Effect on energy supply contribution by incorporating rooftop photovoltaic systems within the city of Johannesburg

A Minor Dissertation Submitted in Partial Fulfilment of the Degree of

MAGISTER INGENERIAE / MAGISTER PHILOSOPHIAE

in

ENGINEERING MANAGEMENT

at the

FACULTY OF ENGINEERING AND THE BUILT ENVIRONMENT

of the

UNIVERSITY of JOHANNESBURG

by

Archford Bobo (215084832)

19 April 2017

SUPERVISOR: Prof Jan-Harm Pretorius

CO-SUPERVISOR: Prof Johan Enslin

Abstract

The City of Johannesburg (COJ), an economic hub of South Africa with a 17% national gross domestic product (GDP) contributes 47% of Gauteng provincial economy. The city has been greatly impacted by the energy sustainability challenges that beset South Africa especially since the 2008 energy crisis. In Queensland, Australia, rooftop solar photovoltaic (PV) has demonstrated to be an impeccable renewable (RE) source that has been utilised at a large scale to ease energy sustainability problems. The availability of over 2200kWh/m^2 of annual average solar irradiance, vast amounts of unused rooftop spaces and land scarcity within COJ makes rooftop photovoltaic (PV) deployment a viable solution to ease the city's energy concerns. The research analyses the impact of implementing rooftop PV systems within COJ from an energy security improvement, greenhouse gas (GHG) emission reduction and employment creation viewpoints using a case study of Langlaagte, Roodepoort and Sandton testing stations. The research used Google Earth Pro (GEP) and Solargis pvPlanner as the main data collection software application tools. Results indicated that 2.28GWh/year could be generated at 15.4% PV panel efficiency and 79% performance ratio contributing approximately 12.14% of the three sites' energy requirements, with a potential to produce 84.76GWh over a 25 year PV module lifespan. The results highlighted annual carbon emission reductions of 2349.43 tonnes, contributing over 12% of the annual emission reductions for the three sites, lessening emissions by 58735.75 tonnes over a 25 year lifespan. The generated energy capacity resulted in the creation of 68 temporary and permanent jobs in the city. Large scale deployment of rooftop PV systems can greatly reduce COJ's current 28.2% unemployment rate. The research results can assist COJ to evaluate the sustainability implications of a full scale deployment of PV systems on the city's suitable rooftops. The research equips the city with informative data that can aid in strategy and policy formulation as the city endeavours to achieve its short and long term sustainability objectives.

Acknowledgements

To God be the glory for giving me the wisdom and power to finish this research. I express my utmost gratitude to Professor Enslin and Professor Pretorius for their tremendous input in making this research a success. Many thanks to Dr Tafadzwa Makonese for his immense contribution to the development of this research. My sincere gratefulness to Thabo Mahlatse, COJ Director of Energy, for his unwavering support through provision of vital technical information during the development of this research. Thanks to Vimbai, my dearest wife for providing warm love and tolerance during the study period. Lastly, I thank my children, Watidaishe and Mufaro, for their support and patience during the research period.

Contents

List of Figures

List of Tables

List of Abbreviations

3D	Three Dimensional
AFD	French Development Agency
BBBEE	Broad Based Black Economic Empowerment
BOT	Build-Operate and Transfer
CDM	Clean Development Mechanisms
CEF	Central Energy Fund
CER	Certified Emission Reductions
CO_2	Carbon dioxide
CO_{2eq}	Carbon dioxide equivalent
COJ	City of Johannesburg
CSIR	Council for Science and Innovation Research
CTF	Clean Technology Fund
CV	Constant Value
DBSA	Development Bank of South Africa
DME	Department of Minerals and Energy
DNI	Direct Normal Irradiation
DSM	Demand Side Management
DTI	Department of Trade and Industry
EISD	Environment Infrastructure and Services Department
ERC	Energy Research Centre
FDI	Foreign Direct Investment
FIP	Feed in Premiums
FIT	Feed in Tariff
GCRO	Gauteng City Region Observatory
GDP	Growth Domestic Product
GEEF	Green Energy Efficiency Fund
GEF	Global Environmental Fund
GEP	Google Earth Pro

GHG	Greenhouse Gas
GHI	Global Horizontal Irradiation
GIES	Gauteng Integrated Energy Strategy
GIS	Geographic Information Systems
GTZ	German Development Agency
GW	Gigawatt
HVAC	Heating Ventilation and Air Conditioning
IDP	Integrated Development Plan
IEA	International Energy Agency
IPAP	Industrial Policy Action Plan
IPP	Independent Power Producers
kg	Kilogramme
km	Kilometre
kW	Kilowatt
kWh	Kilowatt hour
LiDAR	Light Detection and Ranging Data
MDG	Millennium Development Goals
Mt	Megatons
Mt	Metric tonnes
MW	Megawatt
NDP	National Development Plan
NERSA	National Energy Regulator
NGP	New Growth Path
NREL	National Renewable Energy Laboratory
O&M	Operation and Maintenance
PPA	Power Purchase Agreements
PV	Photovoltaic
RE	Renewable Energy
REC	Renewable Energy Certificates
REFIT	Renewable Energy Feed in Tariff

REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
RET	Renewable Energy Technologies
RPS	Renewable Portfolio Standards
SAIPPA	South African Independent Power Producers Association
SAPVIA	South African PV Industry Association
SAREC	South African Renewable Energy Council
SAREC	South African Renewable Energy Council
SASTELA	Southern African Solar Thermal and Electricity Association
SBU	Green Industries Strategic Business Unit
SBU	Strategic Business Unit
SE4ALL	Sustainable Energy for All
SESSA	Sustainable Society of South Africa
SIM	Solar Irradiance Maps
TJ	Terajoule
TOU	Time of Use
TWh	Terawatt hours
UCT	University of Cape Town

Chapter 1 Introduction

Introduction

Despite energy being an essential driver for economic, social development and better quality of life worldwide, energy and ecological security have been the major challenges haunting the global economy that is mostly driven by fossil fuels (Bilgen, 2014). According to Sharma and Chandel (2013) the global energy demands have increased substantially in the past decades and it is projected to rise by more than 50% by 2030. The global advocacy for environmentally friendly energy sources exacerbates the energy crisis resulting in the creation of sustainability challenges. This energy inadequacy has been a cause for concern especially in the developing world where there is no energy guarantee and security.

1.1 Problem statement

1.1.1 South African electricity crisis

South Africa has historically enjoyed an overabundance of cheap electricity generated from coal fired power stations. Cheap electricity tariffs enticed energy intensive industrial and mining companies to invest in South Africa resulting in express industrialisation and rapid energy demand. The history of oversupply, complacency by decision makers and the ambitious national electrification programmes to alleviate energy poverty in low income communities transformed the energy balance sheet to negative (SEA, 2013). The Free Basic Electricity Policy introduced by the Department of Minerals and Energy (DME) saw the residential energy consumption radically rising by 50% from 1994 to 2007 (Ilze et al., 2015). Prolonged periods of underinvestment in power infrastructure led to escalating energy costs and capacity deficiencies that resulted in demand regulations, blackouts and load shedding during peak hours (Pollet, 2015). To highlight the seriousness of the energy crisis Medupi and Kusile coal fired power stations were constructed after 2006 to augment the country's electricity by about 20%. Despite South Africa being a signatory to the Kyoto protocol and the international pressure to shift to RE sources to combat carbon emissions, it proceeded with the construction of coal fired power stations. These two stations contribute about 60 million tonnes of CO_2 into the atmosphere (James, 2012).

The electricity supply challenges became acute by late 2007 with rampant load shedding as the Eskom tried to stabilise the grid (van Ravenswaay et al, 2014). Towards the crisis, the electricity reserve margin fell below the 15% aspiration of Eskom (Ilze et al., 2015). International reserve margin requirements are pegged between 15% and 25%. To indicate the gravity of the crisis Figure 1.1 shows how the reserve margins were trending between 1999 and 2014.

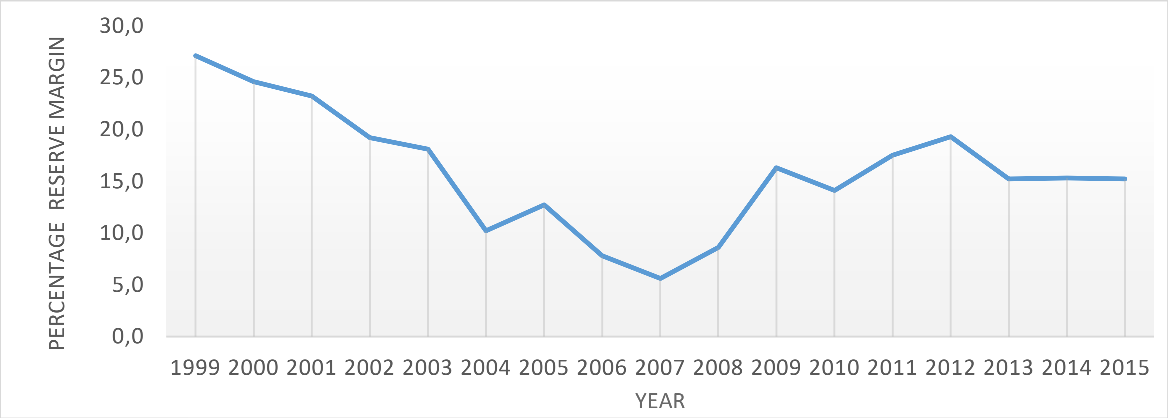


Figure 1.1: Electricity reserve % of South African coal power station fleet from 1999 to 2014.

Source: (Ilze et al, 2015)

The introduction of load shedding skewed and distorted the reserve curve subsequent to 2008, artificially increasing the reserve percentage. Application of power buy backs and other demand side management (DSM) schemes between 2011 and 2012 improved the reserve margins as shown above. Currently the DSM schemes have eased the pressure eliminating scheduled load shedding. However, the national economic potential can't be fully realised or unlocked due to reduced and controlled production to save power.

1.1.2 COJ Electricity Challenge

City of Johannesburg is South Africa's biggest economy generating 17% of the country's GDP and contributing nearly 47% to the Gauteng provincial economy (City of Johannesburg, 2013). The city has a high energy intensive economy due to industrial and mining activities gobbling about two-thirds of the national electricity usage. Johannesburg houses the world's deepest gold mines which are progressively becoming more expensive to mine due to high electricity consumption (City of Johannesburg, 2013). According to City Power (2013) approximately 98% of this electricity is generated from coal, a major contributor of carbon emissions. Power demand in all City Power controlled regions rose to 3000MW in 2010 against a normal maximum demand of 2600MW (City Power, 2013 and Webb, 2014). The 2030 projected demand excluding energy saving techniques and efficiency approaches is expected to reach 5400MW (City Power, 2013).

Johannesburg's population of 4.9 million accounts for approximately 36% of the province's population and 8% of the national populace (StatsSA, 2011 and City of Johannesburg, 2013). By virtue of being the largest city in South Africa, the COJ population has a protracted past of local and transnational migrations caused by diverse nationalities searching for superior economic prospects and enhanced quality of life. Between 2001 and 2011 the city saw an increased population growth of 121 000 people per year with 43 000 homes added annually to indicate a 37% population growth within a decade (City of Johannesburg, 2013). According to StatsSA (2011) the city has a population growth rate of 3.18% and the population is projected to double by 2040 (Joburg 2040, 2011). This ever-increasing population is always exerting pressure on COJ's infrastructure planning and energy resources. According to COJ's Integrated Development Planning report (City of Johannesburg, 2013), the perpetually increasing population enlarges the vulnerable population with a number of people finding habitat in squalor informal settlements with improper amenities. This continually swelling and unregulated population is a serious challenge to the energy infrastructure as it always stresses the electrical grid network. The electricity demand problems are normally witnessed in the informal settlements and high density suburb backyards where dwellers are illegally and unsafely connected to the grid further stressing it.

City Power, a subsidiary of COJ, is the power utility that distributes electricity to consumers in the COJ's licensed domain of supply (Webb, 2014). City Power purchases the major share of its electricity from Eskom, the national power utility, with the remainder coming from an independent supplier, Kelvin power station. As alluded to above, when Eskom reserve margins fall below 15%, City Power and its consumers are greatly affected since they largely depend on the Eskom supply (Webb, 2014). The 2008 energy crisis and the associated blackouts which pushed into early 2016 were a severe inconvenience to the general public, business and the national economy within the city. The effect of load shedding has been adversely affecting the city and the country's economic growth as well as the citizens' quality of life (Webb, 2014).

City Power devised some demand side management (DSM) techniques that significantly eased the electricity demand in the city. Currently load shedding has been halted. As part of the DSM solutions City Power negotiated with about 112 high consumption customers to reduce or shift load without totally halting production at an incentive of R1,11 per kWh

(Webb,2014). Although City Power enjoys a 20-year power purchase agreement with Kelvin Power commencing 2001, the electricity purchase price is greater than the mega flex tariff from Eskom (Webb, 2014). City Power through smart metering introduced Time of Use (TOU) tariffs where residential customers are incentivised to decrease consumption during peak hours. Of course, all these measures have indeed greatly reduced the city's electricity demands with load shedding totally disappearing in the last few months. However, the key question to be asked is whether City Power, a subsidiary of COJ, is living up to its vision of being a world-class electricity supplier and mission of meeting customers' expectations (City Power, 2013). The economic potential of the city is not fully realised because production is curtailed through demand response schemes. Since City Power is in the business of selling electricity it should consider the opportunity cost associated with failure to meet customer demand in an uncontrolled manner.

1.1.3 GHG Emissions Challenge

South Africa is ranked the 12th largest world emitter of CO_2 due to its over reliance on cheap coal contributing about 1.6% of international emissions (Moyo, 2016). In terms of the amount of CO_2 emitted for each megawatt per hour, it is the worst emitter from Poland (*Joburg 2040,* 2011). Although the country is classified as the 28th largest economy in the world, the economy's energy intensiveness results in high environmental costs of producing goods (*Joburg 2040,* 2011). Currently about 72.1% of South Africa's primary energy is generated from coal. Electricity is consuming 93% of the coal, generating about 67% carbon emissions (Eskom, 2015, Baker, 2015). CO_2 annual emissions for 2014/15 period was 223.4 megatons (Mt) (Eskom, 2015).

Traditionally, coal's over-abundance made it a cheap fuel in financial terms resulting in very competitive electricity prices attracting a lot of energy intensive industries. However, when environmental and social externalities are factored in the long term inclusive coal costs make it less attractive. Climate change due to GHG emissions has been viewed as the highest threat to the human health (Tcholakov et al, 2015). According to Gough (2013) climate change is an intergenerational global challenge threatening to exterminate the present and future generations' sustenance. Severe weather conditions including extreme heat waves, air, water and vector borne diseases, malnutrition due to drought or crop failure, food insecurity and extreme temperature induced mortality rates are all concrete evidence of the threat posed by climate change (Tcholakov et al, 2015). Figure 1.2 below shows the ecological risks that are due to climate change.

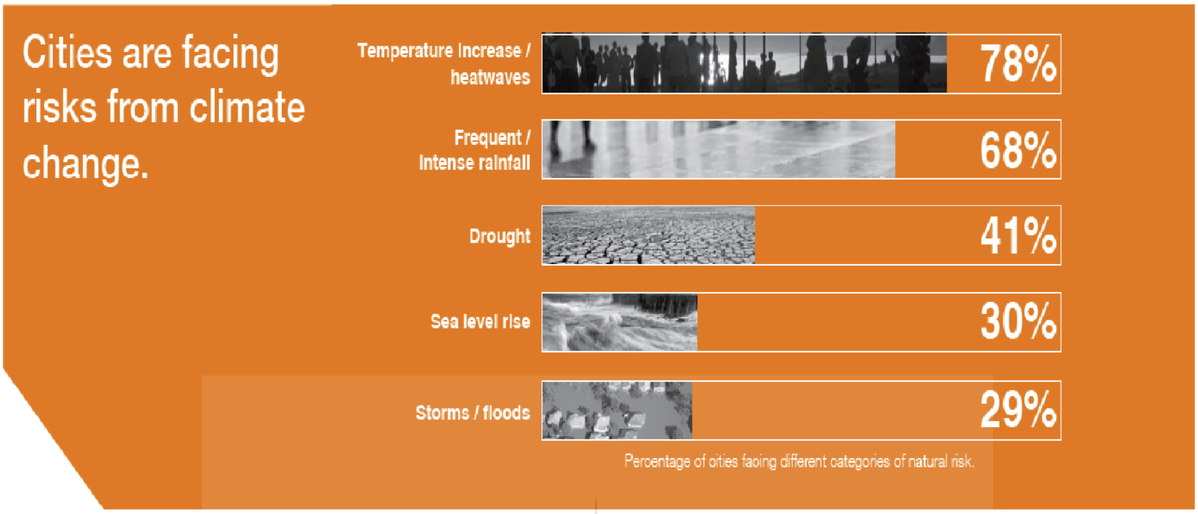


Figure 1.2: Risks due to climate change

Source: CDP et al (2014)

A correlation between the country's GHG emissions and the national GDP clearly elaborates the poor performance of South Africa and is ranked the 8th poorest converter. This relationship is reflected in COJ's economy in terms of the energy sources and the magnitude of carbon intensity. According to the Joburg 2040 growth and development strategy report (2011), 66.7% of the aggregate CO_2 discharges within the metropolis originated from electricity, followed by petrol then diesel. Carbon emission per unit energy consumption is greater for electricity than from liquid fuels due to generation of electricity from coal power stations using low grade coal supplies. Table 1.1 shows COJ carbon emissions by fuel type.

Fuel Type	***CO_2 Emissions (tons)***	***Percentage of total emissions for COJ***
Electricity	*13 029 077*	*66.7%*
Petrol	*3 893 095*	*19.92%*
Diesel	*2 318 334*	*11.86%*
Coal	*102 425*	*0.52%*
Paraffin	*95 843*	*0.49%*
Natural Gas	*93 896*	*0.48%*
Furnace Oils	*7 976*	*0.04%*
LPG	*3 325*	*0.02%*
Total	***19 543 971***	***100%***

Table 1.1: City's carbon emissions by fuel type

Source: City of Johannesburg (2013)

1.1.4 Unemployment Challenges

According to Oluwajodu et al (2015) joblessness is a socio-economic problem that has economic expenses that lessen economic wellbeing, decreases output at the same time eroding the human capital. The United Nations Development Programme (2005 cited by Weir-Smith, 2014) viewed unemployment as a serious concern of the UN Millennium Development Goals (MDG). World unemployment rose till 2004 and rose yet again in 2008 because of the recession (Weir-Smith, 2014). According to the International Labour Organisation (2012, cited by Weir-Smith, 2014) the post 2008 economic slump saw unemployment increasing in most nations and figure 1.3 shows increasing unemployment trends in some developed countries in comparison to South Africa.

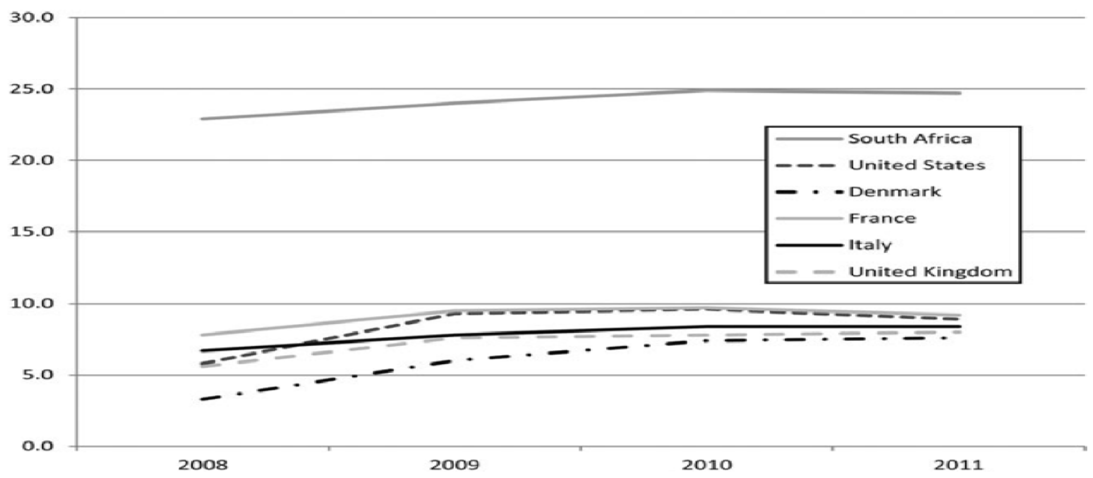


Figure 1.3: Employment trends for selected countries

Source: Weir-Smith (2014)

From figure 1.3 above, although different nations witnessed increased unemployment rates, for South Africa the rate of unemployment was at least 15% higher than the rest.

South Africa has been experiencing increased unemployment rates for the past one and half decades (Oluwajodu et al, 2015). According to Weir-Smith (2014) South Africa set unemployment reduction targets to at most 14% by 2014 in order to achieve the MDG. The global economic crunch had a crushing impact on the country's labour markets with unemployment soaring in 2008 from 27.5% to about 33% in 2010 (Verick, 2012, cited by Ismail and Kollamparambil, 2015). According to Statistics South Africa (2014, cited by Oluwajodu et al, 2015), the rate of unemployment in 2011 was 24.2% and in 2013 it rose to 25.2%. The hardest hit age group were the youth with unemployment figures rising from 51.5% to 60.3%. Youth unemployment in 2014 rose further to 63% (Verick, 2012, cited by Ismail and Kollamparambil, 2015). The South African unemployment rate soared to 26.7% in the first quarter ending March 2016 from 24.5% of the previous quarter against market anticipations of 25.3% (StatsSA, 2016, cited by Trading Economics, 2016). This has been viewed as the highest recording since 2005 with unemployment rising by 10% and employment falling by 2.2%. Figure 1.4 shows the national unemployment rates starting from 2013 to the present. These figures fall far short of the South African 2014 MDG target of 14%.

Figure 1.4: South African unemployment rates

Source: Trading Economics (2016)

According to Todes (2012a, 2012b, cited by Rogerson and Rogerson, 2015), the magnetic effects of Johannesburg causes a persistent influx of indigenous and international migrants who are always seeking for better employment and livelihood opportunities resulting in uncontrolled population growth, a key challenge to the city's future. The city's population is projected to double by 2040 (Joburg 2040, 2011). The city is endowed with 2 261 490 economically active people and an unemployment rate of 25% (StatsSA, 2011). According to CDP et al (2014) report for Johannesburg, 42% of the city's population is aged below 24 years. Of the young age group of 15-35 years in the city 31.5% are not employed (StatsSA, 2011). The City of Johannesburg Integrated Development Plan (IDP) report admits that unemployment is a key challenge to the country and the city (City of Johannesburg, 2013). The tenaciously acute unemployment rate affecting the youth populace is one of the greatest persistent socio-economic challenges faced by most South African municipalities (Yu, 2013). Unchecked youth unemployment usually results in social problems like criminal activities, drug abuse, unplanned pregnancies and other social ills. The high and increasing youth unemployment figures are a clear indication of the degree of the employment problem.

1.2 Research Objectives

History has proved that the city's overdependence on Eskom power has a negative impact on the city's economic development especially when Eskom reserve margins fall below 15%. It is vital that COJ as a major consumer of electricity devise ways to minimise this Eskom overdependence especially in crisis situations. It is the city's duty to create job opportunities for the betterment of the citizens' welfare. There is therefore a need to assess and evaluate the effect of introducing the rooftop PV systems projects within COJ in terms of employment opportunities created. It is crucial to analyse the resultant GHG emission reductions that are realised due to introduction of rooftop PV systems. Listed below are the summarised key objectives of the proposed research:

1. To analyse and determine PV Systems energy supply contribution to the city's energy requirements when installed on COJ's three testing stations rooftops.
2. To analyse and determine rooftop PV Systems' economic contribution through employment creation.
3. To analyse and determine the resultant carbon emission reduction contributions within the city.

1.3 Research Justification

1.3.1 Land Size

The City of Johannesburg has a land size of 1,644km^2. This creates impediments as land space to implement solar or wind farms is insufficient. Therefore, the most appropriate solution is to implement photovoltaic systems on the city's building roof tops.

1.3.2 Energy crisis alleviation

Adequate energy provision is a key driver to sound economic growth and sustainable development. Sustainable development is only pragmatic if there are consistent, perennial and secure sustainable energy supplies. On the contrary the South African economy, Johannesburg in particular, has been experiencing an energy crisis stemming from high power demands, over-dependence on fossilised fuels for power generation and the city's ever bloating population that complicates energy demand planning and projections. Despite the recent stability in energy supply situation because of demand response schemes, the above factors have been threatening security of supply in the city (Webb, 2014). Diversifying the energy mix ensures augmented security of supply (DOE, 2015). The PV systems portfolio can positively counter the forever increasing electricity demands without contaminating the atmosphere through GHG emissions. The proposed PV system is expected to augment capacity of the national energy mix thus contributing to the 42% RE mix expected from IRP 2010-2030 target (DOE, 2015) and contributing to the 8.4GW from solar PV systems by 2030.

Although the DSM schemes have stabilised the energy supply situation within COJ, the city's full economic potential can't be unlocked because the energy demand is not fully met as industries are still starved of their real or actual energy requirements to execute maximum production. The associated opportunity costs derived from energy supply shortages justify the need to augment the energy supply. The ever-increasing population growth within the city compels the city to plan for high internal reserve margins through increased energy supply mix to meet its energy demands. The City Power's vision is to become world-class electricity supplier with a mission of meeting customers' expectations (City Power, 2013). Although it is the desire of every company to live up to its vision and mission statement, the events of the past one and half decades have been pointing to the contrary. COJ's power utility's core business is to sell electricity to consumers which generates significant revenue. Failure to meet the consumers' full electricity demands results in loss of revenue as an opportunity cost. The energy situation within the country in general and the city in particular needs to be augmented to ensure future energy security. The city through the constitution's Bill of Rights (Act No. 108 of 1996) is mandated to provide or facilitate a healthy, harmless, secure environment beneficial to the current as well as the future generations through application of reasonable legal frameworks and other aiding measures that promote sustainable development (Environamics, 2013). This gives the city the obligation to act as the responsible custodian for the people and state's sustainable concerns.

1.3.3 GHG Emissions Mitigation

According to Dr. Noel Brown, ex-director of UNEP North American Region, although signatories to climate change pacts are national governments, it is municipal leaders that are captaining and offering tangible global leadership for GHG emission reductions and efficient energy management (Ward and Mohammed, 2009). Municipalities as administrators and overseers of developmental activities play a key role in the determination of energy and GHG emission depiction in the cities. COJ municipality is strategically positioned to play a major role in energy consumption management and carbon emissions. Since the city is an extensive energy consumer spreading across municipal services and amenities, it can demonstrate leadership by lessening its carbon emissions (Sustainable Energy Africa, 2014). The COJ's high carbon profile thus gives it a critical responsibility to transform South Africa's carbon footprint by implementing carbon emission mitigation strategies and structuring its sustainability policies to align with the Kyoto Protocol and other ratified pacts (Gets, 2013).

This then brings to the fore a need for COJ to invest in sustainable energy systems that comply with the world climate change mitigation objectives.

