass Feed required	Ton/day	60.0	98.0	136.0	174.0	212.0
Boiler Pressure	Bar(g)	17	17	17	17	17
Steam Temperature	°C	420	420	420	420	420
Water Consumption (air cooled)	m^3/day	4.0	6.5	9.0	11.5	14.0
Captive Consumption (operational)	MW	0.4	0.5	0.6	0.7	0.8
Commercial						
Total Plant Equipment Cost	ZAR	79,100,000	119,000,000	154,000,000	182,000,000	203,000,000
Civil works and Grid connection	ZAR	25,000,000	25,000,000	30,000,000	30,000,000	30,000,000
Total Capex	ZAR			*CALCULATED*		
Operations and Maintenance	ZAR/annum	5,000,000	6,000,000	7,000,000	8,000,000	9,000,000
Timing						
Construction period	months	14	14	16	16	18
Drawdown of capital	% / Capex	100%	100%	100%	100%	100%
month 1		10%	10%	10%	10%	5%
month 2		10%	10%	5%	5%	5%
month 3		5%	5%	5%	5%	5%
month 4		10%	10%	5%	5%	5%
month 5		15%	15%	15%	15%	15%
month 6		5%	5%	5%	5%	5%
month 7		5%	5%	5%	5%	5%
month 8		5%	5%	5%	5%	5%
month 9		5%	5%	5%	5%	5%
month 10		5%	5%	5%	5%	5%
month 11		5%	5%	5%	5%	5%
month 12		5%	5%	5%	5%	5%
month 13		5%	5%	5%	5%	5%
month 14		10%	10%	10%	10%	5%
month 15				0%	0%	0%
month 16				10%	10%	10%
month 17						0%
month 18						10%
month 19						
month 20						
month 21						
month 22						
month 23						
month 24						
Plant Availability	% / annum	95%	95%	95%	95%	95%

Biomass powered renewable energy plant

Output (Net)	MW	1	2	3	4	5
Technical						
Project Elevation	m amsl	1753	1753	1753	1753	1753
Distance to grid connection point	km	1	1	1	1	1
Lower Heat Value	GJ/ton	11.77	11.77	11.77	11.77	11.77
Average Moisture content	%	35%	35%	35%	35%	35%
Biomass Feed required	Ton/day	57.0	92.0	127.0	162.0	197.0
Boiler Pressure	Bar(g)	30	30	30	30	30
Steam Temperature	°C	420	420	420	420	420
Water Consumption (air cooled)	m^3/day	5.3	8.6	11.9	15.2	18.5
Captive Consumption (operational)	MW	0.5	0.6	0.7	0.8	0.9
Commercial						
Total Plant Equipment Cost	ZAR	95,000,000	160,000,000	195,000,000	210,000,000	220,000,000
Civil works and Grid connection	ZAR	35,000,000	35,000,000	35,000,000	35,000,000	35,000,000
Total Capex	ZAR			*CALCULATED*		
Operations and Maintenance	ZAR/annum	12,000,000	12,500,000	13,000,000	13,500,000	14,000,000
Timing						
Construction period	months	16	16	16	16	16
Drawdown of capital	% / Capex	100%	100%	100%	100%	100%
month 1		10%	10%	10%	10%	10%
month 2		5%	5%	5%	5%	5%
month 3		5%	5%	5%	5%	5%
month 4		5%	5%	5%	5%	5%
month 5		10%	10%	10%	10%	10%
month 6		10%	10%	10%	10%	10%
month 7		5%	5%	5%	5%	5%
month 8		5%	5%	5%	5%	5%
month 9		5%	5%	5%	5%	5%
month 10		5%	5%	5%	5%	5%
month 11		5%	5%	5%	5%	5%
month 12		5%	5%	5%	5%	5%
month 13		5%	5%	5%	5%	5%
month 14		5%	5%	5%	5%	5%
month 15		5%	5%	5%	5%	5%
month 16		10%	10%	10%	10%	10%
month 17						
month 18						
month 19						
month 20						
month 21						
month 22						
month 23						
month 24						
Plant Availability	% / annum	91.3%	91.3%	91.3%	91.3%	91.3%