The over-abundance of coal made electricity generation cheap resulting in competitive electricity prices (Moyo, 2016). However, when environmental and social externalities are considered in the long term, inclusive coal costs make it less attractive. Climate change due to GHG emissions has been viewed as the highest threat to the human health (Tcholakov et al, 2015). Severe weather conditions including extreme heat waves, air, water and vector borne disease, malnutrition due to drought or crop failure, food insecurity and extreme temperature induced mortality rates are all concrete evidence of the threat posed by climate change due to GHG emissions (Tcholakov et al, 2015). Introduction of PV systems as an alternative energy source can improve public health and reduce natural disasters due to GHG emissions coming from coal fired power stations.

Johannesburg economy is very carbon intensive making it imperative to have an RE biased energy mix (Maia et al, 2011). The existence of the finest global solar resources in South Africa offers the best opportunity to pursue PV projects in Johannesburg. Rooftop PV system will make a significant contribution to GHG emission lessening by decreasing the coal dominance and overdependence during electricity production. The use of PV systems as a clean technology reduces the city's carbon footprint thereby aligning the city's energy strategy with the national policy frameworks like the New Growth Path Policy, Climate Change Response Policy (2011) and Johannesburg Climate Change Strategy which all put special emphasis on cleaner technology and products (Montmasson-Clair et al., 2014). GHG emission reductions can increase the city's revenue through trade of carbon credits as the project can qualify as a Clean Development Mechanisms (CDM) project. The project would make a remarkable contribution to GHG emission lessening and contribute towards climate change mitigation. The introduction of PV systems aligns itself very well with government Energy Efficiency Strategy policy whose goals embrace three cornerstones of sustainable development i.e. environmental, social and economic sustainability (DME, 2009).
South Africa as a fully committed member of the Kyoto Protocol climate accord and pacts thereafter, the nation needs to make a paradigm shift and reprogram its GHG emission reduction thinking. Instead of pulling resources to finance construction of more coal fired power stations the country must invest in renewable energies especially PV systems whose prices are declining faster than the rest of the RE sources (DOE, 2015; James, 2012). The

city's sustainable energy development efforts through PV systems will greatly contribute towards the fulfilment of South Africa's commitment to the Kyoto Protocol on GHG emission mitigation endeavours. At the same time, it will improve the energy security situation in the country and create other socio-economic benefits crucial to meet the city and the country sustainable development goals and objectives. The nation must also note that today's choices of how it extracts, harnesses and uses energy will determine the future energy system sustainability and thus impact the extent of socio-economic progression.

Besides GHG emission reductions, use of PV energy systems will prevent pollution coming from coal mining activities. Coal power generation generally requires massive water capacities. According to Maia et al (2011) Johannesburg is faced with severe water and waste management challenges. Appropriate management and conservation of the limited water resources is promptly needed so that the country can avoid huge sustainability challenges. PV systems are clean and environmentally friendly technologies with no GHG emissions requiring only minimal water quantities to clean them. They therefore promote healthy sustainable environment for employees and the general populace.

1.3.3 Economic Development

The proposed project can ensure economic growth and security by lessening electricity supply deficits. Electricity constraints curtail economic development while improved reserve margins ensure a platform of economic advancement. The introduction of rooftop PV systems ensures the city's economic growth as it promotes industrial development. This complements well with provincial and national developmental objectives at the same time promoting skills development. Successful implementation of this project will encourage private players with appropriate rooftops to consider and invest in PV systems to make a further contribution to the IRP2010-2030 RE national targets and the GHG emissions reduction set out in the peak, plateau and decline targets (National Climate Change Response White Paper, 2011).

The city has a responsibility to embark on appropriate technologies that facilitate the decoupling of economic growth from energy consumption so as to have a trend where energy inputs decrease with economic development (Gets, 2013). Such an approach promotes a competitive metropolitan characterised by a sound and healthy economy that models the city into a vibrant exceptional African city of the future as envisaged in the city's vision. This is only conceivable if the city diversifies its energy portfolio to incorporate at a large-scale a RE blend with a prospect of making it the dominant energy source of the future.

Bringing in PV systems to the City of Johannesburg comes with socio-economic benefits. Solar manufacturing industries are created. This creates job opportunities in the manufacturing, installation and maintenance sectors (IRENA and CEM, 2014). The proposed project will offer contracts to local companies who will hire personnel for the period of the project. Operation and maintenance stages will offer direct, indirect and induced permanent employment opportunities to locals especially general labourers, security guards, transporting, catering opportunities etc. The PV system project will also create other opportunities across the value chain in the form of business opportunities, sales and tax revenues, carbon credit sales revenue and improved foreign direct investment (IRENA and CEM, 2014). The project will also make a significant contribution to poverty alleviation and social sustainability in general. The project will have substantial enduring derived progressive social effects that can be induced to provincial or national scales. Much needed experience can be obtained by locals during the building, operation and maintenance of the PV system. This experience obtained can be utilised to set up other similar projects within and outside South Africa.

1.4 Methodology

The research methodology is a case study of City of Johannesburg's three testing stations. The greater part of the research relied on historical data from the City of Johannesburg, Journal articles, other municipals reports, government white papers and reports, StatsSA, Sustainable Energy Africa and other RE Research databases.

1. To analyse the PV systems energy supply contribution I aggregated the solar panel supply capacities to calculate the nominal capacity.

2. To analyse the job creation potential I used employment factors for the South African context from IRENA as well as historical/secondary data from previous similar projects implemented elsewhere (especially in South Africa) and relate, compare and draw parallels amongst projects to derive employment created through the energy value chain.

3. To evaluate the reduction in carbon footprint I used the Eskom carbon emission factor of 1.03 tons/MWh (Eskom, 2015)

1.5 Data collection and Preparation

Most of the data to calculate potential electricity generated roof rooftop PV systems was obtained using GEP to generate roof area. Global solar irradiance was obtained using Solargis pvPlanner software (Solargis). Using GEP roofs with the best orientation to produce optimum power are detected. Total power generated was obtained using the PV solar energy equation. Carbon Emission data is collected from South African municipality reports, Eskom GHG emission statistics, IRENA reports and other peer reviewed articles. Data for average jobs created per megawatt is obtained from peer reviewed research articles and IRENA reports.

1.6 Data Analysis and Interpretation

The PV energy potential results obtained were evaluated and compared with the current energy situation for the sites under review. An Analysis and interpretation of the impact of deploying rooftop PV systems within COJ is made in terms of energy generated, carbon emission reductions and employment creation

1.7 Conclusion

Conclusions were drawn determining and evaluating whether implementing rooftop PV systems made a significant contribution to the city's energy crisis, employment creation and GHG emission mitigation.

Chapter 2 Literature Review

2.1 Introduction

The literature review serves as a springboard for justification of current research by encapsulating, correlating and evaluating previous and current research works. It reveals and depicts existing parallels and divergences, similitudes and dissimilarities, cohesions and incoherencies that prevail between prior research and the suggested research. The literature review serves as a benchmark that gives a background coverage and evaluation of previously researched works with an intention to marry previous and current research works for value addition purposes to the broader field of study. The literature review process gives the researcher an opportunity to probe the existing knowledge base, exposing deficiencies and limitations of previous research with an intention to reveal and address existing research gaps through further research. The purpose of integrating these two works is to create a synergy that adds value to the existing body of knowledge.

The research problem can be better contextualised and analysed when the energy crisis and sustainability ramifications are first scrutinised from a global standpoint, narrowed to national and finally constricted to municipal perspective.

2.2 Background

2.2.1 Global Electricity Supply Situation

The global energy demand has been snowballing due to the forever ballooning population now exceeding 7 billion and global economic growth through industrial development (Kannan and Vakeesan, 2016). In 1990 the global energy consumption was one billion gigawatts and in 2014 it was approximately ten billion gigawatts, a tenfold upsurge (Bilgen, 2014). The population explosions and the need for accelerated economic growth in the developing world are the key drivers pushing the energy demand to a crisis point. According to Sharma and Chandel (2013) the global energy demand has increased considerably in the past three decades and it's anticipated to upsurge by more than 50% by 2030. The BP Energy Outlook report (2016) states that fossilised fuels continue to be the dominant energy source powering the world economy, providing around 60% of the global energy and it's projected to account for nearly 80% of the aggregate energy supply in 2035.

Currently the global economy is mainly driven by electricity generated from fossilised fuel sources. According to International Energy Agency 2014 report, about 68% of global electricity is generated from fossilised fuels with coal contributing the major share of 40.4%, as illustrated in figure 2.1 below. Generation of electricity from fossil fuels has negative environmental impacts chiefly GHG emissions, greenhouse impacts and global warming, health impacts causing skin and respiratory ailments (Behrouzi et al, 2016). According to Lim et al (2013, cited by Saygin et al, 2015), approximately 1.3 billion people don't have access to electricity with 2.6 billion lacking access to unpolluted cooking services. The use of unsustainable biomass with low energy conversion efficiency is causing the death of approximately 4 million people every year because of air pollution (Lim et al, 2013, cited by Saygin et al, 2015).

The potential depletion of fossil fuel reserves in future coupled with GHG emissions accumulations into the atmosphere has brought the international community together to lobby for alternative energy sources that are ecologically friendly (Awan and Khan, 2014).

The environmental unfriendliness coupled with depletive characteristic of fossil fuels negate them as an unreliable energy source. This has united the international community to lobby for alternative energy sources that are ecologically friendly (Awan and Khan, 2014). The non-exhaustibility and eco-friendliness of RE sources make them a prime choice to sustainable energy development goals.

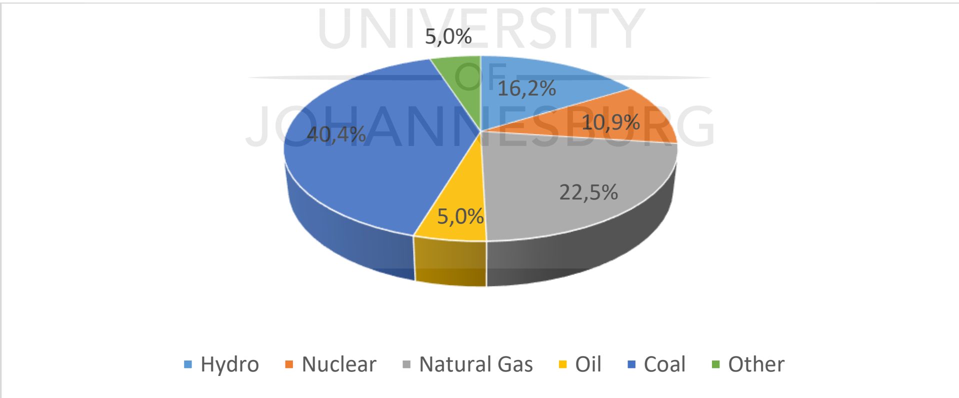


Figure 2.1: World electricity generation from mixed energy sources

Source: International Energy Agency (2014)

2.2.2 RE Developments

The desire to enhance energy security, energy access and mitigate climate change has resulted in a rapid deployment of RE technologies in the past decade (IRENA and CEM, 2014). According to Amin, IRENA Director General, fast-tracking the transition to RE systems offers an exclusive opportunity that fulfils climate change mitigation objectives while stimulating economic progression, creating new job prospects and improving human welfare (IRENA, 2016). Today's choices on energy sector investments will shape and determine the future decades' economic development and the potential to decarbonise global energy (IRENA, 2016). If the climate change mitigation objectives of Paris agreement (2015) and its predecessors are to be accomplished, a transition to RE systems is the most appropriate roadmap. Such an approach will create new economic growth paths, augment incomes, generate jobs and enhance millions of people's health and welfare. The IRENA (2016) report analysed the macroeconomic impacts of RE deployment from a global perspective. The report noted that by doubling the RE share by 2030, the global GDP is projected to rise to 1.1% thereby improving the universal welfare by 3.7% and generating more than 24 million jobs in the RE sector (IRENA, 2016). These figures provide evidence of the existence of a symbiotic and synergetic relationship between climate change mitigation through RE deployment and accomplishing socio-economic goals illustrating how investing in one mutually benefits and impacts the other. Provision of universal energy access and doubling the RE share in the global energy portfolio by 2030 relative to the 2010 figures form part of the UN Sustainable Energy for All (SE4ALL) objectives, initiatives that unite global governments with private sectors to reach a common goal of increasing an RE share growth to 30-36% from 2010's 18%. World governments are thus mandated to come up with clean energy technologies that promote a clean and environmentally friendly electricity supply that ensures sustainable development for current and future generations (Behrouzi, 2016).

2.3 Solar Energy and PV Systems Development

2.3.1 Solar Energy Potential

Technological advances in RE utilisation at large scale and commercial levels has opened new opportunities in the energy sector. Of the available renewable alternatives, the abundance, inexhaustibility and cleanliness of solar energy rationalises its selection as a prime source of energy. Solar energy intercepted by the earth is approximately 1.8×10^{14} kW, much more than the world current and future energy consumption requirements (Kannan and

Vakeesan, 2016). According to Khan and Arsalan (2016) the earth receives solar energy at a rate of about 120 petawatts, implying the daily energy received can suffice over 20 years of the global energy demand.

2.3.2 PV Systems Benefits

PV technology is thus introduced as one of the finest techniques that can harness part of this wasted solar energy to meet the world's sustainability objectives. This vast energy can be channelled at a large scale into a grid connected system to augment national supply. The assimilation of the PV systems into the national grid make them a major determinant in the overall power system reliability with associated positive and negative economic impact.

According to IEA (2014) solar PV systems offer the following advantages:

- Its wide availability globally reduces energy import dependence by countries that are net energy importers.
- It has no price increase risks and ensures security of supply.
- It enhances diversity of energy at the time hedging against price fluctuations of fossilised fuels. This stabilises the long-term electricity generation costs.
- No GHG emissions when in operation.
- The system consumes little or no water unlike thermal power plants that require extensive cooling especially in dry or hot regions.

The year 2014 witnessed a substantial growth in solar PV systems installation, generating approximately 40GW of the 177GW aggregate global capacity (Nhamo and Mukonza, 2016). Figure 2.2 shows the global solar PV capacity growth between 2004 and 2014. The increased investment in solar PV energy systems has been necessitated by favourable national investment policies that promote RE development.

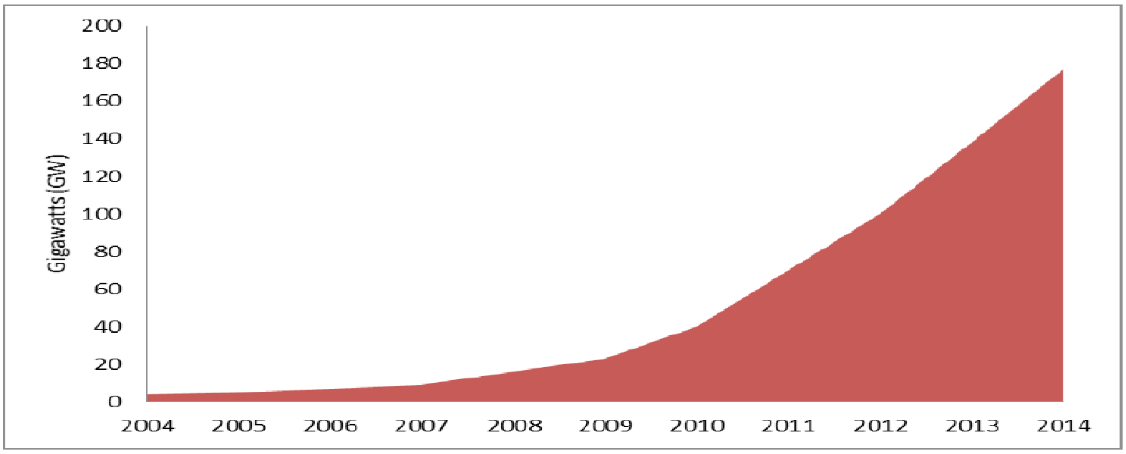


Figure 2.2: Global Solar PV capacity (2004-2014)

Source: Nhamo and Mukonza (2016)

The rapidly falling costs of PV panels have made solar PV generated power more cost competitive compared to fossilised fuels. The cumulative installed capacity for solar PV doubled with prices dropping by 22% (Nhamo and Mukonza, 2016). According to Pandey et al (2016) the wattage cost of solar PV fell from $3.50/W_p$ (1st generation solar cells) to $1/W_p$ for 2nd generation and it's expected to decline further to $0.5/W_p$ in the nearby future. National policies that are pro RE development e.g. feed in tariffs have promoted the popularity and investment in PV systems in most countries (Pandey et al, 2016). The vast share of this PV electricity was contributed by Japan, USA and China (Nhamo and Mukonza, 2016).

2.4 PV Systems Development Trajectory

2.4.1 RE Enabling Policy Initiatives: Global Synopsis

The global solar PV trajectory has been promoted by numerous regulatory and economic policy incentives and public bankrolling. The RE Feed in Tariff (FIT) has greatly stimulated and promoted the rapid deployment of solar PV systems and other RE technologies by guaranteeing RE electricity producers a fixed price (Nhamo and Mukonza, 2016). Japan, Australia and Europe have successfully promoted and popularised the investment and development of RE systems using Feed in Premiums (FIPs), net metering, RE auctions and FITs (IEA, 2014). The United States devised the long-term power purchase agreements (PPA) between power utilities and independent power generators to promote RE development. Some countries have used production or investment tax credits, investment rebates, cash grants etc. as incentives to promote RE investments while others have used renewable energy certificates (REC) as driving incentives for investment (Nhamo and Mukonza, 2016). The Chinese National Development and Reform Commission set a target to commission 100GW of solar power by 2020 with special emphasis being on distributed PV through rooftop arrays especially (UNEP, 2013, cited by Nhamo and Mukonza, 2016). In 2000 Germany enacted the Renewable Energy Sources Act to highlight the political will and commitment to invest in solar technologies and in 2014 it was contributing 35.7GW of the global total solar capacity (Energy for the future, 2015, cited by Nhamo and Mukonza, 2016). RE development is thus only possible if national governments create conducive environments for investment through creation of enabling policy frameworks.

According to IRENA (2015) the solar PV sector is the biggest RE employer in the world accounting for 2.5 million jobs of the estimated 7.7 million total RE jobs. The global manufacturing of PV panels is always soaring thereby lowering costs stimulating accelerated installation growth especially in the Asian countries particularly in Japan and China. Although the drop-in prices for solar PV is a challenge for PV manufacturers in some sections of the market, the resultant job losses experienced are countered by boosted PV installations as well as operations and maintenance expansions which spur employment growth (IRENA, 2015). A lot of job opportunities can be tapped from the solar PV system value chain during assembling, sales and distribution, installation, operation and maintenance etc., alleviating poverty through localised processes. Walwyn and Brent (2015) highlight in table 2.1 below Renewable Energy Technologies (RET) employment prospects in form of jobs created per megawatt of power generated.

Sub-sector	*Global average (jobs/MW)*	*Number of direct and indirect jobs (thousands)*			
		Global	***China***	***Germany***	***India***
Biofuels	*1.9*	*1 379*	*24*	*23*	*35*
Solar PV	*7.7*	*1 360*	*300*	*88*	*112*
Biomass	*1.8*	*753*	*266*	*57*	*58*
Wind Power	*1.7*	*753*	*267*	*118*	*48*
Biogas	*6.3*	*266*	*90*	*50*	*85*
Geothermal	*2.2*	*180*		*14*	
Hydropower (small)	*2.5*	*109*		*7*	*12*
Solar Thermal (CSP)	*2.0*	*53*		*2*	
Total		***4 853***	***947***	***359***	***350***

Table 2.1: RETs jobs (direct and indirect without solar water heating)
Source: Ren 21 (2013) and Wei et al (2010)

Per IRENA (2015) about 34GW of PV panels in 2014 were produced by China contributing about 70% of global production with approximately 80% of PV jobs coming from manufacturing. Future RE employment growth will largely rely on reverting to a robust investment course, perpetual technological advancement, price reductions, consistent and predictable policy frameworks and governments' commitment to the Paris climate change agreements (IRENA, 2015).

According to IEA (2015), international energy associated GHG emissions remained constant in 2015 for the 2nd consecutive year with global CO_2 emissions remaining stable at 32.1 billion tonnes in 2015. IEA preliminary statistics propose that RE based electricity greatly influenced the figures, contributing about 90% of new electricity production in 2015. With the global economy growing by about 3%, it is evident that economic growth is increasingly getting decoupled from GHG emissions. According to IEA (2014) PV systems generated approximately 160TWh/year clean electricity thus reducing about 140 million tonnes of CO_2 per annum. It is projected that solar PV system would contribute 4 $GtCO_2$/year of GHG emissions reductions, amounting to 19% of total electricity emissions discounts by 2050.

2.4.2 Global Climate Change Protocols

. The Rio Summit (1992), Kyoto protocol (1997), Copenhagen agreement (2009), Cancun agreements (2010), Durban conference (2011), Lima conference (2014) and the recently held Paris conference (2015) were key conferences held by world leaders to find the best approaches for climate change mitigation. Most of these protocols failed because there was no legal framework to enforce the negotiated commitments and the mitigation effort pledges were non-binding proclamations (LI, 2016; Tobin 2015). It was agreed at the COP17 Durban Conference that the global temperature rise mustn't exceed 2°C since the industrial revolution (Gough, 2013).

According to Kampmark (2015) the COP21 Paris Conference was an environmental pact that imposed numerous binding and voluntary actions within its custody. The GHG is expected to peak globally before abruptly reducing with an intention to harness temperatures to under 2 degrees Celsius above prior industrial levels. A climate mitigation fund of $100 billion per annum for developing nations was pledged by 2020, with future self-financing from developing countries. The goal of reducing pollution has been made easier by the continuously falling cost of RE technologies. The Paris Pact was the 1st ever worldwide, lawfully binding climate change agreement approved by 195 states (Mesik, 2015).

2.5 Renewable Energy Developments in South Africa

2.5.1 The Advent and Trajectory of Renewable Energies in South Africa

The RE expedition in South Africa has its roots in the 1996 constitution which mandated local governments to deliver services to communities in a sustainable way that promotes social and economic growth as well as a safe, harmless and very healthy environment (Sustainable Energy Africa, 2014). By inference this promoted the implementation of clean technologies, precisely RE projects. To facilitate optimal exploitation of the nation's copious RE resources there was a need by national government to craft and formulate the enabling policies that promote RE investment (DOE, 2015).

It is therefore important to outline pertinent national policy frameworks, plans and white papers that support RE investment and give relevance to the rooftop PV systems projects. According to UNEP (2012, cited by Reinecke et al, 2013) unavailability of energy policies promoting RE at all government tiers is a main factor that can hinder investment especially by private financiers. Johannesburg, by virtue of being the largest economic city of South

Africa by GDP, economic prospects of COJ are totally inseparable from national economic developments and usually the city benefits at a larger scale than other municipalities (Rogerson and Rogerson, 2015).

2.5.2 The South African Governance System

Before analysing key policies that provide an enabling environment to invest in RE particularly PV systems in the City of Johannesburg, it very important to understand how the South African governance system works. The country has a three-tiered unitary governance system modelled as central, provincial and local government. The central government formulates and pronounces the state's broad policy path and the two lower tiers take cue from the central government. However, these lower tiers can still have sufficient autonomy to execute programmes that are paramount and optimally suited to their priorities, available resources as well as their situations. South Africa's new Constitution (1996) gave these tiers the mandate to run and provide specified services or functions since they are closer to the general populace and strategically positioned to respond to the citizens' needs (DOE, 2015).

2.5.3 RE Key Enabling Policies Frameworks

2.5.3.1 The Constitution of South Africa

The constitution's Bill of Rights (Act No. 108 of 1996) compels the government to deliver or facilitate a healthy, harmless, secure environment that benefits current and future generations through application of rational legal frameworks and other aiding measures that stimulate sustainable development (Environamics, 2013). By insinuation this gives the government the mandate to act as the responsible custodian for the people and state's sustainable concerns by creating a conducive environment for RE investment.

2.5.3.2 Energy Policy White Paper (1998)

According to DOE (2015) the Energy Policy white paper was an all-inclusive document that appreciated the existence of inequalities in the energy sector in terms of energy utilisation and accessibility. The paper recognised the urgency to address these imbalances with a view to increase access to inexpensive energy services to the whole populace. The white paper's primary objectives were ensuring universal accessibility to affordable electricity and enhancement in energy governance frameworks. The Energy Policy white paper's significance in the RE arena was its ability to acknowledge and appreciate the express progression of RE technologies that was looming and the associated imminent cost competitiveness and cost effectiveness that would create bountiful prospective economic opportunities (Nhamo and Mukonza, 2016). The white paper highlighted the country's 1.6% global GHG emissions noting the energy domain as the chief contributor to the emissions. The paper emphasised the need to establish an assortment of sustainable energy portfolio providing a cost-effective energy service if social and ecological expenses are factored into the energy equation.

2.5.3.3 The Renewable Energy White Paper

The South African government as a significant global contributor to GHG emissions saw it fit to develop a policy document that could articulate the government's vision, policy principles, strategic goals and objectives for promoting and implementing RE (Department of Minerals and Energy, 2003). The RE white paper was born out of government's consciousness of the imminent depletion realities of coal as an energy source (DOE, 2015). The paper set a diversified target of 10 000GWh of RE to be achieved by 2013 from an energy mix of biomass, wind, solar and small scale hydro to ensure security of supply. The government had an obligation to create an enabling environment through development of strategic structures and instruments that would promote achievement of that target. The RE policy had to be aligned with the DME 2003 Integrated Energy Plan whose primary purpose was to create an energy balance between demand and supply with careful consideration of health, safety and environmental impacts. According to Eberhard et al (2014, cited by Nhamo and Mukonza, 2016), 10 000GWh target excluded solar PV and the target was not achieved in 2013 due to policy implementation delay.

2.5.3.4 The National Energy Act (Act No. 34 of 2008)

Diversification of energy supply in sustainable amounts at reasonable prices was one of the objectives of the National Energy Act (National Energy Act, 2008). The energy mix was meant to support economic growth and alleviate poverty considering the ecological management needs and relationships amongst different economic segments (Environamics, 2013). Emphasis was made on augmented generation and utilisation of RE as well as setting up contingency supplies and sufficient investments. The tone of the act therefore set a vibrant and supportive environment to promote RE growth a sustainable future.

2.5.3.5 The National Climate Change Response White Paper

The National Climate Change Response Policy white paper (2011) was a major white paper that buttressed South Africa's RE objectives. This paper was essentially steered by an approach known as the Long-Term Mitigation Scenario (LTMS) plan. This technique was derived from the realisation that the country had an obligation to contribute to its stake to mitigation with the full knowledge that the economy was a very energy intensive industry heavily dependent on coal. The government embraced peak, plateau and decline trail (National Climate Change Response White Paper, 2011). A tactical trajectory was implemented where South Africa's emissions would propagate for a while, then peak between 2020 and 2025 producing 550Mt CO_{2eq}, remain constant for a decade and absolutely falls from 2030-2035 going forward. This was a major and key stride originating from a developing nation during climate change discussions. The South African President internationalised the pledge by committing the nation to consider mitigation efforts that would lessen the GHG emissions by 34% below the Business As Usual path 2020 provided there was international monetary support and suitable technology transfer. Figure 2.3 illustrates the proposed scenario. For the ambitious peak, plateau and decline scenario to be realised there is need for the national government to collaborate with local government creating the requisite partnerships that promote achievement of a sustainable future as highlighted in figure 2.3 below.