23862327 **BM005**

Measuring Instrument

Biomass powered renewable energy plant

Output (Net)	MW	1	2	3	4	5
Technical						
Project Elevation	m amsl	1753	1753	1753	1753	1753
Distance to grid connection point	km	1	1	1	1	1
Lower Heat Value	GJ/ton	11.77	11.77	11.77	11.77	11.77
Average Moisture content	%	35%	35%	35%	35%	35%
Biomass Feed required	Ton/day	56.0	90.0	124.0	158.0	192.0
Boiler Pressure	Bar(g)	50	50	50	50	50
Steam Temperature	°C	420	420	420	420	420
Water Consumption (air cooled)	m^3/day	9.0	14.5	20.0	25.5	31.0
Captive Consumption (operational)	MW	0.6	0.7	0.8	0.9	1.0
Commercial						
Total Plant Equipment Cost	ZAR	50,000,000	75,000,000	98,000,000	120,000,000	135,000,000
Civil works and Grid connection	ZAR	15,000,000	15,000,000	20,000,000	20,000,000	25,000,000
Total Capex	ZAR			*CALCULATED*		
Operations and Maintenance	ZAR/annum	7,500,000	7,500,000	8,000,000	8,000,000	8,500,000
Timing						
Construction period	months	18	18	20	20	22
Drawdown of capital	% / Capex	100%	100%	100%	100%	100%
month 1		10%	10%	10%	10%	10%
month 2		10%	10%	10%	10%	5%
month 3		10%	10%	5%	5%	5%
month 4		10%	10%	5%	5%	5%
month 5		5.0%	5.0%	5.0%	5.0%	5.0%
month 6		5.0%	5.0%	5.0%	5.0%	5.0%
month 7		5.0%	5.0%	5.0%	5.0%	5.0%
month 8		5.0%	5.0%	5.0%	5.0%	5.0%
month 9		5.0%	5.0%	5.0%	5.0%	5.0%
month 10		5.0%	5.0%	5.0%	5.0%	2.5%
month 11		5.0%	5.0%	5.0%	5.0%	2.5%
month 12		2.5%	2.5%	2.5%	2.5%	2.5%
month 13		2.5%	2.5%	2.5%	2.5%	2.5%
month 14		2.5%	2.5%	2.5%	2.5%	2.5%
month 15		2.5%	2.5%	2.5%	2.5%	2.5%
month 16		2.5%	2.5%	2.5%	2.5%	2.5%
month 17		2.5%	2.5%	2.5%	2.5%	2.5%
month 18		10%	10%	10%	10%	10%
month 19				0%	0%	0%
month 20				10%	10%	10%
month 21						0%
month 22						10%
month 23						
month 24						
Plant Availability	% / annum	90.0%	90.0%	90.0%	90.0%	90.0%

23862327

Solar Measuring Instrument

The following questionnaire is for research purposes only and is not aimed at evaluating or selecting a technology provider for a specific project. The information is strictly confidential and will only be used for academic purposes.

Technical and Commercial information to be supplied in the questionnaire should be rough order of magnitude only and from the technology provider's experience, it is not expected to provide great technical detail or any further breakdown and calculations to substantiate answers.

The technology provider is not held responsible for the accuracy of the data or bound by the commercial items in any way.

The questionnaire is based on the following assumptions:

1 Project elevation is 1753 meters above mean sea level (Johannesburg, South Africa)
2 Average annual solar radiation is 1960 kwh/m^2/year derived from table below:

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Insolation, kWh/m^2/day	6.70	6.10	5.46	4.77	4.21	3.80	4.08	4.78	5.69	5.98	6.29	6.62	5.37
Clearness, 0 - 1	0.57	0.55	0.56	0.59	0.64	0.65	0.66	0.65	0.64	0.58	0.55	0.56	0.60
Temperature, °C	22.23	22.11	21.07	18.66	15.25	11.61	11.46	14.61	18.50	20.20	20.85	21.36	18.16
Wind speed, m/s	3.62	3.50	3.37	3.54	3.74	4.04	4.18	4.74	4.95	4.73	4.31	3.77	4.04
Precipitation, mm	134.00	93.00	92.00	56.00	15.00	8.00	4.00	8.00	28.00	76.00	112.00	113.00	61.58
Wet days, d	14.40	10.40	11.00	7.70	2.50	1.50	0.80	1.90	3.40	8.90	13.10	13.60	7.43

													Total
Days/month	31.00	28.00	31.00	30.00	31.00	30.00	31.00	31.00	30.00	31.00	30.00	31.00	365.00
Insolation, kWh/m^2/month	207.70	170.80	169.26	143.10	130.51	114.00	126.48	148.18	170.70	185.38	188.70	205.22	**1960.03**

3 Solar panels should be ground mounted
4 Grid connection point is a distance of 1km from the generation point

It is requested to complete the questionnaire for each size plant ranging from 1MW - 5MW peak installed power.

Technical inputs from participant:

1 Number of panels required
2 Total area required in m^2
3 Power produced in kwh/year

Commercial inputs from participant:

4 Total plant equipment cost in currency of preference
5 Civil works and Grid Connection cost
6 Annual Operations and Maintenance cost

Timing inputs from participant:

7 Total construction period in months
8 Drawdown of capital required per month as % of Total Capex

Solar powered renewable energy plant

Output (Peak Installed)	MW	1	2	3	4	5
Technical						
Project Elevation	m amsl	1753	1753	1753	1753	1753
Distance to grid connection point	km	1	1	1	1	1
Solar Radiation	kwh/m^2/year	1960	1960	1960	1960	1960
Mounting	ground/roof	ground	ground	ground	ground	ground
Number of Panels required	#	3974	7948	11922	15895	19870
Total Area required	m^2	6554	13108	19662	26216	32770
Power produced	kwh/year	1427442	2854884	4282326	5709767	7137209
Commercial						
Total Plant Equipment Cost	currency	7,718,000	15,436,000	23,154,000	30,872,000	38,590,000
Civil works and Grid connection	currency	8,032,000	15,064,000	21,096,000	27,528,000	32,660,000
Total Capex	currency			*CALCULATED*		
Operations and Maintenance	/annum	150,000	200,000	250,000	300,000	350,000
Timing						
Construction period	months	8	8	8	8	8
Drawdown of capital	% / Capex	100%	100%	100%	100%	100%
month 1		30%	30%	30%	30%	30%
month 2		10%	10%	10%	10%	10%
month 3		10%	10%	10%	10%	10%
month 4		10%	10%	10%	10%	10%
month 5		10%	10%	10%	10%	10%
month 6		10%	10%	10%	10%	10%
month 7		10%	10%	10%	10%	10%
month 8		10%	10%	10%	10%	10%
month 9						
month 10						
month 11						
month 12						
month 13						
month 14						
month 15						
month 16						
month 17						
month 18						
month 19						
month 20						
month 21						
month 22						
month 23						
month 24						

Solar powered renewable energy plant

Output (Peak Installed)	MW	1	2	3	4	5
Technical						
Project Elevation	m amsl	1753	1753	1753	1753	1753
Distance to grid connection point	km	1	1	1	1	1
Solar Radiation	kwh/m^2/year	1960	1960	1960	1960	1960
Mounting	ground/roof	ground	ground	ground	ground	ground
Number of Panels required	#	4275	8550	12825	17100	21375
Total Area required	m^2	6840	13680	20520	27360	34200
Power produced	kwh/year	1713080	3426160	5139240	6852320	8565400
Commercial						
Total Plant Equipment Cost	currency	14,517,603	29,035,205	43,552,808	58,070,411	72,588,013
Civil works and Grid connection	currency	7,482,397	10,964,795	13,447,192	13,929,589	14,911,987
Total Capex	currency			*CALCULATED*		
Operations and Maintenance	/annum	143,000	235,000	295,000	355,000	400,000
Timing						
Construction period	months	6	6	6	6	6
Drawdown of capital	% / Capex	100%	100%	100%	100%	100%
month 1		50%	50%	50%	50%	50%
month 2		10%	10%	10%	10%	10%
month 3		10%	10%	10%	10%	10%
month 4		10%	10%	10%	10%	10%
month 5		0%	0%	0%	0%	0%
month 6		20%	20%	20%	20%	20%
month 7						
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23862327 **PV003**

Measuring Instrument

Solar powered renewable energy plant

Output (Peak Installed)	MW	1	2	3	4	5
Technical						
Project Elevation	m amsl	1753	1753	1753	1753	1753
Distance to grid connection point	km	1	1	1	1	1
Solar Radiation	kwh/m^2/year	1960	1960	1960	1960	1960
Mounting	ground/roof	ground	ground	ground	ground	ground
Number of Panels required	#	4074	8148	12222	16296	20370
Total Area required	m^2	6926	13852	20777	27703	34629
Power produced	kwh/year	1533000	3066000	4599000	6132000	7665000
Commercial						
Total Plant Equipment Cost	currency	12,100,000	24,200,000	36,300,000	48,400,000	60,500,000
Civil works and Grid connection	currency	8,500,000	11,000,000	13,500,000	16,000,000	18,500,000
Total Capex	currency			*CALCULATED*		
Operations and Maintenance	/annum	176,000	352,000	528,000	704,000	880,000
Timing						
Construction period	months	6	7	8	9	10
Drawdown of capital	% / Capex	100%	100%	100%	100%	100%
month 1		30%	30%	30%	30%	30%
month 2		20%	20%	20%	20%	20%
month 3		20%	10%	10%	10%	10%
month 4		10%	10%	10%	10%	5%
month 5		10%	10%	10%	5%	5%
month 6		10%	10%	5%	5%	5%
month 7			10%	5%	5%	5%
month 8				10%	5%	5%
month 9					10%	5%
month 10						10%
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month 23						
month 24						