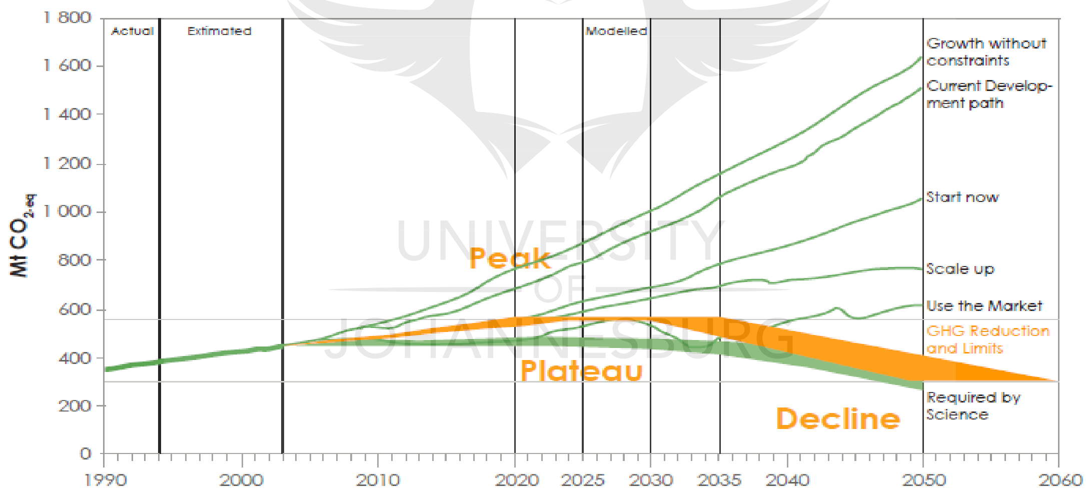


Figure 2.3: South Africa GHG emission reductions and limits

Source: DOE (2015)

2.5.3.6 Industrial Policy Action Plan (IPAP)

IPAP was an inclusive industrial strategy developed by the South African Department of Trade and Industry (DTI) after realising that the industry was a primary contributor of carbon emissions. The DTI through IPAP is very instrumental in the advancement of RE in South Africa. IPAP's main goal is to aid the development of domestic manufacturing base with the green energy sector being prioritised especially solar and wind industries (Montmasson-Clair et al., 2014). This base includes the advancement and distribution renewable technologies.

2.5.3.7 Integrated Resource Plan (IRP 2010-2030)

The Integrated Resource Plan for Electricity published in 2010 was a document that gave influence to the national energy policies to provide a framework for electricity demand management in the country from 2010 to 2030 (DOE, 2015). It officialised and broadened the government's intents and purposes as ascribed in the 2003 RE white paper. The plan targeted 40% of planned future electricity generation to come from renewable sources by 2030.

2.5.3.8 New Growth Path

The Department of Economic Development introduced the New Growth Path (NGP) after conceding the requirement to consider compromises between the current costs and prospective benefits of green economies (Montmasson-Clair et al., 2014). NGP targeted creation of 300 000 new job opportunities in the green economic sectors by 2020, over 400 000 jobs by 2030 with manufacturing contributing 80 000 jobs with the remainder coming from construction, maintenance and operations. NPG was complimented by the Green Economy Accord of 2011 an accord signed by government, labour, business and civil society with an intention to harness green economy prospects to create jobs (Mbadlanyana, 2013).

2.5.3.9 National Development Plan (NDP)

According to Msimanga and Sebitosi (2014) the NDP developed in 2011 offered a strategic platform for policies as well as planning instruments that support a low carbonised economy by describing a transition to a carbon economy that is environmentally sustainable in the short (till 2015), medium (2015-2020) and long term scopes (2020-2030). The NDP highlighted the need to decouple the economy from environmental degradation and carbon intensive energy production without compromising economic competitiveness with an objective to reduce poverty, unemployment and inequality (Montmasson-Clair et al., 2014).

2.6 Gauteng Provincial Government RE Policy Direction

The Gauteng Integrated Energy Strategy (GIES) was published in 2010 by the Department of Local Government and Housing. The key objective was to integratively promote and execute all-encompassing energy pronouncements directing energy supply and usage within Gauteng Province over a 4-year span (2014), 15-year period (2025), 45 year span and yonder (DLGH, 2010). The strategic aim was to improve the province's environment through reduction of

GHG emission contributions, energy poverty alleviation and economic development promotion. Where national sustainable energy initiative projects were already in execution GEIS would complement and create synergies with these projects. The strategy advanced for a RE share of 7% by 2014, 16% by 2025 and 47 % by 2055 from the total energy mix.

In 2011 the Gauteng Green Strategic Programme was published in collaboration with Gauteng City Region Observatory (GCRO) and Gauteng Department of Economic Development with Provincial Government Departments and Gauteng local governments adding input as well. The programme envisaged Gauteng as an RE nucleus redirecting itself towards green advancement and green job creation. RE administration was expected to be coordinated through a central Energy Office handling on all provincial and municipal RE matters. However, such an office is still to be set up.

2.7 RE Deployment Policies

2.7.1 Global RE Deployment Policies

RE deployment policies are very instrumental in motivating RE market development as it creates demand for RETs, triggering investment in the energy sector. Such policies create an enabling environment for investment and augment installations that lead to value creation directly or indirectly. World governments have endorsed a diverse number of policy mechanisms and objectives that stimulate RE deployment.

2.7.1.1 Regulatory Policies and Targets

1. Renewable Portfolio Standards (RPS) and Quota

   Under such policies, the producer is expected to source a prescribed percentage of their power from RE. This incentivises the electricity producer to invest in RE projects by investing directly or indirectly through purchase of tradable green certificates from other power producers (IRENA and CEM, 2014). Policies of this nature can be introduced at national, provincial or municipal level to promote the best cost-efficient technologies.

2. Feed in Tariffs (FITs) and Feed in Premiums (FIPs)

   These policies are popular in the developed and developing world. Eligible RE producers are assured a standard buying price or a supplementary premium rate for the electricity they generate. According to DBCCA (2010, cited by IRENA and CEM, 2014) FIPs and FITs were instrumental in the development of about 75% of the global

PV solar capacity. REN21 (2015) asserts that by the beginning of 2014, FIPs and FITs were adopted by 68 state governments.

2.7.1.2 Financial Incentives and Public Bankrolling

To encourage and motivate private investors numerous financial incentives as well as public bankrolling can be implemented in the RE sector. These can be tax immunities or exemptions, public funding, capital subsidisations, production or investment tax credits etc.

1. Tax exemptions

   These are applied as auxiliary support policies where RE generators are offered full or partial tax exemptions to establish a balanced operating environment with the orthodox energy suppliers. These tax reductions can be applied on imports, sales or value added tax to aid in the importation of RE equipment during the early stages of RE development.
2. Capital Grant, subsidies and rebates

   The government can offer various monetary incentives to private entities to cushion a specified investment percentage of the RE system cost in order to minimise investment expenses. These incentives can enable ease access to financial funding through concessional loans for RE projects (IRENA, 2012b, cited by IRENA and CEM, 2014).
3. Auction Schemes

   The government publicises bids for the installation of specified energy capacities. Potential energy generators respond by submitting offers with unit prices of electricity for evaluation. The selected bidders sign PPAs with power utilities or government. Auction schemes can be technology explicit if there is a requirement to promote specific technologies to diversify the energy mix (IRENA and CEM, 2014). The auctions are sometimes non-aligned to promote the development of a cost competitive or effective technology. Auction designs can give governments a provision to promote the development of the local industry by prescribing local content percentages that ensures value creation across the sectors of the value chain.

Table 2.2 gives a summary of the number of countries that have enacted specified RE deployment support policies.

Policy	Policy Type	Number of Countries
Fiscal Incentives	Tax Reduction	91
	Renewable portfolio standard	29
	Renewable heat obligation/mandate	19
Regulatory policies and targets	Biofuel obligation/mandate	58
	Feed-in tariffs[a]	68
	Net metering	42
Public financing	Auctions/tenders	55

Table 2.2: Number of countries endorsing specific RE support policy frameworks (early 2014)
Source: IRENA (2015)

[a]Includes FIPs

2.7.2 South African RE Deployment Policies

2.7.2.1 Renewable Energy Feed in Tariff (REFIT)

The REFIT programme was introduced in South Africa in 2008 to fast-track RE introduction into the energy market to counter the austere electricity shortages of 2008 (DOE, 2015). It was informed by international best practices and global experience of countries like Germany, Denmark, Spain etc. where REFIT was successfully implemented to encourage acceptance of RE technology at large scale commercial levels (Nakumuryango and Inglesi-Lotz, 2016). The National Energy Regulator (NERSA) in 2009 endorsed a RE tariff policy, recommending a tariff structure aimed at covering generation expenses and a real after tax yield on equity of about 17% wholly indexed for inflation (DOE, 2015). The REFIT pricing strategy confirmed the country's commitment to RE technologies promotion and inspired market inquisitiveness thus drawing global investors' interest.

The REFIT rates published included wind with a tariff of R1,25/kWh, PV solar rated at R3,94/kWh and concentrated solar rated at R3,14/kWh. REFIT tariffs were revised downwards by 25% in March 2011. According to (DOE, 2015) this price reduction precisely mirrored the true market pricing trends and technological advancements as shown in figure 2.4 below.

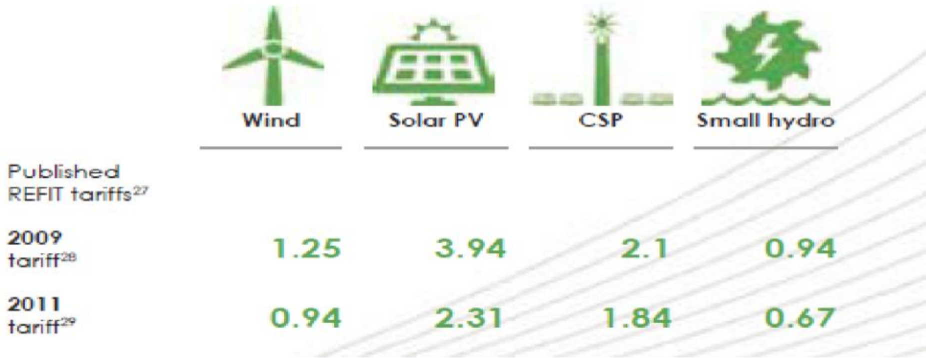


Figure 2.4: Published REFIT tariffs

Source: DOE (2015)

Even though the programme looked promising it encountered legal challenges in terms of the procurement framework and Eskom's desire to back the programme through power purchase agreements. Legal opinion sought revealed that the REFIT programme flouted the procurement and public finance regulations and towards late 2011 NERSA ended the REFIT programme and proclaimed a competitive bidding method called the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) which proved to be an instant success.

2.7.2.2 Renewable Energy Independent Power Producer Procurement Programme (REIPPPP)

The REIPPPP programme was introduced in 2011 by the Department of Energy as a substitute to the stillborn REFIT programme. The programme offers a comprehensive enabling atmosphere for RE Independent Power Producers (IPP) to bid for targeted megawatt allocations as spelt out in the IRP 2010-2030. According to Minnaar (2016) the South Africa IRP 2010-2030 programme targets commissioning of 17.8W of RE generation with 8.4GW coming from solar PV, 8.4GW wind and 1GW from CSP. The REIPPPP exclusive design entails a competitive bidding methodology founded on the best price as well as sustainable development contribution based on 70% price and 30% economic enhancement weighting.

According to DOE (2013, cited by Pollet et al, 2015), South Africa is ranked the 12th most suit after investment destination for implementing RE technologies and has attracted foreign direct investment in excess of $14 billion to date. According to the UNEP 2014 report, South Africa is ranked amongst the world's top ten nations that have invested extensively in RE technologies in a period of less than 5 years. The REIPPPP programme has been internationally acclaimed because of its associated transparency, impartiality, consistency and certainty (Pollet, 2015). The programme has brought a cost effective, sustainable power infrastructure that contributes to electricity supply security coupled with worthy investment and economic development (DOE, 2015). This has been made possible through contributions from government, private domestic and international investors, global donor community etc. who contributed substantial capital and technical knowhow into the RE sector in the country (Minnaar, 2016). According to Pollet (2015), the project so far has contributed over $0.8 billion towards socio-economic sustainable development. To demonstrate government commitment, $1.24 billion was approved from Industrial Development Corporation to support the green economy agenda (Pollet, 2015).

To date the exceptional bidding process has managed to deliver 92 IPP capable of contributing over 6327MW. The REIPPP has augmented the national supply capacity and increased diversity in just three and half years (Minnaar, 2016). To this day, the DOE has managed to procure 5243MWs renewable electricity at competitive prices from Bid windows one to four. Currently 37 projects have been connected giving a total capacity of 1827 MW to the national grid thereby easing the power demand pressure by providing an average of 15% to the grid during peak periods. It was envisaged that by mid-2106 RE contribution is approximated to 7000GWh per annum as 47 REIPPP become fully operational (DOE, 2015). This competitive bidding scheme has seen the RE tariffs for wind declining by 55% to 62 cents per kilowatt hour on average and solar PV dropping by 76% to 79c/kWh. According to (DOE, 2015) the REIPPP projects are already spending on the socio-economic growth and enterprise enhancement obligations. The DOE 2014-2015 Annual report further asserts that an expenditure pattern is unfolding where most expenditures are allocated to health care, accommodation improvements, education and skills training etc.

Figure 2.5 shows PV and Wind RE produced by REIPP during 2014. From November 2013, the REIPP programme has supplied 4,3TWh to the national grid with 15% being contributed during peak hours. Figure 2.5 illustrates RE progress compared to planned targets.

The Department of Energy (2013) states that approximately 4298GWh generated from REIPPPP have been consumed via national grid connection contributing an estimated 4.4 Mt of $CO_{2\ Equivalence}$ emission reductions (Nhamo and Mukonza, 2016). The REIPPPP programme has managed to advocate local content contributions for RE projects thus promoting the development of local manufacturers.

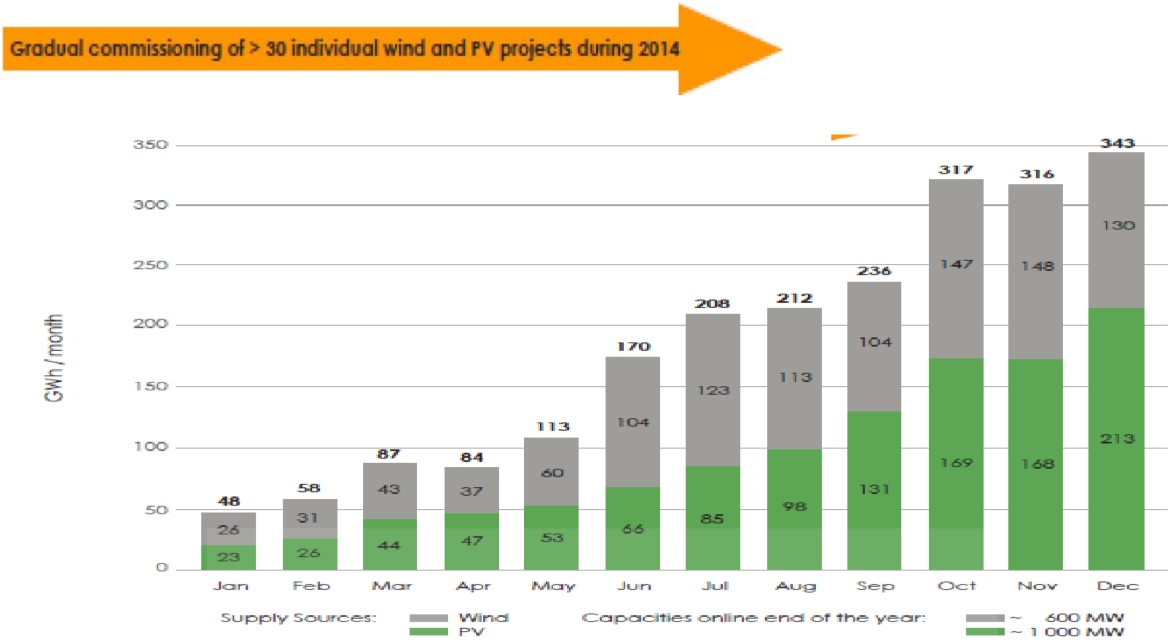


Figure 2.5: RE progress compared to planned targets

Source: DOE (2015)

2.8 Solar PV Growth under REIPPPP

According to Nhamo and Mukonza (2016) solar PV projects lead REIPPPP programmes with a 52% share, contributing an estimated 2219MW. From figure 2.6 below the solar energy cost has been declining for each subsequent bidding window. The price reductions imply that it's getting cheaper to implement RE as evident from the perpetually tumbling prices year on year and these prices have fallen by 76% since 2011 (Nhamo and Mukonza, 2016). The REIPPPP programme has seen the solar PV industry contributing more than 20 000 jobs in the value chain (Nhamo and Mukonza, 2016). There are great numerous job opportunities that can still be created in the solar PV industry as it's still in its infancy in South Africa.

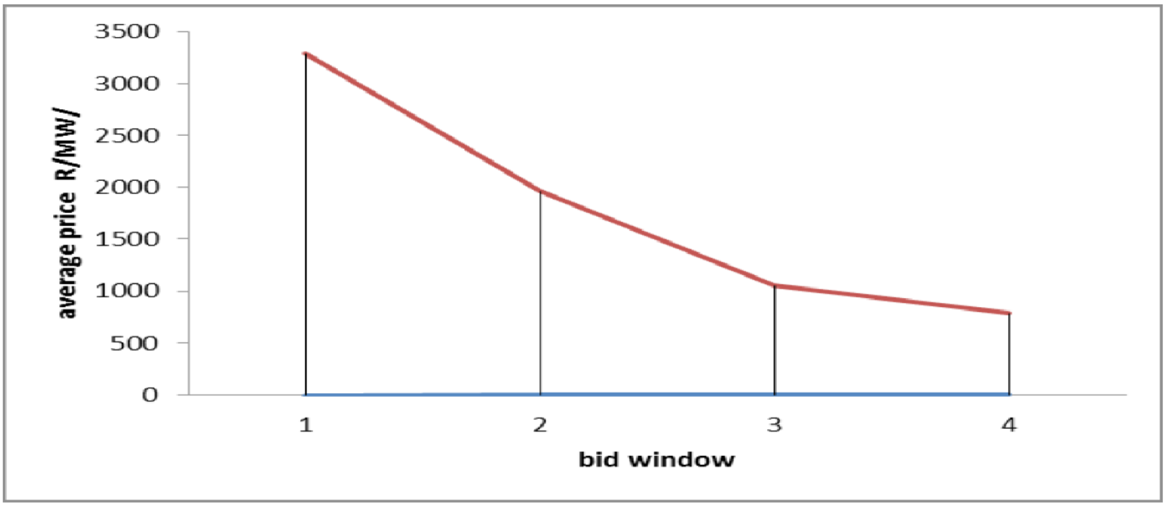


Figure 2.6: Solar PV price drops (2011-2015)

Source: Nhamo and Mukonza (2016)

2.9 RE Developments within City of Johannesburg (COJ)

Because South Africa is a signatory to Kyoto Protocol on Sustainable Development and other protocols thereafter, the City of Johannesburg as a main contributor of carbon emissions has to play a major role in implementing carbon emission mitigation strategies as well as structuring its sustainability policies to align with the ratified protocols.

Currently the RE use is still in its infancy and its contribution to the national grid is still negligible compared to Eskom supplied electricity (Ilze, 2015). The country's IRP 2010-2030'e electricity generation plan targets only 10% RE supply to the national grid with 8400MW targeted for PV systems. This however still implies the grid supply is still highly carbonised. As the global GHG emission regime becomes tighter, considering South Africa's commitment to global climate change pacts and the financial and economic sense it's very logical to consider RE as the energy of the future. Centralised electricity management implied RE development wasn't a focus of municipalities in South Africa. The situation has drastically changed due to the decreasing RE prices, Eskom electricity price escalations, global climate change threats and the confidence and assurance derived REIPPPP's global success story (DOE, 2015).

2.9.1 Landfill Gas to Electricity Project

The current main highlight on the city's RE journey is the landfill gas to energy Clean Development Project (CDP) project. In 2000 COJ's Environment Infrastructure and Services Department (EISD) initiated this project to manage and mitigate odorous and toxic GHG gases discharged from landfills (JIKE, 2012). Major GHG emissions come from CO_2 and methane which is environmentally 21 times more toxic than CO_2. High concentration of gases creates unpleasant environs for the neighbourhood. Methane is a highly flammable gas and high concentrations can cause fire hazards. Managing the landfill gas is very crucial as it aids to lessen GHG emissions that impact the ecological setting. The project is used to fulfil the Kyoto protocol mitigation commitments on CDMs, at the same time generating revenue by selling the Certified Emission Reductions (CERs) as well as selling the electricity generated. Five landfill sites were identified in Johannesburg with a potential to generate 19MW capable of supplying 12 500 middle income households for over 20 years (DOE, 2015). Currently the Robinson Deep landfill site is generating 5MW of electricity which translates to approximately 149 000 tonnes of CO_2 per year. This site has managed to generate 137 888 CERs and destroyed 18 288 457 Nm^3 of landfill gas which was supposed to be discharged into the air. The projected registered with UNFCCC in 2012 and already trading the accrued carbon credits. Other four sites include Marie Louise, Goudkoppies, Ennerdale and Linbro Park.

2.9.2 The PV System Choice within COJ

Solar energy is considered as the highest promising RE source that can stimulate future energy security (Abubakar Mas'ud, 2016). According to Maia et al (2011) the South Africa experiences sunshine for approximately 300 days per year with 8.5 hours a day of average sunshine and a mean radiation of between 4.5 and 6.5kWh/m^2 per day. This makes it an ideal location for PV plants. In cloudy weather PV systems can still function at lessened power output of course. According to Maia et al (2011) and Nhamo and Mukonza (2016) solar PV systems offer the following advantages and disadvantages:

Advantages:

- The solar PV technology is smart and non-polluting eliminating the GHG emission challenges.
- The technology is a silent and motionless technology with no moving components during energy generation resulting in minimised maintenance.
- The technology is easily scalable because of its modular nature. Hence, it's easy to expand the system over phased intervals.
- It's easy to achieve economies of scale.
- There is a great potential for localising the PV industry.

- There are low maintenance costs and minimal water use, very advantageous to COJ considering the water challenges within the city.
- The PV plants offer fixed cost energy generation resources.
- It's a feasible alternative to supply energy to settlements where energy infrastructure is poorly developed like informal settlements or high energy demand areas as it can be modularly expanded.
- PV system roll out is relatively easy.

Disadvantages:

- The technology is still evolving with total energy conversion efficiencies ranging between 10 and 17%.
- The technology has high upfront investment expenses with most success stories being buttressed by subsidised schemes from national governments.
- The technology is found wanting during night peak loads because of the periodic nature of solar. To counter these expensive batteries consuming 30-40% of the system costs are needed and these need replacement every 7-10 years.
- The low efficiency levels imply more space is required to meet capacity requirements e.g. 1MW PV power generation requires about 2-3 acres of land.
- Weather conditions affect energy production with marked declining efficiencies under cloudy conditions.
- Solar insolation is affected by geographic boundaries fluctuating amongst localities.
- Some modules are manufactured from very lethal chemicals e.g. lead, mercury, cadmium etc. and sulphur hexafluoride can be released.

To address these negative effects national and municipal bylaws to inhibit these social and environmental impacts must be issued. PV panel recycling policies at end of life must be implemented and manufacturers must be made responsible for ultimate disposal of solar equipment.

2.9.3 The role of Battery Storage Technology in RE Development

The intermittent nature of RE generation sources due to fluctuating meteorological conditions cause the grid instability and unreliability (Subburaj et al, 2015). The intermittent nature and fluctuations of RE energy is a source for concern especially for solar energy cynics. Despite the RE technology black spots, the current developments in battery storage technologies is good news for RE systems progression and investment. Battery technologies can smoothen and stabilise the intermittent power generated by RE sources by providing stable and reliable power during low power production and storing extra energy during excess energy generation (Zahedi, 2011). An energy storage system is handy as it can aptly offer emergency power as well as meet peak demand challenges. Such a system has load-following capabilities, a very crucial characteristic of generation side management (Zahedi, 2011). Various battery storage technologies on the market include lead acid, redox flow, lithium ion, sodium sulphur batteries etc. The power capacities range from below 100kW to numerous megawatts with capabilities to store energy of up to tens of megawatt hours (Subburaj et al, 2015). According to Subburaj et al (2015) the low cost and technology maturity of lead acid batteries give them continued market acceptance despite their low energy density. The other batteries above have very long life spans that decrease their levelised cost of storing energy. Despite lithium ion's highest energy density in comparison to other storage banks, it still has high energy storage costs which limits its usage. Currently a lot of research is ongoing to come up with batteries with optimised energy densities that are extremely efficient and cost effective in order promote the acceptance and implementation of RE sources like PV systems as grid connected energy sources (Subburaj et al, 2015).

2.10 Rooftop Solar PV Success Stories: Case Study Review

To illustrate practical benefits that can be enjoyed by implementing PV systems into the city, a municipal case study of Queensland, Australia, 2 Johannesburg local case studies and the Stellenbosch panel manufacturing project have been described below. The 1st three case studies highlight how the energy capacity can be increased to close energy security gap, lessen GHG emissions, reducing electricity costs in the process. The Stellenbosch panel manufacturing project illustrates the PV research advancements in South Africa and the potential benefits derived from locally manufacturing PV panels.

2.10.1 Queensland Rooftop PV Solar

According to Markey Bailey, Queensland Australia Energy Minister, by capacity rooftop PV solar on domestic and commercial premises is going to mature into the largest power generation plant in Queensland (Parkinson, 19 February 2016). Currently Queensland boasts of 1.5GW of rooftop PV solar on commercial and domestic premises. Bailey further projects that by 2020 the rooftop PV capacity is going to reach 3000MW. To ease the peak demand, Bailey highlighted the critical need for energy storage technology to help utilities integrate rooftop PV systems into the grid network. For Queensland, the snowballing peak, is mostly from air conditioners, which are accounting for about half the electricity costs. Bailey views the battery storage technology as the game changer with battery storage prices plummeting every day. Incentives to fast track battery storage technology implementation have been adopted in the form of grants. Capital to the tune of Australian $100 000 has been injected for the development of battery safety standards. Battery storage tests conducted so far by Queensland are already highlighting domestic consumption cutbacks during peak demand, saving money in the process. According to Vorrath (15 February 2016), Australian Greens enacted a new policy that aids in cutting the local government energy bills by installing PV solar on municipal buildings. Municipalities are to offer roofs of administrative buildings, libraries, swimming pool buildings, bus depots and hospitals for cheaper power bills.

Coming nearer home, the Johannesburg Clearwater Mall and Pick n Pay Hurlingham rooftop PV solar projects described below are two other encouraging developments by a private investor to illustrate the great potential of rooftop PV solar in alleviating the electricity shortages and carbon footprint reduction, key sustainable objectives as the city matures into the world class African city of the future.

2.10.2 Clearwater Mall Rooftop PV Solar project (Source: Nhamo and Mukonza, 2016)

Clearwater mall rooftop solar PV project, covering about 4000 m^2, is the largest rooftop system in Africa with 2000 panels each offering 250W to give 1.5MW total capacity. Annually it generates 843MWh, lessening the carbon footprint by around 884 tonnes/year thus saving coal amounting to approximately 1000tonnes/year in electricity generation. The solar system lessens grid dependence and saves 10% of the mall's aggregate consumption. If such projects are implemented on malls and other properties with appropriate rooftops, it will be greatly help and fast track the achievement of IRP goals and the city's IDP objectives.

2.10.3 Pick and Pay Rooftop PV System (Source: Msimanga and Sebitosi, 2014)

Pick and Pay supermarket commissioned a 100kW rooftop PV system in October 2010 in Hurlingham in Johannesburg (Msimanga and Sebitosi, 2014). The system is providing 25% of the supermarket's power requirements and reduces carbon emissions by 4000 tonnes in 20 years. The Investment has brought enormous financial benefits though electricity cost savings with a payback of around 7-10 years. An additional 150kW was added to the system in 2011 to reduce the carbon emissions by a further 6000 tonnes in the two decades (Msimanga and Sebitosi, 2014).

2.10.4 The Stellenbosch Panel Manufacturing Project

Photovoltaic Technology Intellectual Property (PTiP), a company jointly owned by University of Johannesburg and Industrial Development Corporation situated in Stellenbosch, developed a 2nd generation photovoltaic thin film panel with over 80% local content material (PTiP News, 2014a). According to PTiP (2014a, 2014b) PTiP modules convert weak sunshine more effectually than the orthodox PV panels with over 15% panel efficiency. PTiP modules are ideal for the South African environment and the high temperature sub-Saharan African regions due to their reduced overheating sensitivity and low temperature coefficient (PTiP, 2014a). According to Vivian Alberts, CEO of PTiP, payback period for the new generation thin-film photovoltaic systems is between 3 to 5 years over a guaranteed 20 year lifespan (PTiP News, 2014b). Vivian Alberts further asserts that the light grey to black module colours make it easy to aesthetically incorporate the modules into most buildings. According to Vivian Alberts, creation of a PV plant can prospectively create more job opportunities in comparison to a coal fired power plant, with downstream activities in sales, merchandising, operation and maintenance services offering providing a significant incentive (PTiP News, 2014b).

2.11 Why Rooftop PV System within COJ?

Of the available RE sources rooftop PV solar systems have been viewed as the sustainable energy game changer as the city attempts to realise its sustainability objectives. This has been necessitated by the PV systems price decreases, Eskom price hikes, climate change challenges, confidence inculcated by REIPPPP and municipal global developments in rooftop PV solar investments e.g. the Queensland Australia case study. Installation of solar PV systems in the city has been necessitated by various reasons that in turn have brought a portfolio of benefits as highlighted below:

- The City of Johannesburg has a land size of 1,644km^2. This gives impediments in terms of space to implement solar or wind farms. Therefore, the most appropriate solution is to implement PV systems on the city's building rooftops. The city is endowed with a lot of appropriate buildings e.g. administrative buildings, clinics and hospitals, libraries etc. which consume considerable quantities of electricity. Installation of rooftop PV solar can reduce electricity bills by a significant amount as highlighted in the Clearwater Mall case study.
- The introduction of PV systems aligns itself very well with government Energy Efficiency Strategy policy whose goals embrace three cornerstones of sustainable development i.e. environmental, social and economic sustainability (DME, 2009).

- Installation of rooftop PV systems reduces dependence on coal generated electricity thereby closing the city and national electricity supply demand gap positively impacting the city's socio-economic sustainability dynamics.
- Diversifying the energy mix ensures augmented security of supply. The PV systems portfolio can positively counter the forever increasing electricity demands without contaminating the atmosphere through GHG emissions. The proposed PV system is expected to augment capacity of the national energy mix thus contributing to the 42% RE mix expected from IRP 2010-2030 target (DOE, 2015) and contributing to the 8.4GW from solar PV systems by 2030.
- The proposed project can ensure economic growth and security by lessening of electricity supply deficits. Electricity constrains curtail economic development and improved reserve margins ensure a platform of economic enhancement.
- PV installation promote the city's economic progression as it promotes industrial development to complement provincial and national objectives at the same time promoting skills development. Such a project can create lot of opportunities across the PV systems value chain in the form increased jobs, business opportunities, sales and tax revenues, carbon credit sales revenue and improved foreign direct investment.
- Successful implementation of this project will encourage private players with appropriate rooftops to consider and invest in PV systems to make a further contribution to the IRP2010-2030 RE national targets and the GHG emissions reduction set out in the peak, plateau and decline targets.
- Johannesburg economy is very carbon intensive making it imperative to have an RE biased energy mix (Maia et al, 2011). The existence of the finest global solar resources in South Africa offers the best opportunity to pursue PV projects in Johannesburg. Rooftop PV system will make a significant contribution to GHG emission lessening by decreasing the coal dominance and overdependence during electricity production. The use of PV systems as a clean technology reduces the city's carbon footprint thereby aligning the city's energy strategy with the New Growth Path Policy, Climate Change Response Policy and Johannesburg Climate Change Strategy which all put special emphasis on cleaner technology and products. GHG emission reductions can increase the city's revenue through trade of carbon credits as the project can qualify as a CDM project. The project would make a remarkable

contribution to GHG emission lessening and contribute towards climate change alleviation.

- The project will have substantial enduring derived progressive social effects that can be induced to provincial or national scales. Much needed experience can be obtained by locals during the building, operation and maintenance of the PV system. This experience obtained can be utilised to set up other similar projects within and outside South Africa.
- Bringing in PV systems to the City of Johannesburg comes with socio-economic benefits. Solar manufacturing industries are created. This creates job opportunities in the manufacturing, installation and maintenance sectors. The proposed project will offer contracts to local companies who will hire personnel for the period of the project. Operation and maintenance stages will offer direct, indirect and induced permanent employment opportunities to locals especially general labourers, security guard, transporting and catering opportunities etc. This also would make a significant contribution to poverty alleviation and social sustainability in general.
- Besides GHG emission reductions, use of PV energy systems will prevent pollution coming from coal mining activities. Coal power generation generally requires massive water capacities. According to Maia et al (2011) South Africa is faced with severe water and waste management challenges. Appropriate management and conservation of the limited water resources is promptly needed so that the country can avoid huge sustainability challenges. PV systems are clean and environmentally friendly technologies with no GHG emissions requiring only minimal water quantities to clean them. They therefore promote healthy sustainable environment for employees and the general populace.
- Johannesburg has 181 informal settlements with an estimated 180 000 households. This coupled with over 10 000 migrants arriving in Johannesburg every month makes provision of electricity and other amenities a great challenge (City of Johannesburg, 2013). According to City Power (2013), informal settlements are the cause of 13% power losses within Johannesburg through illegal electrical connections. In winter many people in informal settlements perish because of fires caused by unsafe cooking as well as heating appliances. PV systems can help to minimise these catastrophes and lessen opportunistic criminal activities happening under cover of the night.

The city's sustainable energy development efforts through PV systems will greatly contribute towards the fulfilment of South Africa's commitment to the Kyoto Protocol on GHG emission mitigation endeavours at the same time improving the energy security in the country and creating other socio-economic benefits crucial to meet the city and the country sustainable development goals and objectives.

2.12 City Power and PV systems Investments

City power, a subsidiary of COJ, is the utility power whose core business is to procure, distribute and sale electricity to the municipality's domestic, commercial and industrial customers within COJ's municipal boundaries (Webb, 2014). The South African power utility, Eskom distributes about 60% of its electricity directly to customers with the remaining 40% being distributed through municipalities. City Power procures the majority of its electricity from Eskom (80%) with Kelvin Power Station an independent supplier, contributing the remaining 20% (City Power, 2013). Currently City Power has approximately 410 000 clients i.e. industrial, commercial and domestic customers. According to City Power (2013), the power distributor is currently on a business model review to become an energy generation company. The company intends to enhance energy supply security, improve its energy mix to include RE based electricity and to reduce GHG emissions. All this is expected to be done without burdening or encumbering the customer with increased costs.

As previously alluded, the continuously tumbling PV solar prices make them a good choice for sustainable energy provision. According to City Power (2013), COJ has embarked on a trajectory to become a sustainable smart metropolitan of the future as highlighted in the Joburg 2040: Growth and Development Strategy. Despite electricity being a key component in unravelling the socio-economic development goals, unrestrained consumption of coal based electricity will continue carbonise the city, menacing the city's sustainability endeavours and threatening quality of life in the city (City Power, 2013). According to Sicelo Xulu, Managing Director of City Power, South Africans are burdened by the ever-increasing electricity costs resulting in reduced electricity consumption by clients. Although this is good for electricity supply stability and a diminished carbon economy, the associated opportunity cost in lost revenue need to be carefully analysed as it has a negative impact on business development. Lower consumption is a wakeup call to devise innovative as well as cost effective approaches that fulfils the city's mandate to achieve commendable service delivery (City Power, 2013).

2.13 Build Operate and Transfer Contract and REIPPPP

According to World Bank Group (2016) Build-Operate and Transfer (BOT) is a contract arrangement where a private entity builds or develops an infrastructure project, operates the scheme and finally transfers proprietorship to the government. Usually the government becomes the company's sole customer with an undertaking to buy a predetermined amount of the project output. This ensures that the firm recoups its capital investment and makes profit in a reasonable timeframe through fee charges rather than tariffs billed to consumers. In the power sector such an agreement is structured in the form of Power Purchase Agreements (PPA)

As the city moves towards electricity generation, there is a need for the city to critically analyse the best possible business model that makes the city take advantage of the existing city rooftops, both private and public. The city can negotiate favourable deals or rent out rooftops of commercial and industrial buildings to install solar PV systems to augment its energy supplies. The city through City Power should take full advantage of the success story of REIPPPP programme to develop its energy system through rooftops. The global PV market trends and competitive bidding approach of REIPPPP which has seen drastic PV solar price reductions should stimulate the city to invest in rooftop PV systems. The City Power in its endeavour to become an energy generating company need not reinvent the wheel. It should use the tried and tested REIPPPP methodology to invest in the domestic, commercial and industrial markets and enjoy benefits of such a successful approach. It should enter into BOT agreements and sign PPA agreements with independent power producers. Such an approach can greatly improve the city's energy situation and unlock the economic potential of the city as it has been suppressed by DSM schemes. The city's carbon footprint can be lessened by large scale investment in PV systems.

2.14 Johannesburg's Business Strategic Position

A robust investment in PV solar systems boosted economic growth of most countries especially China, Germany and Japan. According to Rogerson and Rogerson (2015), Johannesburg is viewed as the countries internationally connected economic hub that hosts big corporates with commercial and investment links traversing Sub-Saharan Africa. It is a critical node for global capitalism especially in the Southern Hemisphere with 74% of South Africa's corporate headquarters domiciled in Johannesburg (Rogerson and Rogerson, 2015). Johannesburg's global connectedness makes it the continent's investment springboard that can attract huge much needed foreign direct investment (FDI) (Rogerson and Rogerson, 2015). COJ should thus take advantage of the economic centre of power held by Johannesburg to lure big business to invest in rooftop PV solar to achieve the municipal and national sustainable objectives. The economic central position of Johannesburg can be utilised to develop a one stop shop for RE and PV systems solutions targeting Africa where RE development is still in its infancy. It is therefore essential to analyse the value chain prospective opportunities that can be realised if large scale rooftop PV investments are done in the city.

2.15 Rooftop PV Systems Value Chain

The PV industry is generally cross-sectional in nature as it interacts with different economic sectors. Analysis of the value creation during PV systems deployment characteristically follows a life cycle approach trajectory, scrutinising the product process from conception, planning, design and manufacturing, grid connections, to operation and maintenance as well as decommissioning, disposal or recycling (IRENA and CEM, 2014). The life cycle perception is normally linked to the value chain analysis methodology. UNEP and SETAC (2009) asserts that as a product flows through the stages of the product chain or life cycle, it gains value through the value chain processes. IRENA and CEM (2014) defines value chain as a connection of all activities that an organisation doing business in a specified industry executes in an endeavour to deliver a valuable service, merchandise or product to the customer with all value adding activities incorporated. The PV system value creation prospects at respective stages of the value chain and associated processes is illustrated below in figure 2.7.

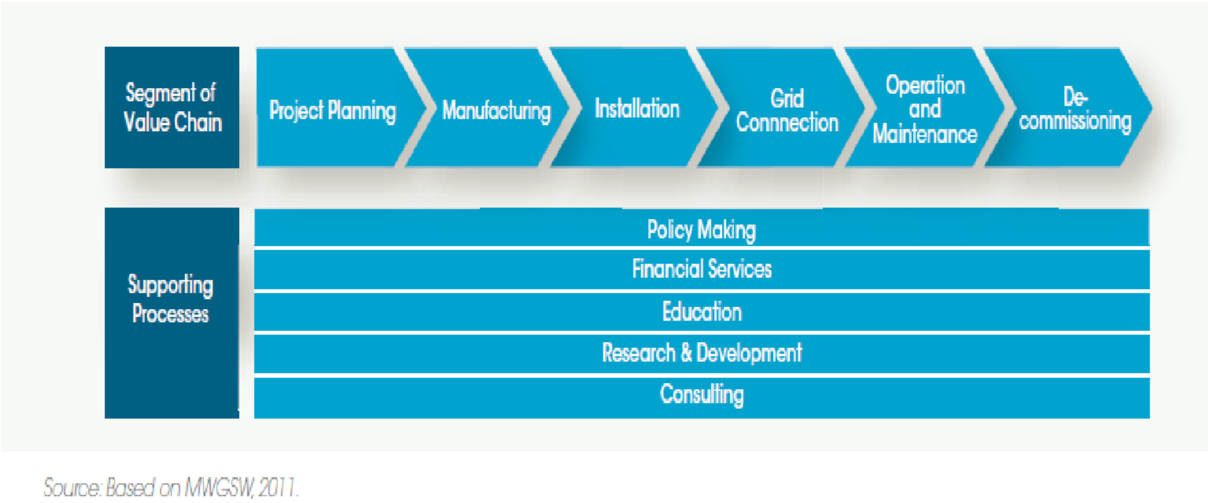


Figure 2.7: Characteristic segments of the PV system value chain

Source: IRENA (2015)

2.15.1 Value Chain Segmentation

2.15.1.1 Project Planning

This covers the preliminary preparatory including planning work for setting up a rooftop PV system project. This incorporates a spectrum of all activities that include resource valuations, feasibility assessments and infrastructure planning. Normally this needs appropriate expertise and experienced manpower. A greater share of domestic value creation is generated if the number of such projects are higher resulting in a higher number of local specialists. In instances where the technology is not very mature, expatriate consultants are engaged in the planning as well as development of the project. Opportunities are mostly created in environments that prefer local knowhow for instance during approval processes which needs administrative and legal expertise. Local specialists need to be consulted in ecological and development matters. In situations where a skills gap exists local value creation can only be retained through education plus training. Solar PV systems project planning normally covers the planning and estimation of modules and this usually requires involvement of a project developer or installer. This segment opens opportunities for one or more engineering companies including consultancies.

2.15.1.2 Manufacturing

Job opportunity prospects are presented during manufacturing of PV modules. Value creation can occur in various manufacturing stages starting from raw material sourcing, module manufacture, assembling etc. Silicon PV module manufacture includes a diverse number production stages that catering for balance of system components for inverter, combiner box, mounting systems, sundry electrical components etc. (IRENA and CEM, 2014). PV manufacturing plant set up can bring several job opportunities to the city. Setting up a PV manufacturing industry can induce the expansion of electrical and electronic industry as most of the components for electricity production come from these industries. Creation of appropriate synergies amongst these related industries can generate significant employment opportunities and raise GDP figures.

2.15.1.3 Installation

The installation stage incorporates all infrastructure activities as well as assembling works of the PV plant. A plan for installation and infrastructure setup needs to be developed and this stage includes civil engineering works covering excavations, foundations, building works, water systems, roads etc. (IRENA and CEM, 2014). For system installation works, if the equipment is imported, manufacturers normally take responsibility for everything on a supply and install basis. Through synergetic developments local organisations can still be engaged to deliver the requisite services. Value creation opportunities are generated as trained local personnel install the rooftop PV systems.

2.15.1.4 Grid Connection

The PV system project developer assesses the municipal grid requirements to negotiate a grid connection pact. The main work involves planning for cable reticulation works and termination to the grid (IRENA and CEM, 2014). Integration of the PV system into the main grid system creates domestic value in the form of highly skilled jobs. More jobs are created in ground works, cable manufacturing, electrical reticulation and installations as local companies are given opportunities. Value addition is gained through grid expansion and reinforcement resulting in augmented energy security and access.

2.15.1.5 Operation and Maintenance (O&M)

This is long-term continuous activity that has great prospects for value creation through job opportunities. Operation covers daily service procedures like PV system monitoring, faults response and general system administration. Maintenance activities incorporates preventive maintenance e.g. scheduled equipment scrutiny and unscheduled maintenance to repair system failures. Frequent and consistent maintenance services covering plant component inspections for physical damages, general system stability, safety, optimal module cleaning, painting, site accessibility, electrical installations inspections and maintenance, structural repairs and security procedures integrity needs to be done (Belectric, 2013). This segment offers vast opportunities for local value creation by offering direct, indirect or induced jobs during plant service. Quality O&M is very critical to minimise non-productive down time periods which are costly. Further value addition is realised through electricity sales from the generating company (IRENA and CEM, 2014).

2.15.1.6 Decommissioning

This is executed at the PV plant's lifespan. When an installation's lifespan is reached, the system is dismantled for disposal or recycling. According to McNeill (2016), landfilling can waste valuable land space as most PV panels comprise of heavy metals like lead and cadmium which can contaminate the environment. Rare elements like indium and gallium are found in some PV modules. There is a need to manage the depletion of these rare elements. Normal recycling or reconstruction is dependent on local regulations and conditions. In environments with clearly defined recycling policies, value creation is generated by formation of recycling industries (IRENA and CEM, 2014). PV modules recycling normally requires skilled personnel who are knowledgeable about recycling procedures concerning solar cells, glass, silver, electronic components, aluminium, steel and copper components. Value creation is witnessed through domestic job opportunities generated in the value chain. According to Wagner (2016), although PV products recycling has already started in Europe, there is no solar panel recycling activities occurring in South Africa at the moment. Wagner (2016) further asserts that only safe disposal of PV modules is happening at hazardous landfills at a cost of R3.50 per kg. Although the PV industry is fairly new, there is need for government to craft and adopt PV waste management policies that develop and promote the PV industry in a sustainable manner.

2.15.1.7 Value Creation through auxiliary processes

Auxiliary processes complement PV systems projects' life cycle and these incorporate policy creation and implementation, financiers, education and training, research and development and consultancy (IRENA and CEM, 2014). These processes happen along the diverse segments of the value chain. Policy frameworks help to overcome institutional blockades and market challenges to build an environment where technology and markets coexist. The policies are very effective if they offer transparent, consistent and long term to lure investors. Financial services play a key role in PV systems development evaluating commercial feasibility as well as justifiable investment opportunities. Education and training windows are opened to close the skills gap to ensure successful deployment of the PV systems. Three value creation levels are thus generated in the RE, education and training segments. Unavailability of local expertise dissuades investors from developing PV projects and if they invest it implies higher labour costs because of externally hired manpower (EWEA, 2012). Proficient specialised institutions execute R&D services and these add substantive and extensive value to the solar PV industry. Consulting services occur all over the value chain sectors. Consulting services happen during different project development phases in the form of technical know-how, legal advice, tax matters or financial consultancy etc.

2.16 RE Investment Financing

The South African government has appreciated and acknowledged its contribution to GHG emissions and has responded positively by developing and modelling various strategic frameworks that mitigate the climate change challenges. The country integrated and adapted the climate change agenda into the complete planning process encompassing the 3 tiers of government (Moyo, 2016). To execute such plans, the government recognised the cost implications of such a capital-intensive venture. The government has been playing a very instrumental role in the mobilisation of funds and other ancillary necessities from both private and public sectors as well as global financing agencies. International funders were engaged to access finances through FDI, domestic loans, equity financing, bonds, stock markets etc.

2.16.1 Public Sector involvement

The public sector is a key player in the climate change funding and investment. The Industrial Development Corporation, a government agency, has incorporated climate change challenges in its planning and implementation strategies (Moyo, 2016). Around R25 billion was reportedly budgeted for the 5-year plan ending 2016 for green industry development in the country. The Green Industries Strategic Business Unit (SBU) was established to disburse the monies. The unit was established to develop, nurture and invest in green businesses that promote sustainable development, building a domestic value chain in the process (Moyo, 2016). The 2012 IDC annual report highlights the financing of 12 projects in the REIPPPP first round and it launched the Green Energy Efficiency Fund (GEEF) to offer low cost financing for power saving technologies (Moyo, 2016). The South African Renewables Initiative (SARi) was launched to recognise the requirement for significant capital to unlock the economic potential of large scale deployment of RE projects (Naidoo, 2011, cited by Moyo, 2016).

2.16.2 PPP and Foreign Direct Investment

The REIPPPP programme is a success story of a PPP investment model which currently has invested over R192 billion coming from international and local private investors (DOE, 2015). Most of the REIPPPP shareholder firms included banks, DFIs, international companies and insurers with approximately 70% of the debt financing coming from commercial banks, insurance funds and pension coffers and the balance funded by DFIs (Moyo, 2016). Approximately 86% of the debt financing was domestic with Old Mutual being a major investor financing 16 projects in the 1st three bids (Moyo, 2016). The most dominant bankrolling structure was project funding with corporate sector funding engagements contributing a third in the 3rd round bidding. To date REIPPPP has mobilised R53.2 billion in foreign funding and investment across aggregate bid frames contributing about 85% of FDI and placing South Africa in the topmost 10 RE global investors of 2014 (DOE, 2015). The REIPPP programme has attracted 92 IPPs capable of generating over 6327MW.

Of the R7.5 billion dedicated to green industries investment, R1.5 billion was disbursed for the domestic Broad Based Black Economic Empowerment (BBBEE). The REIPPPP funding success is largely due to the good design and transparency of the bidding process and an enabling environment where the government is mitigating major risks and the deals are reasonably profitable (DOE, 2015). The IDC devoted R7.5 billion for specific RE projects between 2011 and 2012 (IDC, 2012, cited by Moyo, 2016). The Development Bank of South Africa (DBSA) dedicated between R20 to R30 billion to green energy development projects for the 2011-2015 period. REIPPPP based projects obtained DBSA loans to the tune of R6.2 billion in bid window one (Montmasson-Clair, 2013, cited by Moyo, 2016).

2.16.3 Official Development Assistance

Global bankrolling agencies are making a great contribution to South Africa's climate change response objectives. According to DBSA, about R20.1 billion has been contributed by public funders including multilateral organisations, donors and philanthropists to finance 95 climate change projects between 2003 and 2010. Australia, Germany and France have contributed greatly through the Clean Technology Fund (CTF) as well as the Global Environmental Fund (GEF) with most of this funding coming as concessional loan funding (Moyo, 2016). The bulk of these funds are disbursed through Eskom, metropolitans and the Central Energy Fund (CEF).

2.16.3 Technical Support Funding

Some support institutions give aid through technical assistance. The South African Renewable Energy Council (SAREC) establishment was funded by the GTZ to enable diverse RE industry groups to collaborate on RE issues within South Africa. The Global Environmental Facility disbursed R6 million donation via the World Bank for pre-investment services encompassed in Renewable Energy Market Transformation agenda (Moyo, 2016). The RE white paper was drafted with technical aid coming from the World Bank. The RE market transformation venture was implemented by DBSA in 2007 with World Bank support using GEF funds amounting to $6 million to support the DME as well as NERSA to develop financing mechanisms and legal, policy and governing frameworks (Moyo, 2016). The funding also enhanced government agencies' capacity to promote RE generation initiatives and facilitation of private entity RE investments through grants matching programmes (IDC, cited by Moyo, 2016). Channelling of these funds has mostly been through government arms like DBSA and IDC. R120 million worth of concessional mortgage support instrument was provided by the French Development Agency (AFD) as Green Credit Line to Nedbank and ABSA.

2.16.4 RE Development Partnerships

Collaboration of academia and research centres have proved to be instrumental in developing and formulating climate change strategic frameworks and policies. The Council for Science and Innovation Research (CSIR), University of Cape Town (UCT) Energy Research Centre (ERC), Human Science Research Council etc. have worked very closely with government to advance the RE and climate change causes. Various RE biased associations and groupings have been founded and they extensively relate with government in its attempts to push the green energy agenda forward. These associations include South African PV Industry Association (SAPVIA), Southern African Solar Thermal and Electricity Association (SASTELA), Sustainable Society of South Africa (SESSA), South African Independent Power Producers Association (SAIPPA) etc. Despite the importance of climate funds, they are not a panacea to the challenges and threats that climate change pose. Nakhooda and Norman (2014, cited by Moyo, 2014) observed that creation of a conducive environment that is supported by policy and regulatory frameworks should complement these funds.

2.17 RE Development Challenges

2.17.1 Investment and Monitoring Challenges

2.17.1.1 Monitoring and tracking

The climate change transition trajectory is characterised by numerous challenges. GEF budgeted $52.6 million in the June 2010-2014 period for South Africa's climate change, biodiversity and land degradation programmes. By June 2012, less than half, $15.5 million to be precise, had been utilised, with biodiversity consuming the majority share (Montmasson-Clair, 2013, cited by Moyo, 2016). Montmasson-Clair (2013, cited by Moyo,2016)) further argues that poor monitoring and tracking of climate funds inflows complicates the assessment and evaluation of the funds' utilisation and associated impact.

Despite successes made by government incorporating climate change into appropriate planning processes, some cynics contend that institutional provisions and pragmatic strategies are still insufficient. This is illustrated by the nonexistence of comprehensive and transparent tracking and monitoring instrument, the inability to exactly determine and regulate financial gap in relation to climate change feedbacks as well as nonexistence of official projections of anticipated financial contributions from donors, private and public sectors (Moyo, 2016). Montmasson-Clair (2013, cited by Moyo, 2016) further asserts that the unavailability of an all-embracing framework for synchronisation and management of the funds to guarantee efficient utilisation and appropriate directing of adaption and mitigation programmes is a cause for concern. Zinge (2011, cited by Moyo, 2016) echoes the above sentiments by asserting that South Africa was still evolving its methodology to coordinating the funding of its reaction to climate change with no aggregate finance gap identified yet and no available projections for summative adaption costs. Zinge (2011, cited by Moyo, 2016) further proclaims that there is ambiguity on the contribution proportionality of private, public and sanctioned development funds, thus buttressing the view of nonexistence of harmonisation and tracking of climate funds, an area that still needs development.