Solar powered renewable energy plant

Output (Peak Installed)	MW	1	2	3	4	5
Technical						
Project Elevation	m amsl	1753	1753	1753	1753	1753
Distance to grid connection point	km	1	1	1	1	1
Solar Radiation	kwh/m^2/year	1960	1960	1960	1960	1960
Mounting	ground/roof	ground	ground	ground	ground	ground
Number of Panels required	#	3994	7988	11982	15976	19970
Total Area required	m^2	5991	11982	17973	23964	29955
Power produced	kwh/year	1357800	2715600	4073400	5431200	6789000
Commercial						
Total Plant Equipment Cost	currency	7,480,000	14,960,000	22,440,000	29,920,000	37,400,000
Civil works and Grid connection	currency	5,000,000	10,000,000	15,000,000	20,000,000	25,000,000
Total Capex	currency			*CALCULATED*		
Operations and Maintenance	/annum	220,000	440,000	660,000	880,000	1,100,000
Timing						
Construction period	months	10	10	10	10	10
Drawdown of capital	% / Capex	100%	100%	100%	100%	100%
month 1		20%	20%	20%	20%	20%
month 2		10%	10%	10%	10%	10%
month 3		10%	10%	10%	10%	10%
month 4		10%	10%	10%	10%	10%
month 5		10%	10%	10%	10%	10%
month 6		10%	10%	10%	10%	10%
month 7		10%	10%	10%	10%	10%
month 8		5%	5%	5%	5%	5%
month 9		5%	5%	5%	5%	5%
month 10		10%	10%	10%	10%	10%
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Solar powered renewable energy plant

Output (Peak Installed)	MW	1	2	3	4	5
Technical						
Project Elevation	m amsl	1753	1753	1753	1753	1753
Distance to grid connection point	km	1	1	1	1	1
Solar Radiation	kwh/m^2/year	1960	1960	1960	1960	1960
Mounting	ground/roof	ground	ground	ground	ground	ground
Number of Panels required	#	4998	9996	14994	19992	24990
Total Area required	m^2	6248	12495	18743	24990	31238
Power produced	kwh/year	1664400	3328800	4993200	6657600	8322000
Commercial						
Total Plant Equipment Cost	currency	14,300,000	28,600,000	42,900,000	57,200,000	71,500,000
Civil works and Grid connection	currency	5,200,000	10,400,000	15,600,000	20,800,000	26,000,000
Total Capex	currency			*CALCULATED*		
Operations and Maintenance	/annum	100,000	200,000	300,000	400,000	500,000
Timing						
Construction period	months	5	5	5	5	5
Drawdown of capital	% / Capex	100%	100%	100%	100%	100%
month 1		50%	50%	50%	50%	50%
month 2		20%	20%	20%	20%	20%
month 3		10%	10%	10%	10%	10%
month 4		10%	10%	10%	10%	10%
month 5		10%	10%	10%	10%	10%
month 6						
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Onshore Wind Measuring Instrument

The following questionnaire is for research purposes only and is not aimed at evaluating or selecting a technology provider for a specific project.

The information is strictly confidential and will only be used for academic purposes.

Technical and Commercial information to be supplied in the questionnaire should be rough order of magnitude only and from the technology provider's experience, it is not expected to provide great technical detail or any further breakdown and calculations to substantiate answers.

The technology provider is not held responsible for the accuracy of the data or bound by the commercial items in any way.