2.17.1.2 Prioritisation

Current climate change developments indicate that carbon reduction investments are prioritised over climate resilience investments in terms of commitments from the first world countries. According to Zinge (2011, cited by Moyo, 2016) the principal climate funding mechanism presently available is mortgages contributing 61%, and 81% of this being channelled towards mitigation efforts. Although carbon mitigation is key to decreasing GHG emissions, climate adaptation makes communities develop resilience under adverse conditions like floods, drought etc. Climate change adaptation investment guarantees enhanced sustainable development for countries.

2.17.2 Legal and Policy Barriers for RE Development

Despite the progress made so far in climate change mitigation investments, some critics argue that the decarbonisation of the economy has been happening at a slow pace. Despite increased funding for RE and energy efficiency, it is stated that about 80% of South Africa's energy mix was fossil fuel based between 2004 and 2010 (Moyo, 2016). This was contrary to the government policy position to make a paradigm shift from fossilised fuels. Such a policy contradiction at national and global level was highlighted when the World Bank approved a $3.75 billion loan facility to Eskom to construct Medupi and Kusile coal fired power stations during the above period. This two power stations discharge an estimated 60 million tonnes of CO_2 into the atmosphere every year (Sovacool and Rafey, 2011). Although South Africa was in an energy crisis, some critics argue that if same loan was invested in RE development the energy demand gap and carbon footprint were still going to be greatly reduced. Possibly this is an indication highlighting the challenges of fast tracking the transition to a low carbon economy without in-depth research and planning. Such policy inconsistences can also dissuade investors as they view the government as an aider of their competitors promoting more coal fired power stations development.

According to Murombo (2016), there has been contention about the inability of RE sources to compete with orthodox fuel sources due to the existing regulatory framework. Although PV and other RE sources costs are reducing, they haven't reached grid parity. The associated preliminary capital costs are one of the primary obstacles to RE development. Some studies have however highlighted that despite high initial costs, the RE costs are in the long term comparable to traditional energy sources and nuclear for electricity generation (Murombo, 2016). A case in point is PV solar whose early initial costs are offset by over 30 years of low maintenance expenses. In the long term, maintenance and operation costs are crucial differentiators that make RE development feasible (Murombo, 2016). Murombo (2016) further argues it's indefensible to compare fossil fuels and RE sources using the present economic and social cost structures and legal regulatory framework. The fossil fuels are currently highly subsidised by the government and there is no acknowledgement of the existence of external environmental costs due to fossil fuels.

The DOE is driving government policy on RE through regulators appointed by the energy minister. Eskom, a government parastatal and competitor in the RE sector is also given some control. Lack of expertise in public entities and government results in stakeholders like Eskom having too much influence in energy regulation and policy matters. According to Murombo (2016), Eskom has played a decisive part in the designing and implementation of various if not all electricity policy frameworks. Such influences usually distort the levelness of the playing field at the expense of IPPs, creating difficulties for them to break into the domain controlled by mutually supportive government institutions (Murombo, 2016). As Eskom controls the electricity value chain from generation to distribution, access to the grid network is heavily dependent on Eskom's cooperation. Such power enjoyed by Eskom can have severe implications on prospective IPPs' entry into RE sector. Eskom is thus in a better position to create conditions that favour and protect its business interests at the expense of its competitors who are dependent on it on most of the infrastructure. Failure by the DOE to have the vital skills to develop RE projects results in them consulting a fellow competitor in the energy sector, Eskom. Such an attempt to promote RE development through Eskom is futile as this would render all their current thermal powers stations obsolete in future. Eskom is thus capable of pulling the strings to make its fossil fuel generated electricity cost competitive in the energy market.

From a policy value point, the present approach anticipates RE sources to fit and align with the current legal policy framework or alternatively exist in a regulatory void. There is a need to digress through energy law reforms from traditional energy regulation models so as to unlock the RE potential (Murombo, 2016). According to Shapiro and Tomain (2001, cited by Murombo, 2016), environmental proponents argue that the degree and scale of present challenges is bigger than if increased effective regulations and law enforcement were effected. Other critics contend that most attention has been diverted towards technological and economic feasibility at the expense of the necessary legal framework to execute RETs. The nonexistence or deficiency of legal research works and committed RE law is a huge barrier to RE transition from orthodox fuel sources to improve the energy mix (Murombo, 2016).

Since RE development is a capital-intensive venture, mobilisation of such funding requires legal certainty to guarantee secured investments. It is the expectation of IPPs to get a good return on investment with certainty. According to de Jongh et al (2014, cited by Murombo, 2016), investors are concerned about the conduciveness the political environment make an extensive investment in the RE sector. They view the current environment as one with no transparent regulations and lacking government backing with preference being given to fossil fuels and too much political interference in shaping the energy sector using government monopoly. IPPs are worried about Eskom's perpetual dominance and monopoly buttressed by cheap abundant coal which causes financiers to fear about possibilities of insecure investments (Murombo, 2016).

The existence of political will is very important in RE development as it creates an enabling environment and eliminates other existing barriers (Murombo, 2016). Such political guarantee needs to be informed by a desire to make a paradigm swing from the orthodox regulatory national approach (Mitchell 2008, cited by Murombo, 2016). For South Africa, there has been instability in the commitment subject to the political climate. These inconsistences have been witnessed in prevarications from the state as it deviates RE investments to fossil fuels and nuclear in some instances, a situation that dissuades RE investors (Murombo, 2016).

Murombo (2016) proposes that crafting of legal frameworks with sustainable development bias will undoubtedly address most of the current problems considering sustainability's long-term focus. Promoting RE development under the current policy and legal conditions will never yield the desired sustainability results. It is a fact that the present restructured energy segment laws are still disjointed ignoring the traditional energy sources' complete production cycle. There is a great need to address the legal as well as policy barriers foremost in order for the government and private sector to address other imbedded institutional, technical, social and economic issues (Murombo, 2016). Such interventions will rapidly craft a rights and commitments framework creating certainty and an appropriate environment for RE stakeholders to implement RE projects with certainty. There is a need to adapt the legal policy strategy to suit the South African political, social and economic context to ensure effectiveness as well as compliance (Murombo, 2016)

Chapter 3 Methodology

3.1 Introduction

The COJ rooftops offer a very remarkable opportunity to achieve the city's long term energy security and independence at the same time lessening GHG emissions and unemployment rates (Bryan et al, 2010). Many municipalities the world over are encouraging the utilisation of solar energy techniques to promote the idea of sustainable cities (Kodysh et al, 2013). Rooftop PV eliminates extensive transmission network connections as the networks are installed close to the load. Rooftops offer a vast stretch of unexploited area for solar PV energy production as well as onsite distributed generation that has a potential to lessen electricity transmission and distribution expenses and losses (Gagnon et al, 2016). Because the buildings are already existing there is reduced investment in land. The PV systems are less susceptible to vandalism as the installations are not in secluded areas. It is necessary to identify municipal buildings with great potential for rooftop PV installations and assess their power generation capabilities.

The research methodology is a case study of City of Johannesburg. The greater part of the research relied on historical data from the City of Johannesburg, electronic peer reviewed journal articles, other municipals reports, government, StatsSA, Sustainable Energy Africa and other RE Research databases. The research's purpose was to find solar energy potential of various rooftops of COJ public buildings. The intention was to assist the municipality to recognise prospective sustainable opportunities from rooftop installations. Identification and listing of COJ administrative buildings and their associated addresses initiated the process using information furnished by the city. A total of 3 buildings were identified for this research purpose namely: Langlaagte, Sandton and Roodeport Testing Stations.

3.2 Literature Review

3.2.1 Evaluating the roof area

Evaluating the quantity of rooftop area that is appropriate for PV installations is very critical in solar PV energy production. A diverse number of tools and techniques have been developed to evaluate buildings' prospective solar energy capacities. Melius et al (2013) analysed over 70 documents by the NREL identifying existing techniques to approximate percentage of rooftop space appropriate for PV systems deployment. According to Melius et al (2013) the main solar PV system research question is about the technical potential of solar

PV over the aggregate available roof space area. Various techniques of approximating the rooftop space have been established, starting from basic multipliers of aggregate building space to techniques that utilise intricate geographic information systems (GIS) with others even employing three dimensional (3D) prototypes (Melius et al, 2013).

3.2.2 Assessment of the rooftop

It is important to assess rooftop PV installation potential by analysing diverse roof characteristics. To confirm the accessibility of the roof space for rooftop solar projects it is important to make a site assessment to determine and evaluate the available roof space. There is a need to evaluate the following characteristics for each of the selected sites:

- Available Space

  The accessible rooftop space to install PV rooftop solar needs to be quantified.
- Orientation

  For Gauteng Province, the optimal solar irradiation is captured by rooftops that are north facing.
- Hindrance by shading

  Rooftop installations must be free from any hindrances or obstructions between 9 a.m. and 3 p.m. annually to receive optimal irradiation.
- Tilt Angle

  The best inclination angle for solar PV panels must be approximately equal to the geographic latitudinal angle less nearly 15 degrees to obtain the maximum power yield.
- Type of rooftop

  Although it's feasible to mount and install PV panels on various rooftops it is easier to mount on composition as well as slate roof sheets than on tiled roofs. To avoid needless expenses, it is better to align the roof lifespan with PV installations so that there won't be any need to uninstall and reinstall the PV system unnecessarily between 5 to 10 years of installation.
- Roof structure

  There is a need to assess the roof structure to evaluate whether the structure can withstand additional weight. According to IRP 2010 – 2030 (2011) most roof fixed PV arrays and associated supporting structures weigh around 14.6 to 24.4kg/m^2 and this can be supported by the majority the roofs that meet the endorsed standards.

3.2.3 Azimuth or Tilt Angle: The South African Context

To obtain optimal diurnal solar insolation right through the year, solar panels must be fixed at appropriate tilt angles and azimuths angles for the panels' lifetime (Le Roux, 2016). According to Le Roux optimal angles at which PV panels are fixed are often contested with most publications on the subject regularly relying more on scientific or mathematical models of solar resources instead of measured data which caters for weather and pollution impacts (Le Roux, 2016). Data obtained from SAURAN from 9 measuring locations within South Africa was used to calculate the annual solar irradiance on fixed PV panels using all applicable angles (Le Roux, 2016). The above stations' measured data gave conclusions that in South Africa north facing PV panels with a 30^{o} tilt angle gave the best annual solar insolation capturing 98% of the solar insolation (Le Roux, 2016). The results also established that an optimally fixed PV panel can be 10% more effective than a horizontally positioned PV panel in terms of annual insolation collection. It was concluded that the optimum fixed tilt angle is akin to the latitudinal location and the optimal secured azimuth angle is a function of the longitudinal angle less the absolute latitudinal angle, σ (Le Roux, 2016). According to Handoyo et al (2013) the quantity of solar radiation falling on a PV panel is dependent on latitude, tilt and azimuth angles, period of the day, day within a year and the incident radiation angle etc. It is only azimuth and tilt angles that can be controlled to optimise the quantity of radiation flux falling on the panel. Danny et al (2007, cited by Handoyo et al, 2013) highlighted that solar panels with tilt angles nearly equal to a place's latitude receives the optimum annual solar insolation. However, Matshoge and Sebitosi (2010) argue that the optimum annual energy production is not only dependent on the relationship between fixed panel tilt angle and latitude but is also dependent on various climatic factors and location linked parameters. Factors like wind direction and speed, environmental temperature, global irradiation and other climatic conditions complicate or convolute the optimal tilt and azimuth positions (Matshoge and Sebitosi, 2010). Tables for maximum tilt and azimuth angles for various locations within South Africa were successfully generated thus giving an easy support tool to promote PV growth and development in South Africa (Matshoge and Sebitosi, 2010). Using appropriate GPS tools the coordinates of respective locations can be determined to get the optimum azimuth and tilt angles.

3.2.4 Methodologies for Calculating Rooftop Areas

According to Byrne et al (2015) methodologies for determining rooftop PV potential basically have three main categories which are:

1. Sample Methodology

   Sampling methods can be applied to give reliable approximations of roof spaces available that can later be extrapolated to get the aggregate area (Byrne et al, 2015). The methodology has its foundation in a research by Izquierdo et al (2008 and 2011, cited by Byrne et al, 2015). Schallenberg-Rodriguez noted that the method is appropriate for large regional valuations of rooftop energy potentials (Byrne et al, 2015). Although the method is less accurate compared to a census of all rooftop study areas, it has proven to deliver reliable estimates.

2. Multivariate Sampling Methodology

   According to Wiginton et al (2010, cited by Byrne et al, 2015) the approach attempts to correlate population density with the roof area available. This approach has extra variables that advance particularity unlike the above approach. The methodology is comparatively inexpensive but time consuming due to added variables.

3. Complete Census Methodology

   The approach depends on calculation of the entire rooftop area in the area under study. The computation can be done using available statistical data collection containing building information like floor quantities, area and total quantity of buildings etc. or by using advanced cartographic data that gives a digitised model of the area under study (Byrne et al, 2015). The data sets enable calculation of rooftop areas of regions under study using advanced software packages or applications like GIS. Despite its capability to produce high quality results, the methodology is time intensive and more expensive in comparison to the other two approaches (Byrne et al, 2013).

3.2.5 Rooftop Area Estimation Approaches

- Constant Value (CV) Approaches

The CV approaches estimate rooftop appropriateness by basically assuming a certain fraction or percentage of the building rooftop space being suitable to accommodate PV panels (Gagnon et al, 2016). These methods of approximating roof space availability are prevalent because they are easy to use providing results rapidly, not resource or time intensive and they offer a crucial starting point for prospective rooftop PV energy production in a segment or region (Melius et al, 2013). Most of the CV approaches consider individual rooftop structures and approximate a multiplier that can be applied for the whole region. The majority of the CV studies make assumptions concerning the proportion of flat versus sloped roofs, the quantity of structures with appropriate rooftop alignments as well as the quantity of obstructed space by heating, ventilation and air condition (HVAC) equipment and associated shades. Although CV methods are attractive to several researchers due to ease of use, there is little validation and assumptions on nuances affecting buildings.

- Manual Selection Approaches

Using the best possible resolution, the manual selection approach assesses building structures independently to obtain an aggregated suitable rooftop area and prospective energy generation (Gagnon et al, 2016). Manual selection uses a refined albeit extra time intensive technique that chooses rooftops from sources like Google Earth, aerial photography etc. to provide hints to rooftop PV set up positions (Ordonez et al, 2010, cited by Gagnon et al, 2016). Despite being time consuming and difficult to replicate at a large scale, the method offers the most accurate approximation of the aggregate area obtainable from the rooftop (Gagnon et al, 2016).

- GIS based Approaches

The GIS based methods are robust approaches applicable for large scale approximations of appropriate rooftop areas. The major peculiarity between GIS methods and the formerly deliberated methods is that the pronouncements about suitability of rooftops are not finalised using prearranged constant values or manual selection of buildings (Melius et al, 2013). Ideal figures for rooftop traits are entered into a computer model with the GIS application software determining the areas of great suitability. This normally results in rapid, more objective and precise approach for identifying rooftop accessibility. The GIS based approaches offer more precision than CV methods with better capability to handle bigger data sets than manual selection approaches. According to Melius et al (2013) GIS based approaches have been utilised to derive rooftop aptness and they are capable of developing and validating an appropriateness-estimation technique built on best standards and practices originating from existing literature. GIS techniques utilise 3D models to evaluate solar PV resource or shadow impacts on buildings. These 3D images are usually produced from orthophotography or light detection and ranging data (LiDAR) combining them with orientation, slope and building structural data to approximate overall solar PV energy generation prospects. Nowadays LiDAR information is generally available at greater resolutions and is usually the desired method too estimate rooftop areas (Melius et al, 2013).

3.3 Estimating Rooftop PV Potential Methodology

The process of estimating the rooftop PV potential imbeds other processes to calculate the parameters or factors that will be used in the main equation. Two main parameters that need to be found prior to the main calculation are rooftop area and solar irradiance.

3.3.1 Calculating the Rooftop Area Using Google Earth Pro

The aerial images of the building rooftops were obtained from Google Earth Pro by entering the physical address of the sites under review. The aerial images were verified for preliminary estimation of the PV rooftop potential based on alignment, inclination, blockades etc.

1. The following steps were used to determine the area of the building using Google earth Pro:
    - Open Google Earth Pro Application
    - Search for location by typing the physical address of the site
    - Move cursor to the location and zoom out the location by continuously dragging the right click button till you get the right image size like Figure 3.1, 3.2 or 3.3.
    - In the menu bar select Tools option.
    - Choose Ruler option
    - Select 3D Polygon. This measures the area of a geometric shape after creating a polygon.
    - On the satellite image move your cursor to your starting point on the edge of the roof.
    - Mark all the edges that make the perimeter of the roof. On your last point GEP creates an enclosed polygon.
    - On finishing the markings, GEP automatically created the perimeter and area of the entire rooftop.
    - Save the created image or polygon which has automatically created coordinates under my Places for later reference as the Gross Rooftop Area.

2. Repeat the polygon formation process by selecting all sections that are not suitable for PV rooftop installations i.e. all areas with hindrances. Save the unsuitable polygons as Unwanted Rooftop Area. If the unwanted areas are segmented, save them separately and sum up those segments to get total unwanted area.
3. You can later view the saved images characteristics by right clicking the saved files.
    - Choose properties to view the perimeter and area measurements.
    - To distinguish unwanted from wanted areas choose style/colour tab under properties and differentiate wanted from unwanted sections using different colours around the gross and unwanted perimeters as highlighted in figure 3.4 and 3.5 below.
4. If the roof is segmented measure the different segments and totalise them to get gross area. The suitable or wanted area is obtained by subtracting gross rooftop area from total unwanted area using equation 3.1.

$$Aw = Ag - Au \qquad \text{Equation 3.1}$$

   Where Aw is the total suitable or wanted rooftop area, Ag is the gross rooftop area and Au is the unwanted rooftop area that includes areas with all types of hindrances.
5. Repeat the process for different sites to get their rooftop areas.
6. Verify the estimated figures from Google Earth Pro by making a site visit taking some photographs of the roof. Identify any hindrances and other concerns that couldn't be detected from Google Earth aerial images so as to exclude their area.
7. Tabulate information about all hindrances in the database.
8. Estimate the aggregate rooftop area for PV installations.

Figures 3.1 to 3.5 show spatial images of the sites under review. Figure 3.1 to 3.3 show the available roof spaces with figure 3.4 to 3.5 showing the suitable area spaces for rooftop installation.

Figure 3.1: Langlaagte roof space from GEP

Figure 3.2: Roodepoort roof space from GEP

Figure 3.3: Sandton roof space from GEP

Figure 3.4: Langlaagte roof area for PV installations

Source: GEP image

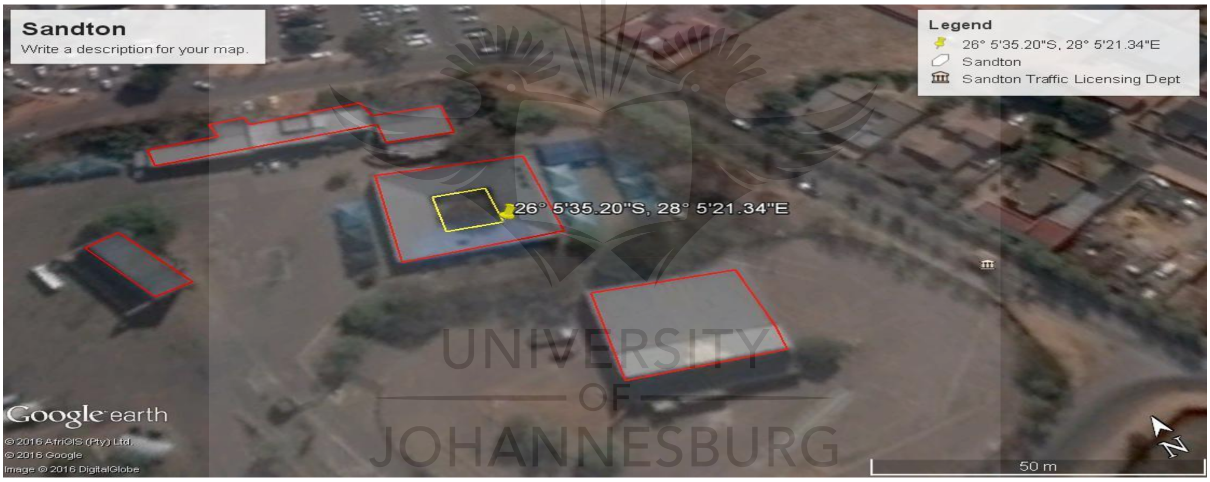


Figure 3.5: Sandton roof area for PV installations

Source: GEP image

3.3.2 Solar Irradiance Maps (SIMs)

According to Yaiche et al (2014) solar maps are meant to encourage better public consciousness concerning solar energy, facilitating consumers to realise solar potential vested on their properties as well as enabling augmented solar utilisation by property owners. A SIM can thus serve as an integrated database to store comprehensive information about solar resources (Yaiche, 2014). SIMs enable users to quickly and easily assess solar potential of their buildings and they can produce quantifiable results capable of informing decisions coming from governments and the public in general (Yaiche et al, 2014).

According to Winkler et al (2012) SIMs offer a rapid way to assess the amount and type of solar energy accessible at any specific location. SIMs offer very crucial first-order estimations of solar energy generation potential at particular sites and they are used widely in experimental studies to investigate solar power potentials on different sites and estimating solar energy capacity (Winkler et al, 2012). These maps are generated by various scientific research or commercial organisations who apply a collection of site conditions to particular solar irradiance prototypes. Most of these maps are freely available and are extensively used and quoted in development proposals of solar projects (Winkler et al, 2012). The frequent inadequacy of ground based data makes the substantiation of onsite irradiance a great challenge in most cases resulting in inaccurate or distorted solar power potential estimations (Winkler et al, 2012). According to Munzhedzi and Sebitosi (2009) the solar map normally gives guidance in the designing and capacity sizing of most of the PV installations. Munzhedzi and Sebitosi (2009) highlight the main setback of solar maps as only considering solar radiation as the only factor affecting PV panel power output yet there are other factors that influence panel sizing and pricing. Enhanced information implies faster decisions to find ideal locations, saving money as well as embracing RE resources into production at a faster rate (Yaiche et al, 2014). The South African SIMs used for the project were obtained from Solargis as shown below. Figure 3.6 and 3.7 show the strong potential of South Africa to use PV solar energy across the country.

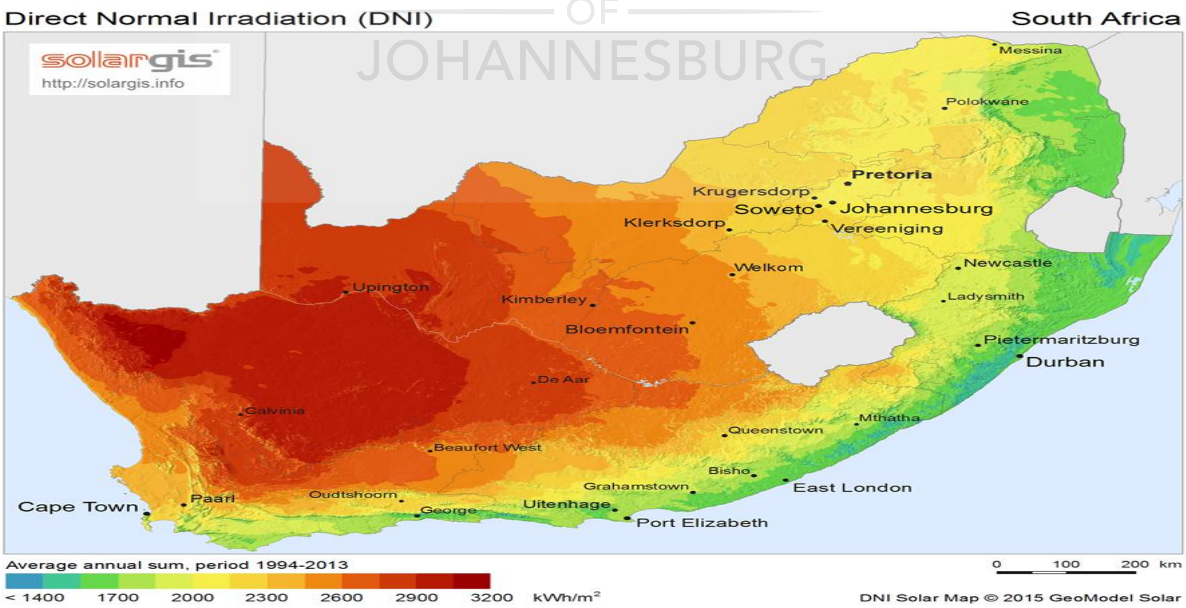


Figure 3.6: Direct Normal Irradiation

Source: http://solargis.info

Hernandez-Moro and Martinez-Duart (2013) view and consider Global Horizontal Irradiation (GHI) figures to determine the PV solar energy resource available. The GHI for South Africa is shown in 7 below illustrating high potential PV usage across the country.

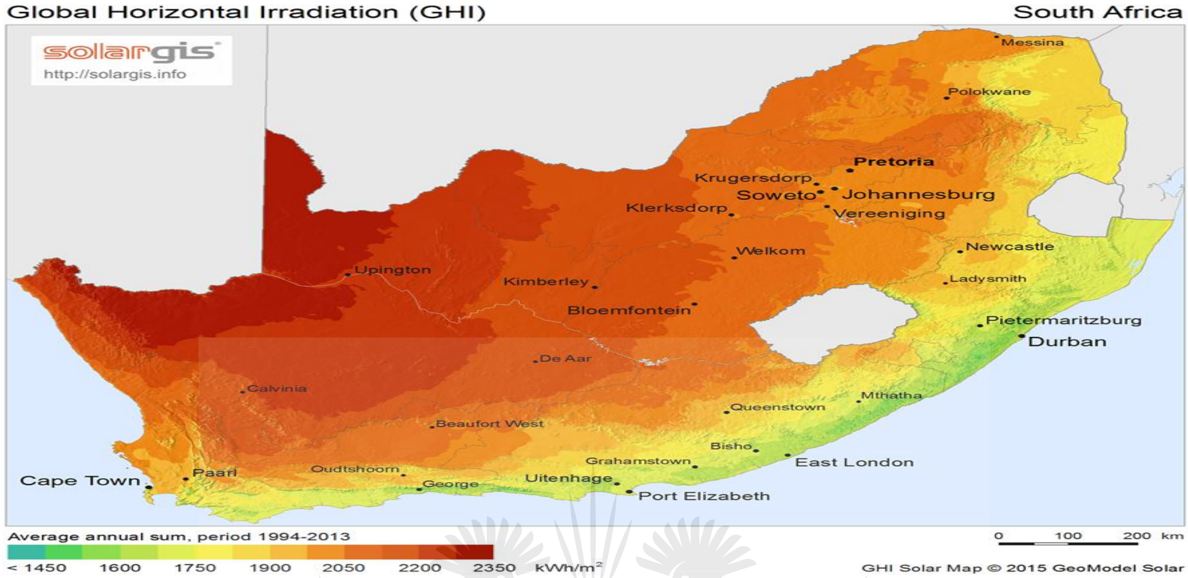


Figure 3.7: Global Horizontal Irradiation

Source: http//solargis.info

It is essential to incorporate various climatic conditions during PV installation consideration. Despite the existence of a direct proportionality between PV panel power output and radiation, there is an inverse proportionality between power output and temperature (Munzhedzi and Sebitosi, 2009). If resources permit, it’s crucial to directly measure solar radiation directly on the ground on specified locations as this gives superior and more refined data compared to satellite data which exaggerates the estimates and an underachieving installation (Dekker et al, 2012).

3.3.3 The SolarGIS pvPlanner

According to Sustainability Outlook (2011), SolarGIS is a software simulation platform that offers online solar resource repository to the solar energy generation industry especially in PV solar energy predictions founded on historical information. SolarGIS pvPlanner tool is a simulation software used to plan and optimise PV systems using climatic and geographical high temporal data at spatial resolution. SolarGIS pvPlanner enables quick comparison of different sites and module technology type and choices, mounting types, inverter efficiencies, DC and AC losses including availability. Respective simulations are documented as standard yield reports in PDF with data exports in XLS format. The pvPlanner software is a vital tool for PV projects of various magnitudes. SolarGIS pvPlanner helps to calculate or evaluate reliably PV energy potential without much investment or resources. By searching for a site using a geographic location you can generate a report showing a site's geographic position, site' s annual average solar irradiance, azimuth, PV potential etc. The annual average solar irradiation (kWh/m^2/year) was calculated using SolarGIS pvPlanner generated reports.

3.3.4 Calculating the Rooftop PV Potential

Calculating the amount of power generated by a PV installation:

$$E = A \times r \times H \times PR \qquad \text{Equation 3.2}$$

Where:

E is the Energy generated (kWh)

A is the rooftop aggregate area (m^2)

r is the PV panel efficiency or peak output ratio calculated from the peak power (kWp) of a single panel divided by area of a single PV panel.

H is the Annual average solar irradiation (kWh/m^2/year)

It is important to note that PR value is a very crucial value to assess the PV installation quality as it gives installation performance that doesn't rely on panel orientation or inclination. The PR value is derived from the following losses depending on the technology, system size and site location:

- Temperature (5-18%)
- DC Cables (1-3%)
- AC Cables (1-3%)
- Inverter (4-10%)
- Shading, site specific (0-80%)
- Weak radiation (3-7%)
- Dust, snow etc. (2%)

The PV panel efficiency for crystalline silicon is approximately 19% and for thin film panels is about 12%. The Peak Installed Capacity and Power output for each panel are calculated thus:

$$\text{Peak Installed Capacity (KWp)} = \text{Roof space Area} \times \text{Peak Output Ratio} \qquad \text{Equation 3.3}$$

$$Power_{out} = Panel\ Area \times Solar\ Irradiance \times Panel\ Efficiency \qquad \text{Equation 3.4}$$

Improvements in panel efficiencies in recent years have seen changes in performance factor and degradation factor value changes. Hernandez-Moro and Martinez-Duart (2013) have considered 75-85% range as the performance factor for inverter efficiencies including the impact of temperature on PV panel efficiency. Reichelstein and Yorston (2013) utilise a derating factor of 85% for AC-DC conversion. For degradation factor Hernandez-Moro and Martinez-Duart (2013) propose a value of 0.6% as the degradation factor to cater for lessened module efficiencies due to degradation. Reichelstein and Yorston (2013) use a 0.5% degradation factor.

3.4 GHG Emissions Calculations

Over 40% of CO_2 emissions are due to electricity as well as heat production (IEA, 2015). This is due to grave overdependence on fossilised fuels which produces approximately two-thirds of the world electricity, primarily coming from coal. Proper implementation of emission mitigation measures can help decouple the increased electricity demand from growth in associated CO_2 emissions.

A city's capacity to undertake effective climate change mitigation and observe progress is dependent on accessibility to satisfactory quality GHG emissions data (Department of Environmental Affairs, 2014). Climate action planning starts with building a GHG repository. Such a repository enables the city to appreciate emission contributions of diverse city activities. It enables and guides the municipality to decide the optimal direct alleviation attempts, generate strategies to reduce GHG discharges and monitor progress.

3.4.1 Carbon Emission Calculation Methodology

To calculate GHG emissions reduction equivalent from using rooftop PV solar technology, an estimating methodology that utilises emission factors is the most ideal and practical approach. Emission calculation techniques outline the calculation methods, associated activity data and emission factors that are utilised in the determination of aggregate emissions derived from specific activities (World Resources Institute, 2014). World cities have to choose the most suitable approaches based on the objectives of their inventories, data availability and national inventory consistency requirements.

The emission factor methodology estimates emissions by multiplying activity figures by a specified emission factor attached to the emission under measure:

GHG Emissions = Activity Data x Emission Factor *Equation 3.5*

Where Activity Data is measurable data of a level of activity that results in GHG emissions occurring during a specific period.

Emission factor measures the mass of GHG emissions comparative to an activity unity e.g. an estimate of CO_2 emissions from electricity use encompasses multiplying kilowatt hours (kWh) consumed by an emission factor of $kgCO_2/kWh$ or tons/MWh emitted dependant on the fuel source utilised to produce the electricity.

3.4.2 GHG Emission Factors

According to World Resources Institute (2014) climate change mitigation strategies need accurate approximations of GHG emissions to enable crucial planning and mitigation assessment efforts. Emission factors are regarded as a vital tool that is utilised in the construction of national emission databases. They relate the values of atmospheric pollutants released with activities that are associated with the pollutant discharge. There is a need to put emphasis on the GGH inventory quality as this forms the foundation of the climate change legally binding commitments. The IPCC Good Practice Guidance highlights the need to compare countries' emission factors with the recommended IPCC default figures to establish informative comparisons of country emission factor specifics applied (World Resources Institute, 2014). Activity data can be collected from several sources including national government departments and statistics bureaus, university institutions, research centres, scientific and technical publications, journal articles and reports etc. According to the World Resources Institute (2014) it is generally preferable to utilise locally available or national data figures over international figures, as well as data publicly available, peer-reviewed data and reputable data sources obtained from government publications.

GHG discharge data is expressed in metric tonnes of GHG or as CO_2 equivalent. The GHG data inventories are normally utilised as the source for setting GHG alleviation objectives and analysing performance against time. Emissions need to be tracked with time to provide historical emission information trends as well as tracking the impact of policies as well as actions that reduce municipal wide emissions. When municipalities set emissions targets, they need to identify the base year for the targets which will enable clarification of emissions tracking (World Resources Institute, 2014). Despite the production of other gases like CH_4, N_2O etc. during fossil fuel combustion, CO_2 is the most dominant GHG emitted during electricity generation contributing about 99% GHG emissions from immobile combustion of fossilised fuels.

3.4.3 City of Johannesburg GHG Emissions

According to the City of Johannesburg GPC report the highest energy consumption in Johannesburg comes from electricity utilising 38.77% (63,833 TJ) of energy. About 72.45% of CO_2 emissions come from electricity due to the high carbon intensity of coal fired power stations. It is necessary to create and structure a historical base year and COJ backdated this to 2007 as it had the most inclusive data available. Most of the electricity activity data was collected from Eskom and City Power.

Figure 3.8 show the COJ's energy supply sources by type of fuel whereas figure shows GHG emissions according to the fuel used.

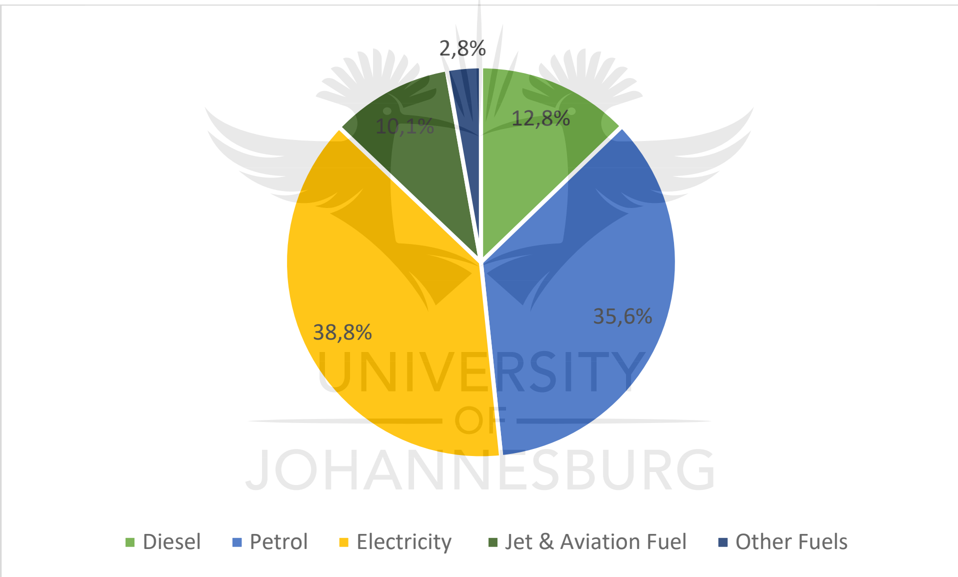


Figure 3.8: COJ energy sources according to fuel type

Source: City of Johannesburg GPC Report

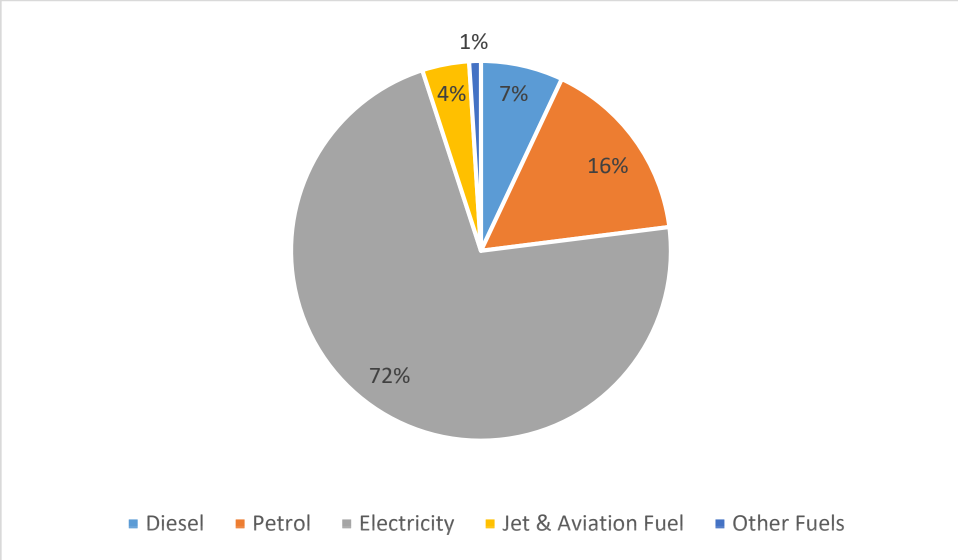


Figure 3.9: Johannesburg's GHG emissions by fuel

Source: City of Johannesburg GPC Report

For the COJ the emission factor applicable from Eskom is 1.03 tons per MWh (Eskom, 2015).

To calculate the carbon emission reductions for COJ the annual potential energy generated from rooftop PV systems was multiplied by the Eskom emission factor of 1.03tons/MWh to give the GHG emissions that could be saved by implementing the rooftop project on the 3 sites.

3.5 Employment Opportunities Assessment

Three primary methods are used to assess the gross influence the RE industry has on potential employment opportunities namely employment factor, gross input/output model and supply chain analysis. Although it is resource intensive, the input/output approach is more comprehensive than the employment factor technique as it shows the inter-sector relationships within the economic structure (IRENA and CEM, 2014). The Supply Chain Analysis is used less frequently compared to the other two approaches as it uses an added micro as well as business oriented technique when it is rarely beneficial to assess macro-economic effects. The most preferred approach amongst the three is the employment factor approach.

3.5.1 Employment Factor Methodology

According to IRENA and CEM (2014) employment factors are recommended as the quickest and simplest way of assessing the employment effects of the RE industry. Employment factors give the quantity of jobs that can be generated per unit capacity e.g. per MW, divided into manufacturing, assembling, operation and maintenance as per unit of principal energy of fuel source being utilised (Rutovitz and Harris, 2012)). Although they can present employment data, they don't offer an economic assessment of other features of value creation. The methodology estimates employment for various RE sectors within the value chain. Various units are used to quantify employment creation potential with the most common being jobs/MW as well as person-year/MW. Permanent jobs in the manufacturing and Operation and Maintenance sectors use jobs/MW whereas temporary jobs in the construction sector use person-years/MW. Permanent jobs in Operation and Maintenance are described in terms of jobs per MW whereas temporary jobs in manufacturing or construction are described as person years per MW of the capacity installed. Employment factor approaches give information concerning direct employment for jobs in the RE sector and their application is not costly provided reliable information is available (IRENA and CEM, 2014).

Table 3.1 shows potential jobs created per MW by different energy technologies.

Energy Source	**Manufacturing & Installation (Job-Years/MW)**	**Operation and Maintenance (Jobs/MW)**
Wind		
Minimum	2.6	0.1
Maximum	15	0.6
PV		
Minimum	7.1	0.1
Maximum	43	0.7
Concentrated Solar Photovoltaic (CSP)		
Minimum	4.6	0.2
Maximum	36	1.0

Table 3.1: Jobs Created per MW by different technologies
Source: IRENA and CEM (2014)

Table 3.2 shows employment factors that are utilised during the 2015 global analysis.

Technology	Job	Employment Factor	Country	Reference
Solar PV	Manufacturing, Construction, Installation	5.75-6.21 jobs/MWp	Not specified	Sooriyaarachchi et al (2015)
	Operation and Maintenance (O&M)	1.2-4.8 jobs/ MWp	Not specified	Sooriyaarachchi et al (2015)
	PV Module Manufacturing	3-7 jobs/ MWp (Direct jobs)	European Union	Sooriyaarachchi et al (2015)
		12-20 jobs/MWp (Indirect jobs)		
	PV Panel Production	10 jobs/MWp (Direct jobs)	Turkey	Sooriyaarachchi et al (2015)
	Wholesale, Retail, Installation and Maintenance	36 jobs/MWp (Direct jobs)		
	Installation	346 jobs/MWp (Direct jobs)		
	Operation and Maintenance	27 jobs/MWp (Direct jobs)		
	Construction/Installation	11 job years/MW	OECD countries	Rutovitz and Harris (2012)
	Manufacturing	6.9 job years/MW		
	O&M	0.3 jobs/MW		

Table 3.2: Summary of employment factor by job sector
Source: Sooriyaarachchi et al (2015) and Rutovitz and Harris (2012)

The solar rooftop PV employment potential was calculated using the employment factor values in tables 3.1 and 3.2.

Chapter 4 Data Collection and Preparation

4.1 Introduction

The Data Collection and Preparation process focused on gathering data for calculating the rooftop energy generation potential, carbon emission reduction potential and the resultant employment creation potential. The data collection process was only restricted to three testing stations namely Langlaagte, Sandton and Roodepoort.

The main emphasis of the data collection process was centred on how to obtain measurable unknown parameters of the energy equation 3.2 in the methodology i.e. $E = A \times r \times H \times PR$. Each site's total rooftop area, A (m^2) and the annual average solar irradiation, H ($kWh/m^2/year$) needed to be gathered and applied into the energy equation. The remaining energy equation parameters were obtained from the data specification sheet of the chosen panel or model i.e. the Enersol 300 Polycrystalline. The Google Earth Pro software was used to measure the suitable roof areas (m^2) of the chosen sites. Using Solargis pvPlanner software, monthly average solar irradiation was gathered to generate an annual average solar irradiation (kWh/m^2). To calculate the carbon emission reduction, carbon emission factor values were obtained from Eskom data sheets. Data for average jobs created per megawatt was obtained from previous peer reviewed research articles and IRENA reports.

Table 4.1 shows the data sheet specifications for EnerSol 300 Polycrystalline PV module that was used during the research process.

EnerSol 300 Polycrystalline PV Module Specification		
Description	Unit	Quantity
Panel Dimensions	mm	1956x992x40
Panel Area	m^2	1,94
Weight	kg	29
Number of cells	each	6x12
Polycrystalline	w/module (peak)	300
Module efficiency	%	15.4
Average Performance ratio	%	79
DC/AC losses	%	5.5 / 1.5
Module Lifespan	years	25

Table 4:1: EnerSol 300 Module Specification
Source: The Power Store (2017)

4.2 Langlaagte Testing Station: Data Collection

4.2.1 Geographic Location

Using Solargis pvPlanner software, Langlaagte Testing Station location was identified by the following coordinates: 26^{0} 12’ 56.23” S, 28^{o} 0’ 19.79” E.

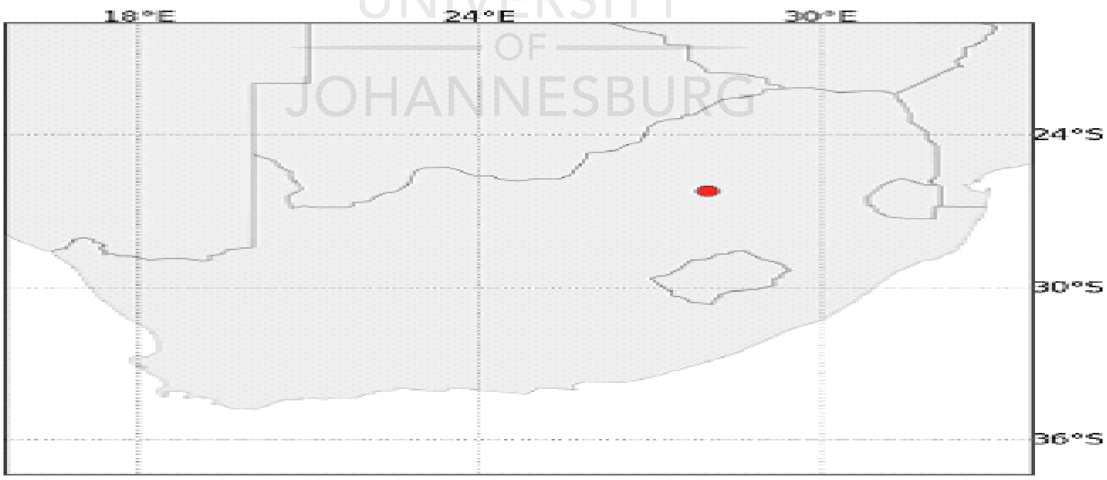


Figure 4.1: Langlaagte Testing Station geographic location

Source: Solargis pvPlanner software generated coordinates

Figure 4.2: Langlaagte Testing Station GEP image

4.2.2 Langlaagte Annual Average Solar Irradiation

The Solargis pvPlanner software was used to generate Global Horizontal Irradiation and Global in-plane Irradiation data as shown in Table 4.2 and 4.3 respectively. The software also generated the optimal angle at which the PV panels could be installed. The software generated the average annual solar irradiation for Langlaagte testing station, a key parameter used to calculate the rooftop PV energy potential, as illustrated in Table 4.4.

Month	Gh_m	Gh_d	Dh_d	T_{24}
Jan	193	6,21	2,54	20,3
Feb	168	6,01	2,37	19,6
Mar	165	5,33	2,01	17,9
Apr	144	4,78	1,51	15,1
May	135	4,35	0,99	11,2
Jun	120	3,99	0,84	8,5
Jul	133	4,27	0,89	8,2
Aug	158	5,1	1,17	11,4
Sep	182	6,07	1,58	15,4
Oct	198	6,38	2,12	18,2
Nov	196	6,55	2,28	19,2
Dec	206	6,65	2,53	20,3
Year	1998	5,47	1,74	15,44

Table 4.2: Global Horizontal Irradiation and air temperature

Source: Generated Solargis pvPlanner report for Langlaagte

Where:

Gh_m Global Irradiation Monthly Sum (kWh/m^2)

Gh_d Global Irradiation daily sum (kWh/m^2)

Dh_d Diffuse Irradiation daily sum (kWh/m^2)

T_{24} Diurnal air temperature (^{0}C)

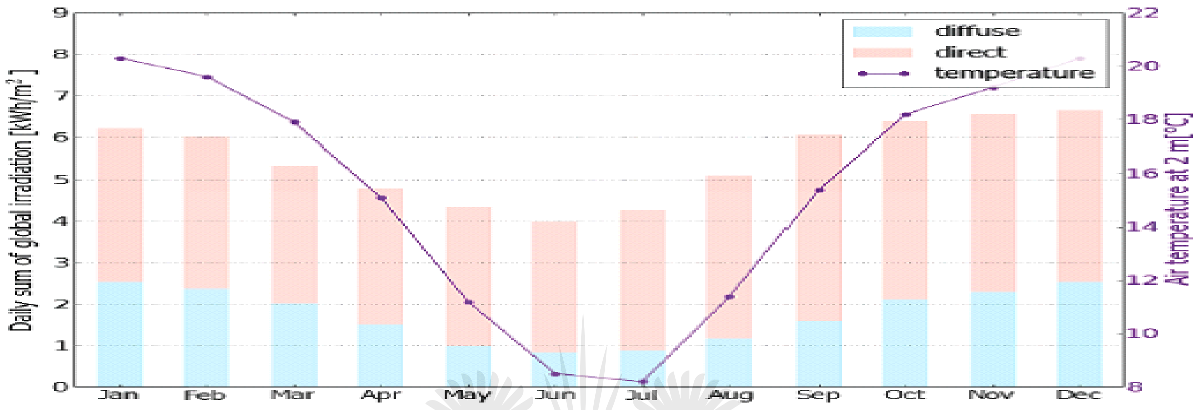


Figure 4.3: Annual global irradiation

Source: Generated Solargis pvPlanner report for Langlaagte

Month	Gi_m	Gi_d	Di_d	Ri_d	Sh_{loss}
Jan	172	5,53	2,36	0,05	0,2
Feb	162	5,77	2,29	0,05	0,2
Mar	177	5,71	2,06	0,04	0,2
Apr	176	5,86	1,67	0,04	0,1
May	190	6,13	1,21	0,04	0,1
Jun	181	6,03	1,07	0,03	0,3
Jul	195	6,3	1,13	0,04	0,1
Aug	208	6,71	1,4	0,04	0,1
Sep	209	6,98	1,74	0,05	0,1
Oct	199	6,41	2,12	0,05	0,1
Nov	179	5,95	2,15	0,05	0,2

Table 4.3: Global in-plane irradiation
Source: Generated Solargis pvPlanner report for Langlaagte

Where:

Gi_m is the global irradiation monthly sum (kWh/m^2)

Gi_d is the global irradiation daily sum (kWh/m^2)

Di_d is the diffuse irradiation daily sum (kWh/m^2)

Ri_d is the reflected irradiation daily sum (kWh/m^2)

Sh_{loss} are global irradiation losses due to terrain shading (%)

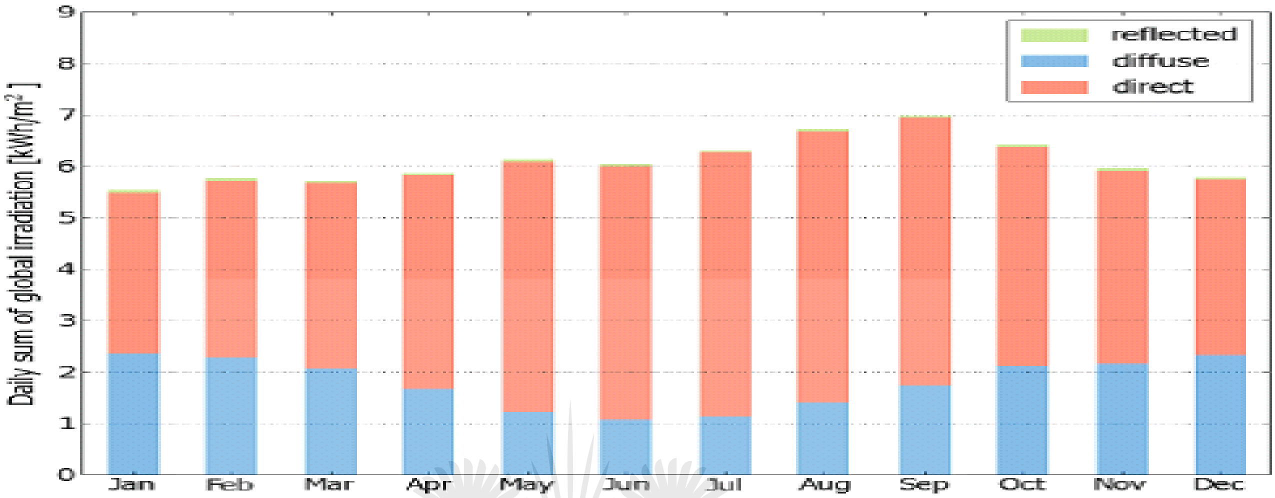


Figure 4.4: Daily total global irradiation

Source: Generated Solargis pvPlanner report for Langlaagte

Orientation	kWh/m²	Relative to optimally inclined
Horizontal	1997	89.7%
Optimally inclined (29°)	2227	100%
2-Axis tracking	2920	131.1%
Selected option	2227	100%

Table 4.4: Average annual sum of global irradiation for diverse surfaces
Source: Generated Solargis pvPlanner report for Langlaagte

The annual average solar irradiation used for Langlaagte Testing Station was 2227 kWh/m^2/year.

4.2.3 Langlaagte Rooftop Area Results

GEP was used to calculate the rooftop area for Langlaagte Testing Station using the methodology described in chapter three. Figure 4.5 shows the aerial images of the roof spaces that were used for PV installations. Figure 4.6 illustrates the suitable, marked in yellow and unsuitable (blue) areas for rooftop PV installations.

Figure 4.5: Langlaagte roof space from GEP

Figure 4.6: Langlaagte roof area for PV installations

Source: GEP image

To calculate the roof area equation 3.1 from chapter 3 was used:

$$Aw = Ag - Au \qquad \text{Equation 3.1}$$

Where Aw is the total suitable or wanted rooftop area, Ag is the gross rooftop area and Au is the unwanted rooftop area that includes areas with all types of hindrances. The total suitable area was calculated as illustrated in Table 4.5.

Section	Area (m2)	Roof Area Type
Langlaagte1	585.2	Wanted
Langlaagte U1	-38.26	Unwanted
Langlaate2	361.08	Wanted
Langlaate3	309.12	Wanted
Langlaagte4	664.91	Wanted
Langlaagte5	701.37	Wanted
Langlaagte6	255.11	Wanted
Langlaagte7	256.46	Wanted
Langlaagte8	105.18	Wanted
Langlaagte9	102.53	Wanted
Langlaagte10	188.31	Wanted
Langlaagte11	121.86	Wanted
Langlaagte12	131.87	Wanted
Total	**3744.74**	**Wanted**

Table 4.5: Langlaagte rooftop area
Source: GEP

4.3 Sandton Testing Station: Data Collection

4.3.1 Geographic location

Sandton Testing Station is located by the following coordinates: 26^{0} 05’ 35.2” S, 28^{o} 05’ 21.34” E.