The questionnaire is based on the following assumptions:

1 Project elevation is 69 meters above mean sea level (Port Elizabeth, South Africa)

2 Wind speed characteristics and Weibull parameters for the shape factor (k) and scale factor (c) are given below:

vmean = mean velocity; var = variance; k = shape factor; c = scale factor; vmp = most probable velocity; vmax = maximum velocity; Pd = power density

Year	vmean (m/s)	var (m/s)	k	c (m/s)	vmp (m/s)	vmax (m/s)	Pd (W/m^2)
2005	4.828	10.464	1.545	5.366	2.734	9.187	179.539
2006	4.667	9.228	1.594	5.204	2.802	8.665	155.224
2007	5.092	10.092	1.669	5.700	3.297	9.136	189.683
2008	5.234	11.099	1.633	5.848	3.274	9.542	211.895
2009	5.671	11.434	1.753	6.368	3.933	9.830	246.499
Whole year	5.099	10.585	1.629	5.696	3.176	9.314	196.625
Seasonal wind speed characteristics for the whole year							
Summer	5.363	9.881	1.786	6.029	3.808	9.180	203.926
Winter	4.643	10.379	1.487	5.138	2.426	9.112	168.806
Spring	5.691	12.036	1.712	6.381	3.821	10.029	256.505
Autumn	4.490	9.679	1.489	4.970	2.353	8.803	152.381
Variation of wind characteristics with height for the whole year							
Height (m):							
10	5.099	10.585	1.629	5.696	3.176	9.314	196.625
20	5.619	12.853	1.629	6.277	3.500	10.163	263.073
50	6.388	16.612	1.629	7.136	3.979	11.668	386.568
80	6.822	18.948	1.629	7.621	4.250	12.462	470.921
100	7.039	20.170	1.629	7.863	4.384	12.857	517.181

3 Grid connection point is a distance of 1km from the generation point

It is requested to complete the questionnaire for each size plant ranging from 1MW - 5MW peak installed power.

Technical inputs from participant:

1 Rotor diameter in meters
2 Hub height in meters
3 Power produced in kwh/year

Commercial inputs from participant:

4 Total plant equipment cost in currency of preference
6 Civil works and Grid Connection cost
7 Annual Operations and Maintenance cost

Timing inputs from participant:

8 Total construction period in months
9 Drawdown of capital required per month as % of Total Capex

Wind powered renewable energy plant

Output (Peak Installed)	MW	1	2	3	4	5
Technical						
Project Elevation	m amsl	69	69	69	69	69
Distance to grid connection point	km	1	1	1	1	1
Annual mean wind velocity	m/s	5.099	5.099	5.099	5.099	5.099
Annual variance in wind velocity	m/s	10.585	10.585	10.585	10.585	10.585
Most probable wind speed	m/s	3.176	3.176	3.176	3.176	3.176
Maximum wind speed	m/s	9.314	9.314	9.314	9.314	9.314
Wind power density	W/m^2	196.625	196.625	196.625	196.625	196.625
Number of turbines	#	1	1	1	2	2
Rotor diameter	m	60	90	112	90	100
Hub Height	m	80	80	80	80	80
Power produced	kwh/year	3000000	6000000	8935200	12000000	14892000
Commercial						
Total Plant Equipment Cost	currency	14,300,000	26,400,000	36,300,000	52,800,000	57,750,000
Civil works and Grid connection	currency	5,720,000	10,560,000	14,520,000	21,120,000	23,100,000.0
Total Capex	currency			*CALCULATED*		
Operations and Maintenance	/annum	300,300	554,400	762,300	1,108,800	1,212,750
Timing						
Construction period	months	12	12	12	12	12
Drawdown of capital	% / Capex	100%	100%	100%	100%	100%
month 1		10%	10%	10%	10%	10%
month 2		10%	10%	10%	10%	10%
month 3		10%	10%	10%	10%	10%
month 4		5%	5%	5%	5%	5%
month 5		25%	25%	25%	25%	25%
month 6		5%	5%	5%	5%	5%
month 7		5%	5%	5%	5%	5%
month 8		5%	5%	5%	5%	5%
month 9		5%	5%	5%	5%	5%
month 10		5%	5%	5%	5%	5%
month 11		5%	5%	5%	5%	5%
month 12		10%	10%	10%	10%	10%
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Wind powered renewable energy plant

Output (Peak Installed)	MW	1	2	3	4	5
Technical						
Project Elevation	m amsl	69	69	69	69	69
Distance to grid connection point	km	1	1	1	1	1
Annual mean wind velocity	m/s	5.099	5.099	5.099	5.099	5.099
Annual variance in wind velocity	m/s	10.585	10.585	10.585	10.585	10.585
Most probable wind speed	m/s	3.176	3.176	3.176	3.176	3.176
Maximum wind speed	m/s	9.314	9.314	9.314	9.314	9.314
Wind power density	W/m^2	196.625	196.625	196.625	196.625	196.625
Number of turbines	#	1	1	1	2	2
Rotor diameter	m	75	101	113	101	113
Hub Height	m	80	80	80	80	80
Power produced	kwh/year	3416400	6832800	10249200	13665600	17082000
Commercial						
Total Plant Equipment Cost	currency	16,500,000	33,000,000	49,500,000	66,000,000	82,500,000
Civil works and Grid connection	currency	7,425,000	14,850,000	22,275,000	29,700,000	37,125,000
Total Capex	currency			*CALCULATED*		
Operations and Maintenance	/annum	375,804	751,608	1,127,412	1,503,216	1,879,020
Timing						
Construction period	months	8	8	8	8	8
Drawdown of capital	% / Capex	100%	100%	100%	100%	100%
month 1		30%	30%	30%	30%	30%
month 2		10%	10%	10%	10%	10%
month 3		5%	5%	5%	5%	5%
month 4		5%	5%	5%	5%	5%
month 5		20%	20%	20%	20%	20%
month 6		10%	10%	10%	10%	10%
month 7		10%	10%	10%	10%	10%
month 8		10%	10%	10%	10%	10%
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Wind powered renewable energy plant

Output (Peak Installed)	MW	1	2	3	4	5
Technical						
Project Elevation	m amsl	69	69	69	69	69
Distance to grid connection point	km	1	1	1	1	1
Annual mean wind velocity	m/s	5.099	5.099	5.099	5.099	5.099
Annual variance in wind velocity	m/s	10.585	10.585	10.585	10.585	10.585
Most probable wind speed	m/s	3.176	3.176	3.176	3.176	3.176
Maximum wind speed	m/s	9.314	9.314	9.314	9.314	9.314
Wind power density	W/m^2	196.625	196.625	196.625	196.625	196.625
Number of turbines	#	1	1	1	2	2
Rotor diameter	m	77	92	108	92	100
Hub Height	m	80	80	80	80	80
Power produced	kwh/year	2803200	5606400	8409600	11212800	14016000
Commercial						
Total Plant Equipment Cost	currency	12,100,000	24,200,000	36,300,000	48,400,000	60,500,000
Civil works and Grid connection	currency	3,630,000	7,260,000	10,890,000	14,520,000	18,150,000
Total Capex	currency			*CALCULATED*		
Operations and Maintenance	/annum	393,250	786,500	1,179,750	1,573,000	1,966,250
Timing						
Construction period	months	14	14	14	14	14
Drawdown of capital	% / Capex	100%	100%	100%	100%	100%
month 1		10%	10%	10%	10%	10%
month 2		10%	10%	10%	10%	10%
month 3		20%	20%	20%	20%	20%
month 4		5%	5%	5%	5%	5%
month 5		5%	5%	5%	5%	5%
month 6		5%	5%	5%	5%	5%
month 7		5%	5%	5%	5%	5%
month 8		5%	5%	5%	5%	5%
month 9		5%	5%	5%	5%	5%
month 10		5%	5%	5%	5%	5%
month 11		5%	5%	5%	5%	5%
month 12		5%	5%	5%	5%	5%
month 13		5%	5%	5%	5%	5%
month 14		10%	10%	10%	10%	10%
month 15						
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month 24						

Wind powered renewable energy plant

Output (Peak Installed)	MW	1	2	3	4	5
Technical						
Project Elevation	m amsl	69	69	69	69	69
Distance to grid connection point	km	1	1	1	1	1
Annual mean wind velocity	m/s	5.099	5.099	5.099	5.099	5.099
Annual variance in wind velocity	m/s	10.585	10.585	10.585	10.585	10.585
Most probable wind speed	m/s	3.176	3.176	3.176	3.176	3.176
Maximum wind speed	m/s	9.314	9.314	9.314	9.314	9.314
Wind power density	W/m^2	196.625	196.625	196.625	196.625	196.625
Number of turbines	#	1	1	1	1	2
Rotor diameter	m	58	90	105	128	114
Hub Height	m	80	80	80	80	80
Power produced	kwh/year	2628000	5256000	7884000	10512000	13140000
Commercial						
Total Plant Equipment Cost	currency	9,900,000	19,800,000	29,700,000	39,600,000	49,500,000
Civil works and Grid connection	currency	2,970,000	5,940,000	8,910,000	11,880,000	14,850,000
Total Capex	currency			*CALCULATED*		
Operations and Maintenance	/annum	386,100	772,200	1,158,300	1,544,400	1,930,500
Timing						
Construction period	months	12	12	12	12	12
Drawdown of capital	% / Capex	100%	100%	100%	100%	100%
month 1		30%	30%	30%	30%	30%
month 2		5%	5%	5%	5%	5%
month 3		10%	10%	10%	10%	10%
month 4		5%	5%	5%	5%	5%
month 5		10%	10%	10%	10%	10%
month 6		5%	5%	5%	5%	5%
month 7		5%	5%	5%	5%	5%
month 8		5%	5%	5%	5%	5%
month 9		5%	5%	5%	5%	5%
month 10		5%	5%	5%	5%	5%
month 11		5%	5%	5%	5%	5%
month 12		10%	10%	10%	10%	10%
month 13						
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month 21						
month 22						
month 23						
month 24						