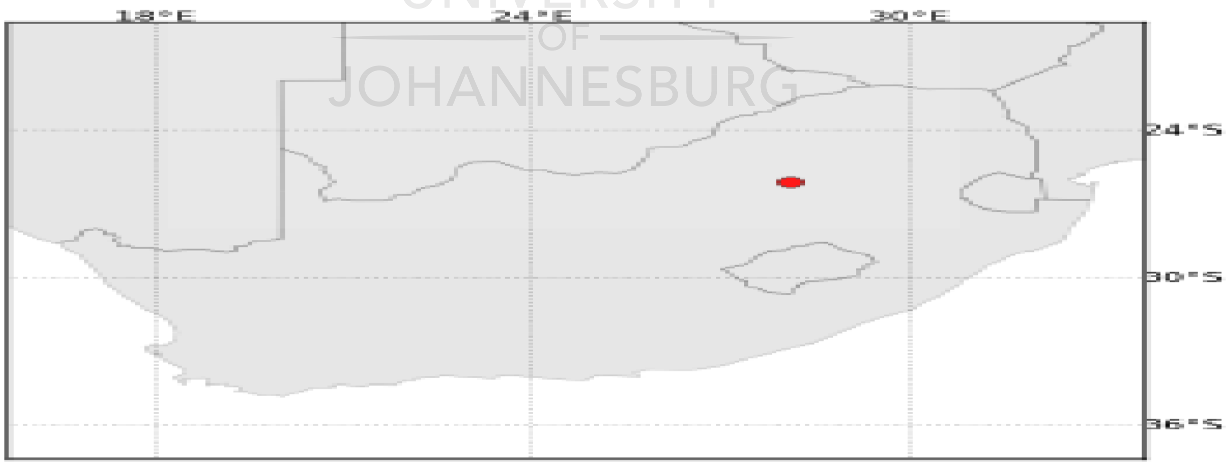
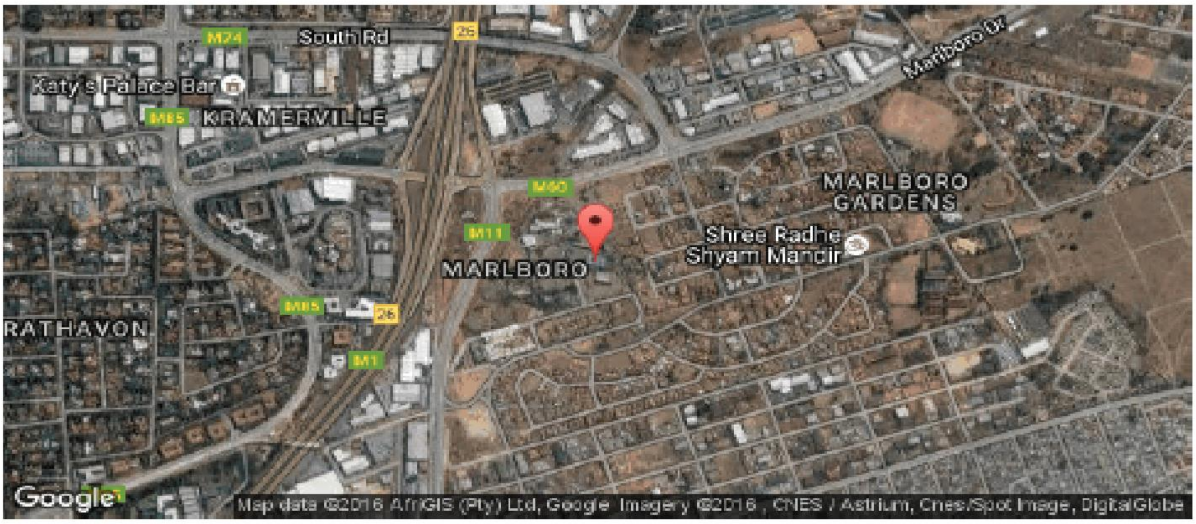


Figure 4.7: Sandton Testing Station geographic location

Source: Solargis pvPlanner generated coordinates



Google Maps © 2016 Google

Figure 4.8: Sandton Testing Station GEP image

4.3.2 Sandton Annual Average Solar Irradiation

The Solargis pvPlanner software was used to generate Global Horizontal Irradiation and Global in-plane Irradiation data as shown in table 4.6 and 4.7 respectively. The software also generated the optimal angle at which the PV panels could be installed.

Month	Gh_m	Gh_d	Dh_d	T_{24}
Jan	193	6,22	2,53	20,8
Feb	170	6,06	2,38	20,1
Mar	166	5,34	2,03	18,5
Apr	143	4,77	1,52	15,7
May	135	4,34	1,02	11,9
Jun	120	3,99	0,87	9,2
Jul	132	4,25	0,92	8,8
Aug	157	5,06	1,2	12
Sep	180	6,07	1,63	15,9
Oct	196	6,33	2,13	18,7
Nov	194	6,47	2,32	19,7
Dec	204	6,59	2,55	20,7
Year	1989	5,45	1,76	16

Table 4.6: Global Horizontal Irradiation

Source: Generated Solargis pvPlanner report for Langlaagte

Where:

Gh_m Global Irradiation Monthly Sum (kWh/m^2)

Gh_d Global Irradiation daily sum (kWh/m^2)

Dh_d Diffuse Irradiation daily sum (kWh/m^2)

T_{24} Diurnal air temperature (^0C)

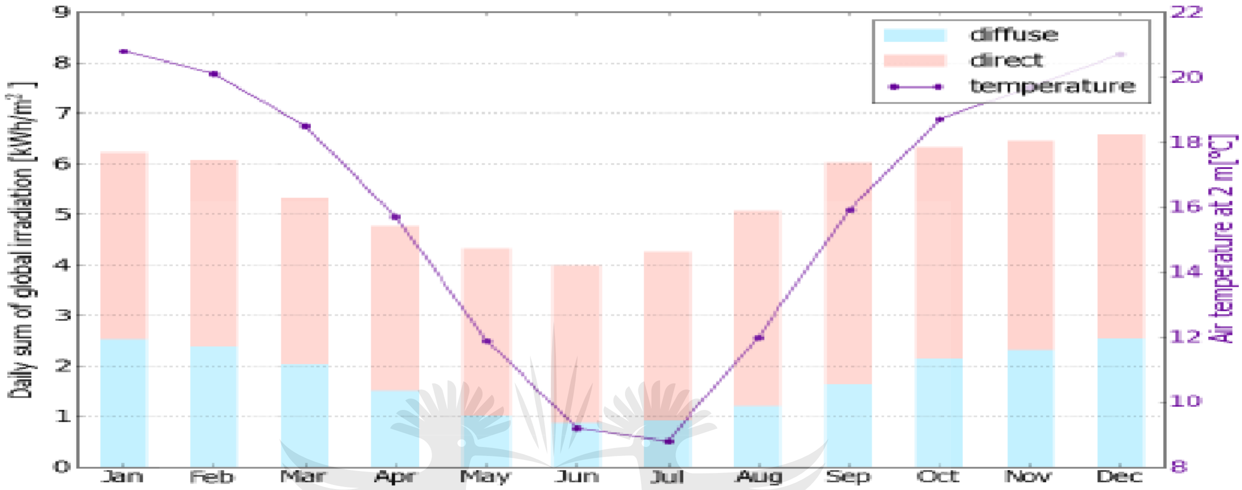


Figure 4.9: Annual global irradiation

Source: Generated Solargis pvPlanner report for Sandton

Month	Gi_m	Gi_d	Di_d	Ri_d	Sh_{loss}
Jan	172	5,53	2,35	0,05	0,1
Feb	163	5,82	2,31	0,05	0,1
Mar	178	5,72	2,09	0,04	0
Apr	175	5,84	1,69	0,04	0,1
May	189	6,11	1,24	0,04	0,2
Jun	181	6,01	1,1	0,03	0,2
Jul	193	6,24	1,16	0,04	0,1
Aug	206	6,64	1,44	0,04	0,1
Sep	207	6,89	1,79	0,05	0
Oct	197	6,35	2,14	0,05	0
Nov	177	5,88	2,19	0,05	0,1
Dec	178	5,74	2,35	0,06	0,1
Year	2215	6,07	1,82	0,04	0,1

Table 4.7: Global in-plane irradiation
Source: Generated Solargis pvPlanner report for Sandton

Where:

Gi_m is the global irradiation monthly sum (kWh/m^2)

Gi_d is the global irradiation daily sum (kWh/m^2)

Di_d is the diffuse irradiation daily sum (kWh/m^2)

Ri_d is the reflected irradiation daily sum (kWh/m^2)

Sh_{loss} are global irradiation losses due to terrain shading (%)

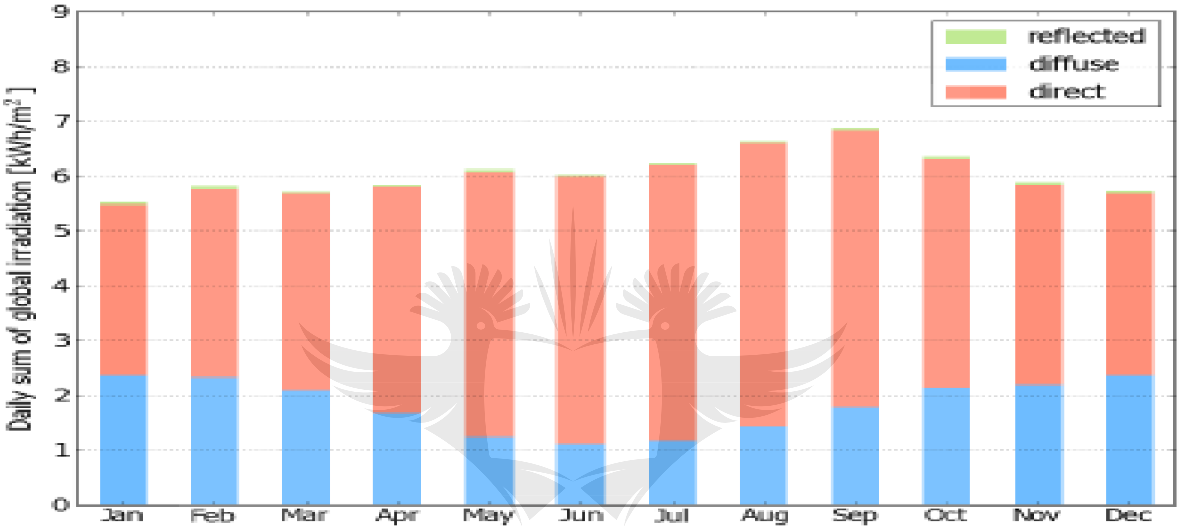


Figure 4:10: Daily total global irradiation

Source: Generated Solargis pvPlanner report for Sandton

Orientation	**kWh/m²**	**Relative to optimally inclined**
Horizontal	1989	89.8%
Optimally inclined (29°)	2215	100%
2-Axis tracking	2895	130.7%
Selected option	2215	100%

Table 4.8: Average annual sum of global irradiation for diverse surfaces
Source: Generated Solargis pvPlanner report for Sandton

The annual average solar irradiation used for Sandton Testing Station was 2215 $kWh/m^2/year$.

4.3.3 Sandton Rooftop Area Results

GEP was used to calculate the rooftop area for Sandton Testing Station using the methodology described in chapter three. Figure 4.11 shows the aerial images of the roof spaces used for PV installations. Figure 4.12 illustrates the suitable, marked in red and unsuitable (yellow) areas for rooftop PV installations.

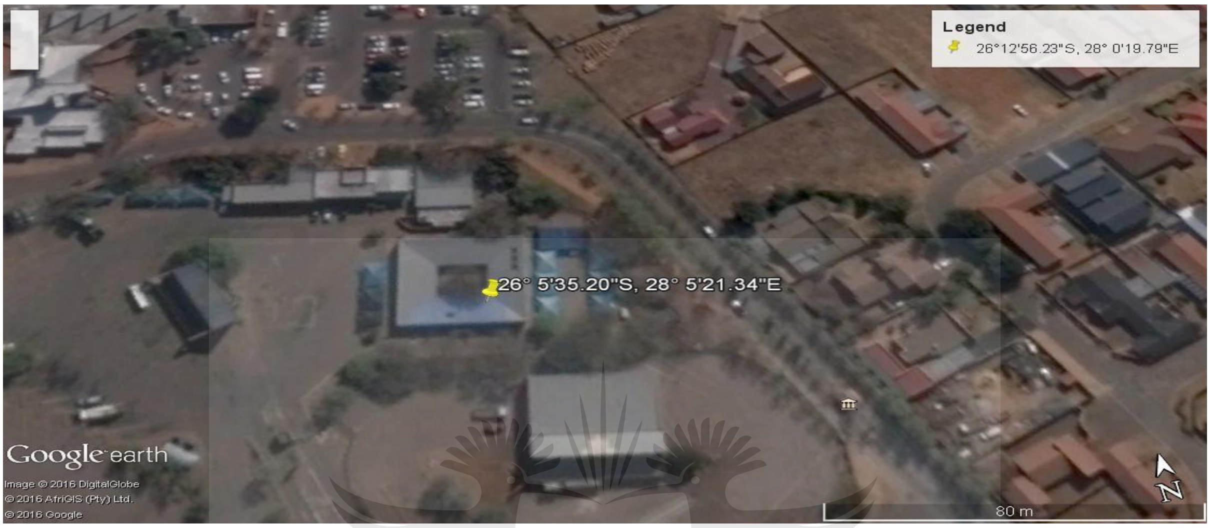


Figure 4.11: Sandton roof space from GEP

Figure 4.12: Sandton roof area for PV installations

Source: GEP image

Section	**Area (m2)**	**Roof Area Type**
Sandton1	814.90	Wanted
SandtonU1	-129.77	Unwanted
Sandton2	173.81	Wanted
Sandton3	446.44	Wanted
Sandton4	637.72	Wanted
Sandton5	139.88	Wanted
Total	**2082.98**	**Wanted**

Table 4.9: Sandton rooftop area

4.4 Roodepoort Testing Station

4.4.1 Geographic location

Roodepoort Testing Station is located by the following coordinates: 26^{0} 09’ 33.13” S, 27^{o} 51’ 58.08” E.

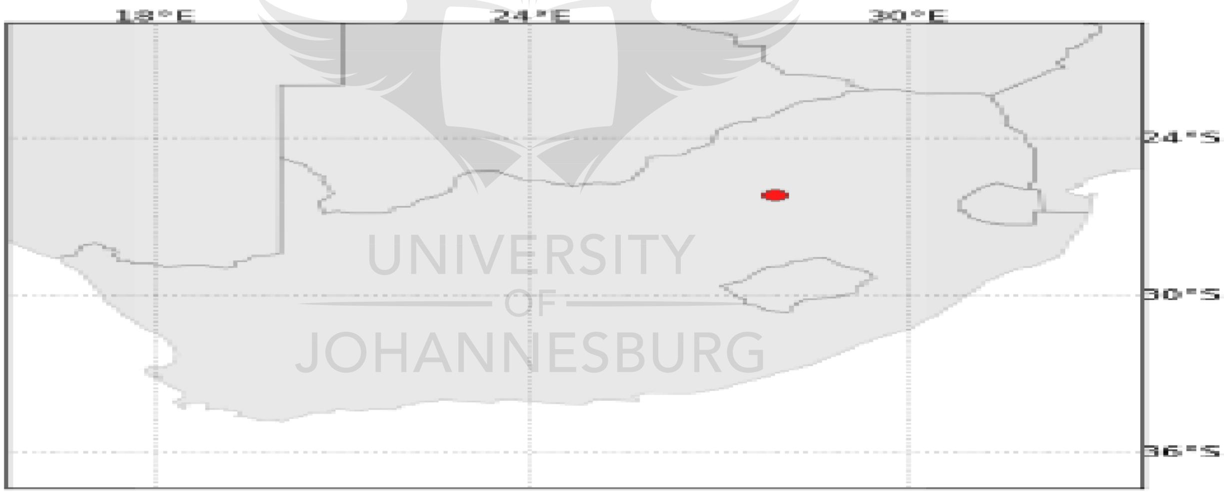
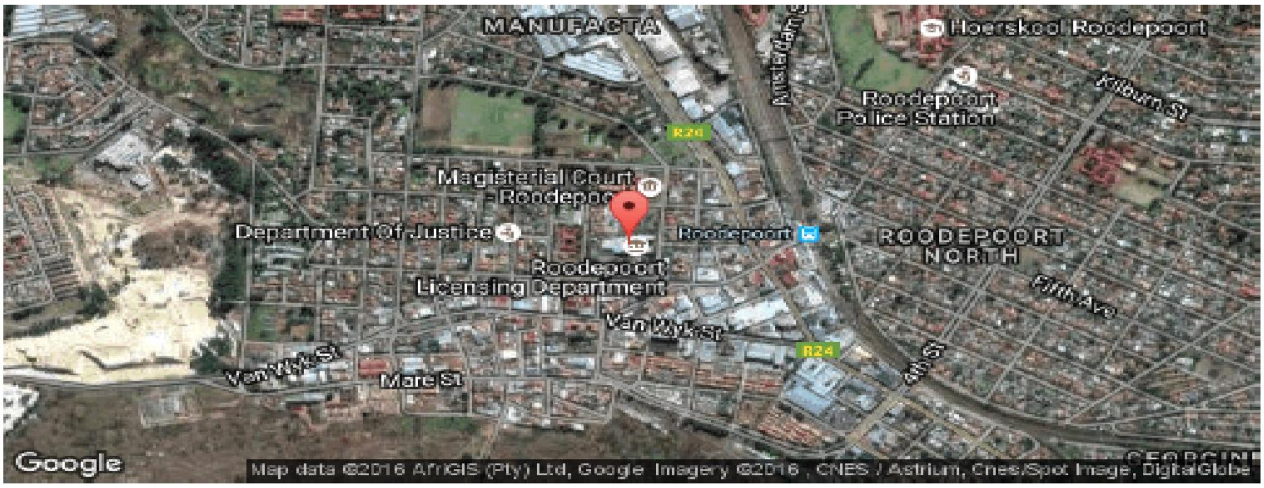


Figure 4.13: Roodepoort Testing Station geographic location

Source: Solargis pvPlanner generated coordinates



Google Maps © 2016 Google

Figure 4.14: Roodepoort Testing Station GEP image

4.4.2 Sandton Annual Average Solar Irradiation

The Solargis pvPlanner software was used to generate Global Horizontal Irradiation and Global in-plane Irradiation data as shown in table 4.10 and 4.11 respectively. The software also generated the optimal angle at which the PV panels could be installed.

Month	Gh_m	Gh_d	Dh_d	T_{24}
Jan	193	6,23	2,54	20,3
Feb	168	6	2,38	19,6
Mar	165	5,33	2,02	17,9
Apr	143	4,75	1,52	15,1
May	135	4,35	1	11,1
Jun	120	4,01	0,84	8,4
Jul	133	4,28	0,88	8,1
Aug	158	5,11	1,16	11,3
Sep	183	6,09	1,58	15,3
Oct	198	6,37	2,11	18,1
Nov	196	6,54	2,28	19,2
Dec	205	6,61	2,54	20,3
Year	1996	5,47	1,73	15,4

Table 4.10: Global Horizontal Irradiation and air temperature – climate reference
Source: Generated Solargis pvPlanner report for Roodepoort

Where:

Gh_m Global Irradiation Monthly Sum (kWh/m^2)

Gh_d Global Irradiation daily sum (kWh/m^2)

Dh_d Diffuse Irradiation daily sum (kWh/m^2)

T_{24} Diurnal air temperature (^0C)

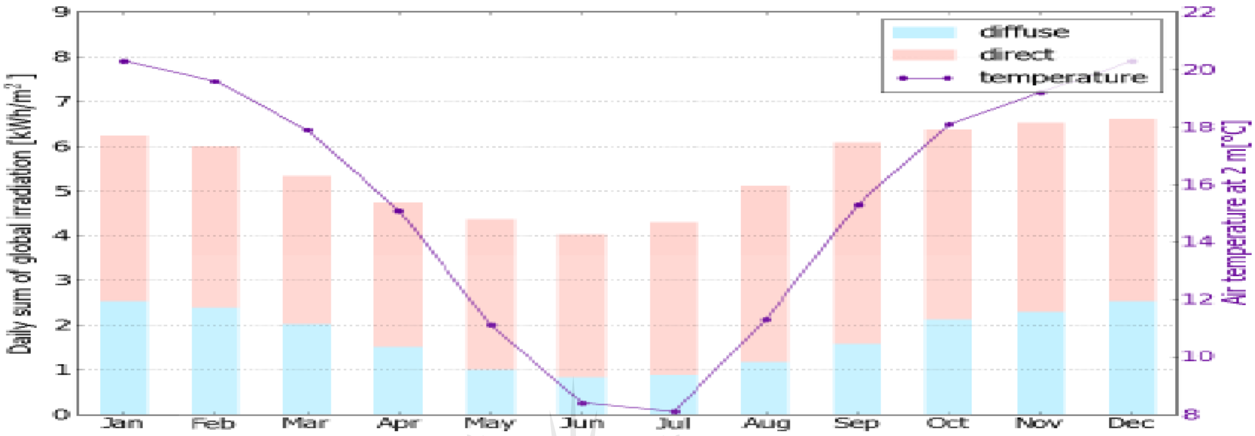


Figure 4.15: Annual global irradiation

Source: Generated Solargis pvPlanner report for Roodepoort

Month	Gi_m	Gi_d	Di_d	Ri_d	Sh_{loss}
Jan	172	5,54	2,35	0,05	0,3
Feb	161	5,76	2,3	0,05	0,2
Mar	177	5,71	2,07	0,04	0,1
Apr	174	5,81	1,67	0,04	0,2
May	190	6,13	1,22	0,04	0,1
Jun	182	6,05	1,07	0,03	0,3
Jul	195	6,3	1,12	0,04	0,1
Aug	208	6,71	1,39	0,04	0,1
Sep	210	7	1,74	0,05	0,1
Oct	198	6,39	2,11	0,05	0,2
Nov	178	5,94	2,15	0,05	0,2
Dec	178	5,75	2,33	0,06	0,2
Year	2224	6,09	1,79	0,04	0,2

Table 4.11: Global in-plane irradiation
Source: Generated Solargis pvPlanner report for Roodepoort

Where:

Gi_m is the global irradiation monthly sum (kWh/m^2)

Gi_d is the global irradiation daily sum (kWh/m^2)

Di_d is the diffuse irradiation daily sum (kWh/m^2)

Ri_d is the reflected irradiation daily sum (kWh/m^2)

Sh_{loss} are global irradiation losses due to terrain shading (%)

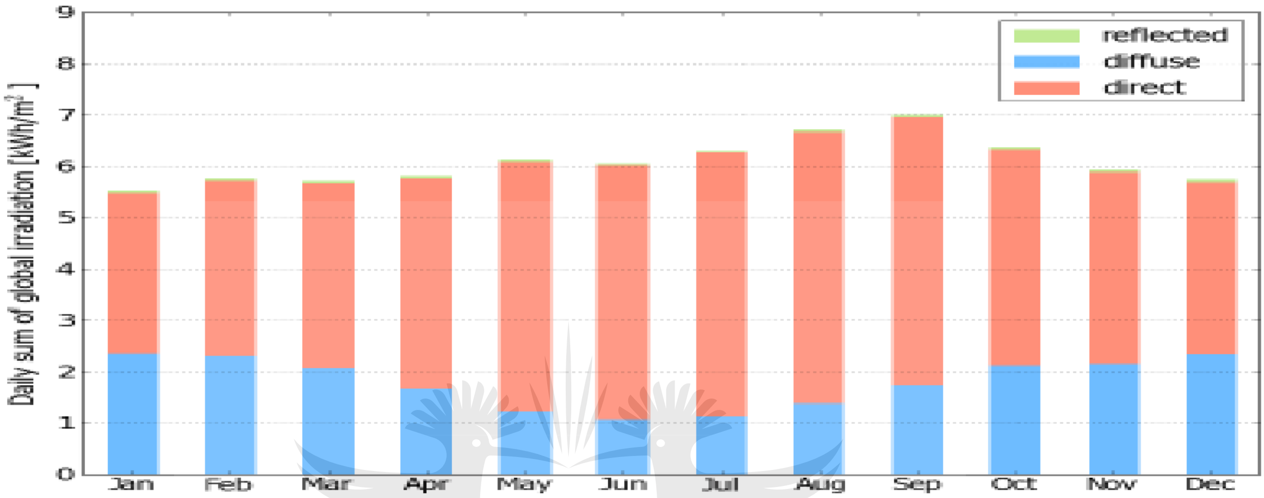


Figure 4.16: Daily global irradiation

Source: Generated Solargis pvPlanner report for Roodepoort

Orientation	kWh/m^2	Relative to optimally inclined
Horizontal	1996	89.7%
Optimally inclined (29°)	2225	100%
2-Axis tracking	2914	131%
Selected option	2224	100%

Table 4.12: Average annual sum of global irradiation for diverse surfaces
Source: Generated Solargis pvPlanner report for Roodepoort

The annual average solar irradiation used for Roodepoort Testing Station was 2224 kWh/m^2/year.

4.4.3 Roodepoort Rooftop Area Results

GEP was used to calculate the rooftop area for Roodepoort Testing Station using the methodology described in chapter three. Figure 4.17 shows the aerial images of the roof spaces used for PV installations. Figure 4.18 illustrates the suitable areas, marked in red, for rooftop PV installations.

Figure 4.17: Roodepoort roof space from GEP

Figure 4.18: Roodepoort roof area for PV installations

Source: GEP image

Section	**Area (m2)**	**Roof Area Type**
Roodepoort1	342.88	Wanted
Roodepoort2	124.44	Wanted
Roodepoort3	573.33	Wanted
Roodepoort4	383.96	Wanted
Roodepoort5	611.40	Wanted
Roodepoort6	194.66	Wanted
Roodepoort7	167.51	Wanted
Roodepoort8	39.97	Wanted
Roodepoort9	44.17	Wanted
Roodepoort10	31.32	Wanted
Roodepoort11	68.47	Wanted
Roodepoort12	23.31	Wanted
Total	**2605.42**	**Wanted**

Table 4.13: Roodepoort rooftop area

4.5 Carbon Emission Reduction Data gathering

The carbon emission factor of 1.03tons/MWh obtained from Eskom (2015) fact sheets was used for the carbon emission reduction calculations for the three sites.

4.6 Employment Creation Potential Data gathering

Employment factors for the South African environment were obtained from IRENA (2013) as shown in Table 4.14.

Technology	CMI Jobs (Job years/MW		Operation and Maintenance (Jobs /MW)
	Construction/Installation	Manufacturing	
PV	52.3	16.8	0.73

Table 4.14: Employment Factors for South African Analysis
Source: IRENA (2013) Report

Table 4.15 shows the Employment factors from the 2015 Global Analysis. The variance between Table 4.14 and 14.15 employment factors is due to the differing environments and the level of maturity of the PV technology in different countries as deliberated in the discussion section in chapter 5.