Measuring Instrument

Wind powered renewable energy plant

Output (Peak Installed)	MW	1	2	3	4	5
Technical						
Project Elevation	m amsl	69	69	69	69	69
Distance to grid connection point	km	1	1	1	1	1
Annual mean wind velocity	m/s	5.099	5.099	5.099	5.099	5.099
Annual variance in wind velocity	m/s	10.585	10.585	10.585	10.585	10.585
Most probable wind speed	m/s	3.176	3.176	3.176	3.176	3.176
Maximum wind speed	m/s	9.314	9.314	9.314	9.314	9.314
Wind power density	W/m^2	196.625	196.625	196.625	196.625	196.625
Number of turbines	#	1	1	2	2	2
Rotor diameter	m	82	91	87	91	121
Hub Height	m	80	80	80	80	80
Power produced	kwh/year	3267480	6534960	9802440	13069920	16337400
Commercial						
Total Plant Equipment Cost	currency	19,800,000	39,600,000	59,400,000	79,200,000	99,000,000
Civil works and Grid connection	currency	5,544,000	11,088,000	16,632,000	22,176,000	27,720,000
Total Capex	currency			*CALCULATED*		
Operations and Maintenance	/annum	329,472	658,944	988,416	1,317,888	1,647,360
Timing						
Construction period	months	16	16	16	16	16
Drawdown of capital	% / Capex	100%	100%	100%	100%	100%
month 1		10%	10%	10%	10%	10%
month 2		5%	5%	5%	5%	5%
month 3		5%	5%	5%	5%	5%
month 4		5%	5%	5%	5%	5%
month 5		5%	5%	5%	5%	5%
month 6		20%	20%	20%	20%	20%
month 7		5%	5%	5%	5%	5%
month 8		5%	5%	5%	5%	5%
month 9		5%	5%	5%	5%	5%
month 10		5%	5%	5%	5%	5%
month 11		5%	5%	5%	5%	5%
month 12		5%	5%	5%	5%	5%
month 13		5%	5%	5%	5%	5%
month 14		5%	5%	5%	5%	5%
month 15		0%	0%	0%	0%	0%
month 16		10%	10%	10%	10%	10%
month 17						
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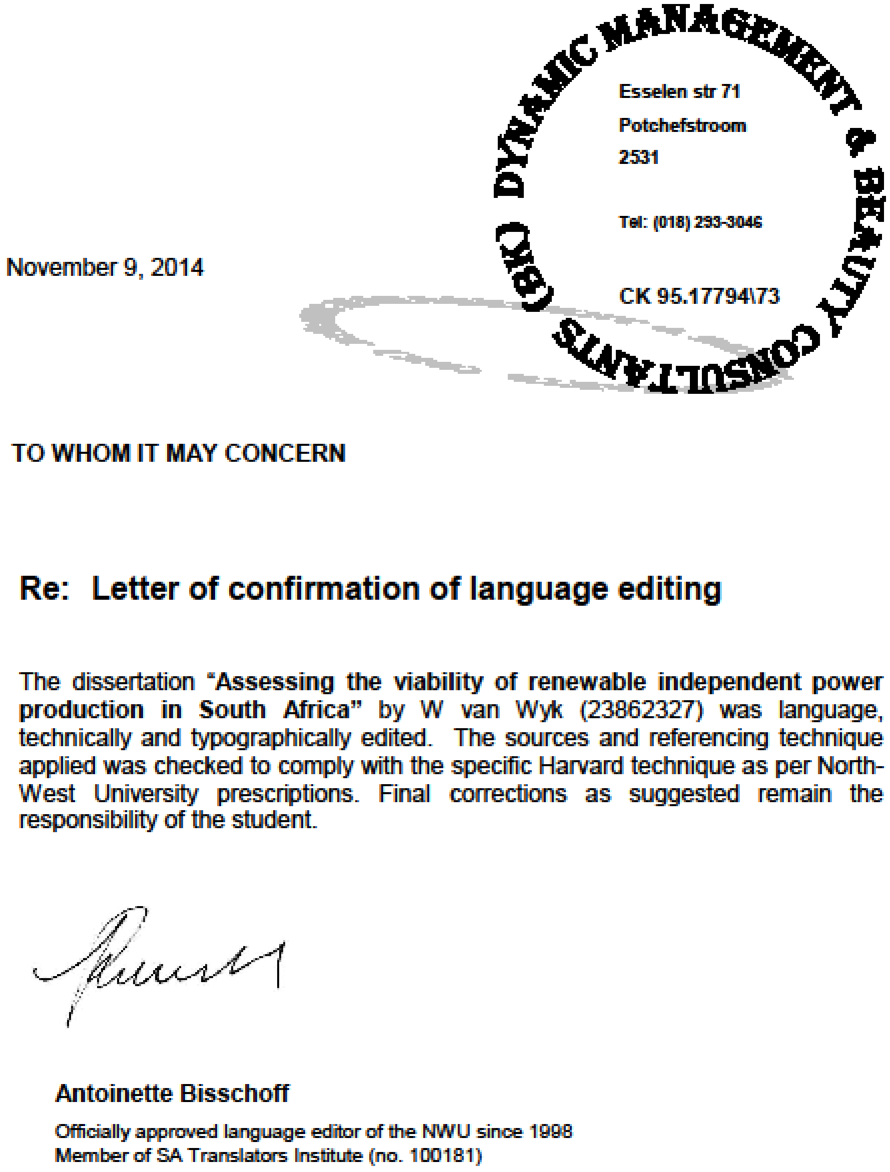
Annexure 2: Inputs and assumptions of financial model

Description	Unit	Value	Reference
Project Initiation date (start EPC)	yyyy/mm/dd	01/01/2015	Start date (input)
Months to full Operation	mm	Input	questionnaire
Full Operation	yyyy/mm/dd		Calculated
Shares Issue	R	1000	
R per Share	R/share	1	
Debt	% of Total project cost	70%	Control Variable
Equity	% of Total project cost	30%	Calculated
Debt Repayment Period from Operation Date	Years	15	
Interest Rate Paid	%/annum	11%	Prime + 2% / control variable
Interest Rate Earned	%/annum	5%	Standard Bank
Required rate of return from Equity Investor(s)	%	18%	
Income Tax	%	28%	SARS
Weighted Average Cost of Capital/Discount Rate	%	10.94%	Calculated
Electricity Price Escalation	%	6%	CPI
2015	R/kWh	Calculated	Goal seek function
Electricity Purchase Price	R/kWh	= selling price	Calculated
1 x Carbon credit	R/ton CO_2	0	Control variable
Sales Growth	%	6%	CPI
Grid Emission Factor	ton CO_2/MWh	1	
Rand:Euro		14.50	
Rand:US Dollar		11.00	
Water Cost	R/m3	12.00	Ekurhuleni
Operations and Maintenance cost	R/annum	Input	questionnaire
Operating expenses escalation	%	6%	CPI
Maintenance Reserve	% of Operations and Maintenance	10%	
Accounts Receivable	months	1.00	
Accounts Payable	months	1.00	
Spares & Consumables	% of Operations and Maintenance	3%	
Administrative costs	% of Operations & Maintenance	10%	
Equipment salvage value	% of Equipment	0%	SPIPPPP
Development Costs + Premia	% of Capex	6%	SPIPPPP
Contingency	% of Capex	5%	

Description	Unit	Value	Reference
Project Life	Years	20	SPIPPPP
Wear and tear allowance	Years	3	SARS
Depreciation percentage	%/annum	5%	20 year project life
Accelerated wear and tear tax depreciation – year 1	%	50%	SARS
Accelerated wear and tear tax depreciation – year 2	%	30%	SARS
Accelerated wear and tear tax depreciation – year 3	%	20%	SARS
Total Plant Equipment Cost	R	Input	questionnaire
Civil Works and Grid connection	R	Input	questionnaire
Drawdown	% during each month of construction	Input	questionnaire

Annexure 3: Letter from language editor



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CK 95.17794\73

November 9, 2014

TO WHOM IT MAY CONCERN

Re: Letter of confirmation of language editing

The dissertation **"Assessing the viability of renewable independent power production in South Africa"** by W van Wyk (23862327) was language, technically and typographically edited. The sources and referencing technique applied was checked to comply with the specific Harvard technique as per North-West University prescriptions. Final corrections as suggested remain the responsibility of the student.

Antoinette Bisschoff

Officially approved language editor of the NWU since 1998
Member of SA Translators Institute (no. 100181)