Technology	Job	Employment Factor	Country	Reference
Solar PV	Manufacturing, Construction, Installation	5.75-6.21 jobs/MWp	Not specified	Sooriyaarachchi et al (2015)
	Operation and Maintenance (O&M)	1.2-4.8 jobs/ MWp	Not specified	Sooriyaarachchi et al (2015)
	PV Module Manufacturing	3-7 jobs/ MWp (Direct jobs) 12-20 jobs/MWp (Indirect jobs)	European Union	Sooriyaarachchi et al (2015)
	PV Panel Production	10 jobs/MWp (Direct jobs)	Turkey	Sooriyaarachchi et al (2015)
	Wholesale, Retail, Installation and Maintenance	36 jobs/MWp (Direct jobs)		
	Installation	346 jobs/MWp (Direct jobs)		
	Operation and Maintenance	27 jobs/MWp (Direct jobs)		
	Construction/Installation	11 job years/MW	OECD countries	Rutovitz and Harris (2012)
	Manufacturing	6.9 job years/MW		
	O&M	0.3 jobs/MW		

Table 4.15: Summary of employment factor by job sector: 2015 Global analysis
Source: Sooriyaarachchi et al (2015)

4.7 Data Collection Challenges

It was difficult to get COJ architectural roof drawings needed to calculate the roof areas of the selected testing stations. These drawings were supposed to work hand in hand with the GEP software to verify areas. The unavailability of any budget for software tools for data gathering made the researcher resort to free software or trial version software. GEP and Solargis pvPlanner were the two main software applications used during the research process. The Solargis pvPlanner software tool used to calculate the annual solar irradiations was a trial version that had restrictions on the number of reports to run before software lock up, a maximum of six runs. This gave the researcher restrictions on the reports to generate during the software familiarisation process and there was no opportunity to see the implications of varying parameters like the azimuth or tilt angles to maximise the solar irradiance. Availability of fully licensed software would have produced more comprehensive data and results especially by identifying the optimal roof tilt angles. Despite these limitations, the annual solar irradiation figures obtained from Solargis pvPlanner software are more accurate and precise than the values that could be obtained from solar irradiation maps which are more generalised. The GEP free software doesn’t fully simulate the hindrances encountered during peak shedding. Although shading effects were considered during rooftop area calculations, availability of software that can simulate maximum shading could have yielded better quality data. Most of the employment factors that are readily available are from developed countries especially the European Union countries. The geographical and environmental diversity South Africa in relation to these countries can produce data that deviate results by marked margins.

4.8 Conclusion

Once all the requisite data was gathered, the next mission was to do the appropriate calculations analysing the how the available data can aid in the achievement of the set-out objectives of potential rooftop PV energy derived, carbon emission reductions and employment creation. The next chapter utilises and evaluates the collected data, analysing the associated implications of this to the city.

Chapter 5 Results Analysis and Discussion

5.1 Results

The results section utilised the gathered data to calculate and quantify the measurable research objectives drawing a comparison between status before and after implementing rooftop PV systems.

5.1.1 Potential Energy Generated

The estimation for potential energy yield from PV rooftop deployment within the COJ was derived from the energy equation 3.2 in the Methodology chapter as shown below:

$$E = A \times r \times H \times PR \qquad \textit{Equation 3.2}$$

This prospective energy or power output is heavily dependent on the PV panel used whether it's crystalline silicon, polycrystalline, amorphous silicon multi-junction and thin-film polycrystalline. These PV panels have diverse efficiencies ranging from 8.2 to 22.9%. The rooftop areas (A) for the three sites were obtained using Google Earth Pro as discussed in the Methodology chapter. The annual solar irradiation (H) results were obtained from the generated Solargis pvPlanner reports as previously discussed in chapter 3. The remaining parameters like panel efficiency (r) and performance ratio (PR) were available parameters obtained from the PV panel specification sheet. The PV module used to calculate the rooftop PV electricity potential for the 3 sites was an EnerSol 300 Polycrystalline module. Table 5.1 shows the specifications of the module used.

EnerSol 300 Polycrystalline PV Module Specification		
Description	Unit	Quantity
Panel Dimensions	mm	1956x992x40
Panel Area	m^2	1.94
Weight	kg	29
Number of cells	each	6x12
Polycrystalline	w/module (peak)	300
Module efficiency	%	15.4
Average Performance ratio	%	79
DC/AC losses	%	5.5 / 1.5
Module Lifespan	years	25

Table 5.1: EnerSol 300 Module Specification
Source: The Power store (2017)

Table 5.2 below shows the PV energy generated for the three sites using different variables from equation 3.2.

Site Name	Suitable Area (A) (m^2)	PV Panel Efficiency (r) (%)	Annual Solar Irradiation (H) ($kWh/m^2/yr$)	Performance Ratio (PR) (%)	Energy Generated (kWh)
Langlaagte	3744.74	15.4	2227	79	1014587.95
Roodepoort	2605.42	15.4	2224	79	704953.28
Sandton	2082.92	15.4	2215	79	561298.82
			Total Energy Generated		**2280840.05**

Table 5.2: PV Energy Potential for Langlaagte, Roodeport and Sandton Testing Stations

As highlighted in table 5.2 the total energy generated from rooftop PV installations was approximately 2281MWh. According to City Power records the total energy consumption for the three sites amounted to 18781MWh/year in 2015. Table 5.3 shows a comparison of rooftop PV energy generated and the 2015 energy consumption for the three sites.

Site Name	PV Energy (MWh/yr)	2015 Composite Consumption (MWh/yr)	PV Energy Contribution (%)
Langlaagte	1014.59	7804.52	13
Roodepoort	704.95	5874.61	12
Sandton	561.30	5102.72	11
Total Energy	**2280.84**	**18781.85**	**12.14**

Table 5.3: Comparison of rooftop PV Energy and 2015 Energy Consumption

Installation of rooftop PV systems within COJ brings an average energy contribution of 12.14% of the sites' energy requirements. This figure indicates the substantial contribution that rooftop PV systems can offer to COJ's energy requirements. Over a 25 year PV module life span the energy generated amounts to 57000MWh. Although the financial analysis of the energy savings is beyond the scope of this research, it can be assumed that the energy savings can amount to approximately 12% of the total energy costs. Using high efficiency panels of 22.9% could result in rooftop PV energy generation figures of 4303MWh/year for the 3 sites thus making a 22.91% contribution to the city's energy requirements.

Figure 5.1 below shows a graphical comparison of rooftop PV contribution to the 2015 energy consumption for the 3 sites.

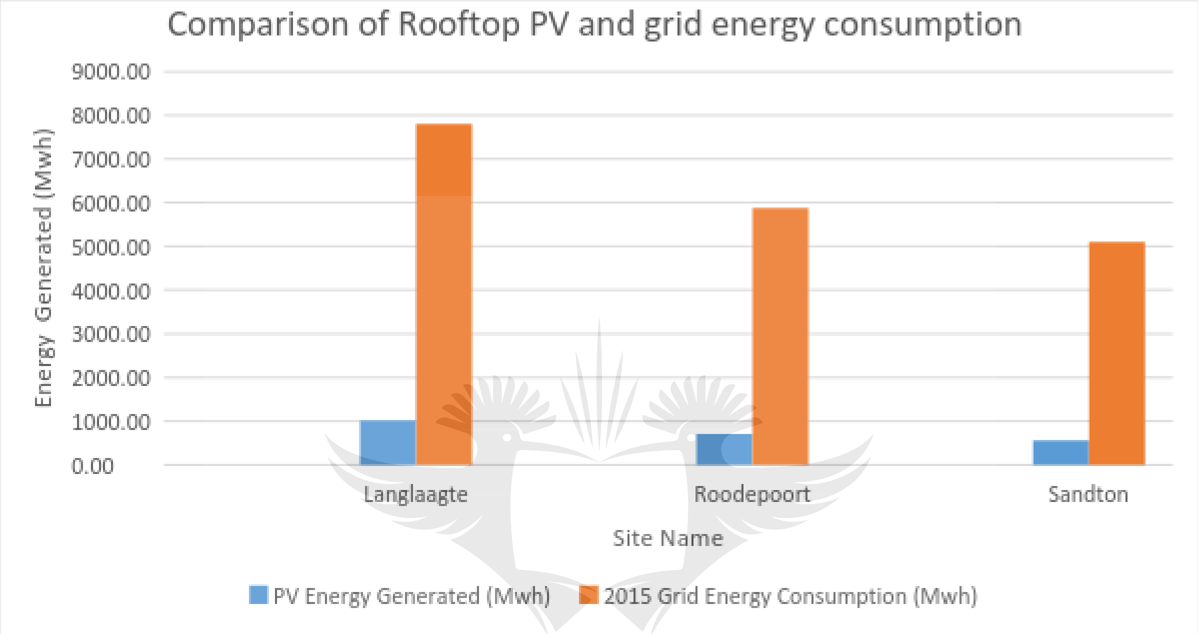


Figure 5.1: Rooftop PV and Current Grid Energy Consumption comparisons

5.1.2 Carbon Emission Reductions

To calculate the carbon emission reductions for COJ equation 3.5 was used. The annual potential energy generated from rooftop PV systems was multiplied by the Eskom emission factor of 1.03tons/MWh to give the GHG emissions that could be saved by implementing the rooftop project on the 3 sites. The emission reductions were calculated using the 1.03tons/MWh emission factor from Eskom factsheets as highlighted in table 5.4.

Site Name	Activity Data (MWh)	Emission Factor (tons/MWh)	GHG Emissions Reductions/Year (tons)	25 Year Emission Reductions (tons)
Langlaagte	1015	1.03	1045.45	26136.25
Roodepoort	705	1.03	726.15	18153.75
Sandton	561	1.03	577.83	14445.75
		Total Emissions	**2349.43**	**58735.75**

Table 5.4: GHG Emission Reductions for Langlaagte, Roodeport and Sandton Stations

Site Name	2015 Annual GHG Emissions (tons)	Annual PV GHG Emission Reductions (tons)	% GHG Emission Reductions
Langlaagte	8038.66	1045.45	13.01
Roodepoort	6050.85	726.15	12.00
Sandton	5255.80	577.83	10.99
Total GHG Emissions	**19345.30**	**2349.43**	**12.14**

Table 5.5: Comparison of 2015 grid GHG emissions against rooftop PV emission reductions

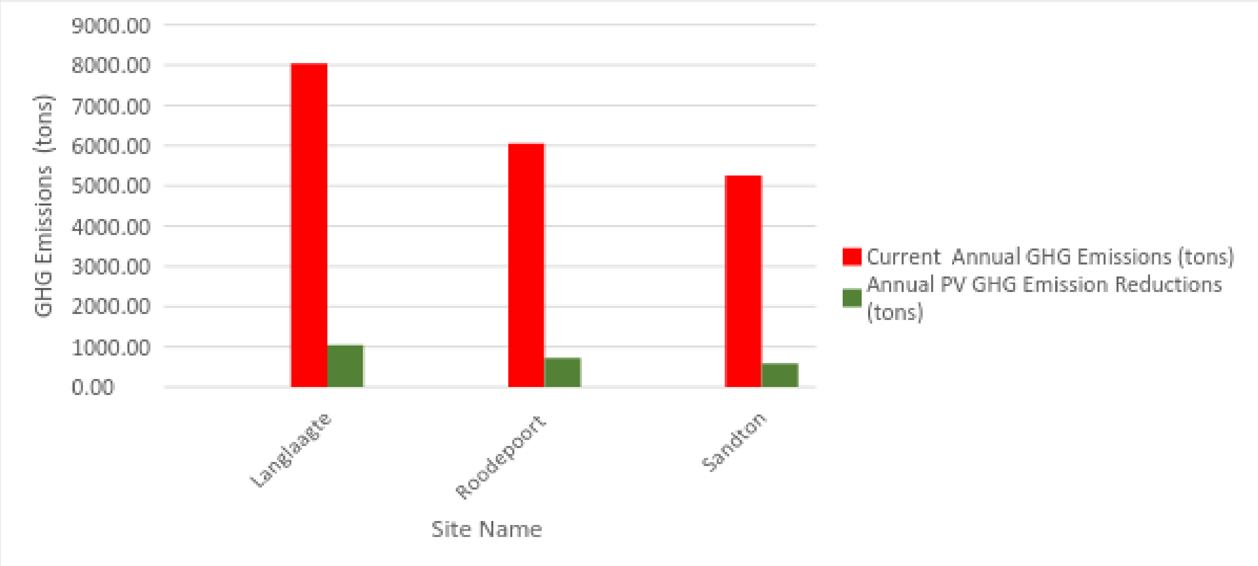


Figure 5.2: Comparisons of 2015 GHG emissions and rooftop PV GHG emission reductions

From table 5.5, the effect of incorporating rooftop PV systems within COJ could reduce GHG emissions by 12.14%, contributing an annual reduction of about 2349.43 tonnes for the three sites. For the module's 25-year lifespan, 58735,75 tonnes of GHG emission could be saved. At high efficiencies of 22.9%, assuming a PR of 0,79, then 3493,63 tonnes of GHG emissions could be saved and over a 25-year lifespan this translates to 87340,82 tonnes emission reductions.

5.1.3 Potential Employment Creation

According to the Department of Energy, South Africa experiences more than an average 2500h hours of sunshine per year. Table 5.6 shows the power generated for the three sites.

Site Name	PV Energy (MWh/yr)	Sunshine Hours per year	Power Generated (MW)
Langlaagte	1014.59	2500	0,406
Roodepoort	704.95	2500	0,282
Sandton	561.30	2500	0,225
Total for 3 Sites	**2280.84**	**7500**	**0,913**

Table 5.6: Power generated per site

Table 5.7 shows IRENA (2013) South African employment factors that were used during the research process.

Technology	**CMI Jobs (Job years/MW**		**Operation and Maintenance (Jobs /MW)**
	Construction/Installation	Manufacturing	
PV	52.3	16.8	0.73

Table 5.7: Employment Factors for South African Analysis
Source: IRENA (2013) Report

Table 5.8 below shows the potential jobs that could be created if rooftop PV systems were implemented within COJ for three sites under review.

Site Name	**Job Sector**	**Power Potential (MW)**	**EF (Job years/MW)**	**EF (Jobs/MW)**	**Jobs Created**
Langlaagte	Construction/Installation	0,406	52.3		22
	Manufacturing	0,406	16.8		7
	O & M	0,406		0.73	1
			Total Jobs		**30**
Roodepoort	Construction/Installation	0,282	52.3		15
	Manufacturing	0,282	16.8		5
	O & M	0,282		0.73	1
			Total Jobs		**21**
Sandton	Construction/Installation	0,225	52.3		12
	Manufacturing	0,225	16.8		4
	O & M	0,225		0.73	1
			Total Jobs		**17**

Table 5.8: Employment Creation for Langlaagte, Sandton and Roodepoort

5.2 Results Analysis and Discussion

The prospective energy output generated from the deployment of rooftop PV in the COJ highlights the significant influence that RE technologies can have to the city's overall energy requirements. The effect of the rooftop PV energy deployment can be better appreciated if the energy generated is compared to the city's energy requirements as well as analysing the associated economic and social implications of such deployments to the city's development.

The potential rooftop PV energy output obtained for the three sites at 15.4% efficiency and 79% performance ratio was 2.28GWh/year. If higher efficiency panels of 22.9% are used, an energy potential of 3.39GWh/year could be generated and this could yield 84.76GWh over a 25 year PV lifespan. If rooftop PV installations are incorporated within the COJ, this can contribute approximately 12.14% to the three sites' energy requirements. Such a contribution has a huge implication to the energy policy framework formulation within the city.

Implementing rooftop PV systems on the 3 sites would reduce annual carbon emissions by 2349.43 tonnes. Over a 25year lifespan of the PV panel, the carbon emissions would reduce by 58735.75 tonnes. Table 5.3 gave a comparison of 2015 grid based GHG emissions against rooftop PV GHG emission reductions. Implementing rooftop PV systems on Langlaagte reduces annual carbon emissions by 13.01%. Deployment of rooftop PV systems on Roodepoort and Sandton Testing Stations reduce GHG emissions by 12 and 10.99% respectively. The overall GHG emission reduction for the three sites amounted to 12.14%. If the rooftop PV project is deployed on the seven COJ testing stations that can result in an average 5482 tonnes reduction in GHG emissions per year. Implementing the rooftop project on most of the city's administrative buildings, clinics, libraries etc. could result in significant emission reductions in the city.

Deployment of rooftop PV systems on the three testing stations resulted in considerable employment creation within COJ. A total of 30 jobs were created at Langlaagte Testing Station. Roodepoort created a total of 21 jobs whereas Sandton created a total of 17 jobs. Considering the high unemployment of over 24% within South Africa, implementing rooftop PV systems at a large scale within COJ can significantly reduce unemployment figures.

The rooftop PV technologies are intricate systems that depend more on the availability of solar irradiation which is seasonal and time dependent in nature. Solar irradiation is more pronounced in summer than in winter. This means there is need to store extra solar energy during periods of overabundance to enable future consumption during periods of high energy demands. The increased energy capacity will ensure solar energy reliability, availability and a stable electrical system. Storage options available include various and latest battery technologies, flywheels, hydraulic pumping, compressed air etc.

Achieving a rational or sensible energy potential estimation is only feasible if accurate data is collected. Despite every effort to ensure optimal data gathering processes, data errors and inaccuracies can't be totally avoided especially during area measurement processes. Some roof areas that are assumed to be suitable for PV installations through GEP aerial images might be physically unsuitable. The area measurements and energy potential approximations were mainly based on created polygons which practically might fail to align and compliment with the physical panels.

Estimating the potential solar energy is a complex exercise that involves many assumed variables that are not easily verifiable. Parameters like panel efficiency, performance ratio and annual solar irradiation etc. are assumed to be constant in the calculations throughout the panels' lifespan. The panel efficiency and performance decrease with panel age. According to Basson and Pretorius (2016) weather changes can cause seasonal variations in PR of +/- 10% with climate change trends affecting the annual solar irradiance in the long run. The global climate change trends can also affect the annual solar irradiance in the long run. Variation of these parameters can distort the estimates for the 25-year life span. These parameter deviations don't only affect the potential energy generated but they have a knock-on effect on the carbon emission reduction and employment creation calculations as the calculations are dependent on generated energy.

Getting the best energy production is heavily dependent on the optimal tilt angle and direction of solar panels. Various research studies have shown that optimum energy generation occurs when the panels are tilted at an angle that is close to the location's degree of latitude i.e. about 26 degrees north for the sites under review. This tilt angle is dependent on the period of the year or season with higher tilt angles preferred during winter periods. It is imperative that the COJ should formulate city policies that encourage future buildings to be constructed with roof orientations that optimise rooftop PV installations, making them more north facing at the finest tilt angles.

The cross-cutting nature of the RE sector across all sectors of the economy makes it difficult to capture employment data in the form of standard national statistics. Employment statistics are derived from diverse sources that utilise heterogeneous approaches, assumptions and time lines. Sound statistical information concerning RE employment is very crucial to enable informed policy making choices. Good quality and up to date EF data is only available from a few selected countries like the USA and OECD countries. For the rest of the countries the available data is restricted and unreliable. According to IRENA (2013) there are no EFs for decommissioning jobs in RE sector. The EFs are derived from experience of leading RE countries and this is not representative of countries with RE industries still developing or maturing with differing cost structures and lower labour productivities (IRENA, 2013). When evaluating employment prospects, it is therefore crucial to make a provision for specific national circumstances, implying local EFs could differ considerably from global figures as they are tuned to specific countries' characteristics. Technological advancements can significantly reduce EFs over time resulting in reduced jobs per MW.

Chapter 6 Conclusion and Future Work

6.1 Conclusion

COJ's energy, climate change and unemployment challenges can be greatly improved by introduction of RE energy sources. Implementing rooftop PV systems can significantly contribute to enhancement of the COJ's energy capacity as well as GHG emission reductions and employment creation. PV rooftop projects should be considered as a noteworthy strategy for sustainable development. Installing rooftop PV systems within COJ has a potential to generate 12.14% of the city's energy requirements, contributing about 2.28GWh/year. Deploying rooftop PV systems on the 3 sites under study reduced annual carbon emissions by 2349.43 tonnes, contributing over 12% of GHG emission reductions. A considerable number of jobs were created because of the deployment of rooftop PV systems. Total of 68 temporary and permanent jobs were created during the deployment rooftop PV systems. Such a deployment at a large scale can greatly reduce the city's unemployment rate and the national unemployment rate currently at over 24%. For the country's pledge to reduce GHG emissions by approximately 42% by 2025 to bear fruits, municipalities and the government should consider large-scale implementation of rooftop PV systems. The government and municipalities should view rooftop PV systems as a great climate change mitigation strategy. The introduction of rooftop PV systems into COJ can have a positive impact on the city and country's sustainable development goals as highlighted by the additional PV energy generated, GHG emission reductions and employment creation.

6.2 Future Work

According to Ahlfeldt (2013), the cost of rooftop PV systems within the South African market varies between R20/W and R27/W for 10kW to 1MW commercial and industrial PV projects. For the three sites Table 6.1 highlights at a high level financial costs for pursuing the rooftop PV projects at the three sites. The minimum and maximum implementation costs for the three sites would amount to R 18 260 000,00 and R 24 651 000,00 respectively. Capital costs to produce a MW of rooftop PV energy would then require a minimum of R20 million and a maximum of R27 million for the three sites.

Site Name	Power O/p (W)	Min Cost /W	Max Cost/W	Min Site Cost	Max Site Cost
Langlaagte	406000	R 20,00	R 27,00	R 8 120 000,00	R 10 962 000,00
Roodepoort	282000	R 20,00	R 27,00	R 5 640 000,00	R 7 614 000,00
Sandton	225000	R 20,00	R 27,00	R 4 500 000,00	R 6 075 000,00
Total	**913000**	**R 20,00**	**R 27,00**	**R 18 260 000,00**	**R 24 651 000,00**

Table 6.1: Cost of generating energy for the three sites

Due to time constraints, the research didn't delve much into the financial analysis of deploying rooftop PV systems on the three sites. Further research on the financial implications of implementing such a project in terms of payback period, return on investment, internal rate of return, break even analysis, grid parity, levelised cost of electricity etc. can still be pursued to enable city authorities to make informed decisions about rooftop PV systems investments.

Bibliography

BP energy outlook. (2016). 1-98.

Joburg 2040, growth and development strategy. (2011). Johannesburg: City of Johannesburg.

National climate change response white paper. (2011).

Gauteng municipalities. Available from: http://www.localgovernment.co.za/provinces/view/3/gauteng. (Accessed 11 June 2016).

Abubakar Mas'ud, A., Wirba, A.V., Muhammad-Sukki, F., Albarracín, R., Abu-Bakar, S.H., Munir, A.B. & Bani, N.A. (2016). A review on the recent progress made on solar photovoltaic in selected countries of sub-Saharan Africa. *Renewable and sustainable energy reviews,* 62441-452.

Ahlfeldt, C. (2013). The localisation potential of photovoltaics (PV) and a strategy to support large scale roll-out in South Africa.

Aldy, J.E. (2016). Mobilizing political action on behalf of future generations. *Future of children,* 26(1):157-178.

Awan, A.B. & Khan, Z.A. (2014). Recent progress in renewable energy – remedy of energy crisis in Pakistan. *Renewable and sustainable energy reviews,* 33236-253.

Baker, L. (2015). Renewable energy in South Africa's minerals-energy complex: A 'low carbon' transition? *Review of African political economy,* 42(144):245-261.

Basson, H. & Pretorius, J. (2016). *International Conference on Renewable Energies and Power Quality (ICREPQ'16).* Conference proceedings of the Xth conference held in Y.

Behrouzi, F., Nakisa, M., Maimun, A. & Ahmed, Y.M. (2016). Global renewable energy and its potential in Malaysia: A review of hydrokinetic turbine technology. *Renewable and sustainable energy reviews,* 621270-1281.

Belectric. (2013). *Service and Maintenance of Photovoltaic Systems: All Round Service Package.* Available from: http://www.belectric.com/fileadmin/MASTER/pdf/brochures/BEL_PVD_Service_EN_www.pdf. (Accessed June 30).

Bilgen, S. (2014). Structure and environmental impact of global energy consumption. *Renewable and sustainable energy reviews,* 38890-902.

Bryan, H. Rallapalli, H. & Rasmussen, P. & Fowles, G. (2010). *39th ASES National Solar Conference 2010, SOLAR 2010.* Conference proceedings of the Xth conference held in Y. Phoenix, AZ, United States: American Solar Energy Society.

Byrne, J., Taminiau, J., Kurdgelashvili, L. & Kim, K.N. (2015). A review of the solar city concept and methods to assess rooftop solar electric potential, with an illustrative application to the city of Seoul. *Renewable and sustainable energy reviews,* 41830-844.

CDP, C40 & AECOM. (2014). *CDP Cities 2014 Johannesburg.* Available from: http://www.circlesofclimate.org/wp-content/uploads/2016/02/2014-johannesburg-in-focus.pdf. (Accessed January 10 2017).

City of Johannesburg (2013). *City of Johannesburg: 2012-2016 integrated development plan: 2013/2014 review.* Johannesburg: City of Johannesburg.

City of Johannesburg GPC Report. Available from: http://carbonn.org/uploads/tx_carbonndata/GPC%20Report%20for%20the%20City%20of%20Johannesburg_01.pdf. (Accessed 16 July 2016).

City Power (2013). *City power Johannesburg (SOC) ltd business plan 2013-2016.* City Power.

Dekker, J., Nthontho, M., Chowdhury, S. & Chowdhury, S.P. (2012). Investigating the effects of solar modelling using different solar irradiation data sets and sources within South Africa. *Solar energy,* 86(9):2354-2365.

Department of Energy (2013). *Integrated energy planning report.* Department of Energy.

Department of Environmental Affairs. (2014). Available from: https://www.environment.gov.za/sites/default/files/docs/greenhousegas_invetorysouthafrica.pdf. (Accessed 16 July 2016).

National energy act, 2008. Government gazette. (2008). *Print (0).* (Vol. No. 521 No. 31638).

Department of Minerals and Energy (2003). *White paper on renewable energy.*

DLGH (2010). *Gauteng integrated energy strategy.* Johannesburg: Department of Local Government and Housing.

DME (2009). *National energy efficiency strategy of the republic of South Africa. Government gazette no. 32342.* Department of Minerals and Energy.

DOE (2015). *State of renewable energy in South Africa.* Pretoria: Department of Energy.

Environamics (2013). *Final scoping report: Proposed Bokamoso photovoltaic solar facility and associated infrastructure near Leeudoringstad, North West province.* Environamics.

Eskom. (2015). *List of fact sheets.* Available from: http://www.eskom.co.za/IR2015/Documents/Eskom_fact_sheets_2015.pdf. (Accessed 15 August 2016).

EWEA (2012). *Green growth – the impact of wind energy on jobs and the economy.* European Wind Energy Association.

Gagnon, P., Margolis, R., Melius, J., Phillips, C. & Elmore, R. (2016). Rooftop solar photovoltaic technical potential in the United States: A detailed assessment. *Rep.no.NREL/TP-6A20-65298). Retrieved March,* 30 2016.

Gets, A. (2013). *Powering the future: Renewable energy roll-out in South Africa.* Johannesburg: Greenpeace Africa.

Gough, I. (2013). Climate change, social policy, and global governance. *Journal of comparative*

Handoyo, E.A., Ichsani, D. & Prabowo, (2013). The optimal tilt angle of a solar collector. *Energy procedia,* 32166-175.

Hernández-Moro, J. & Martínez-Duart, J. (2013). Analytical model for solar PV and CSP electricity costs: Present LCOE values and their future evolution. *Renewable and sustainable energy reviews,* 20119-132.

IEA. (2015). Available from: https://www.iea.org/newsroomandevents/pressreleases/2016/march/decoupling-of-global-emissions-and-economic-growth-confirmed.html. (Accessed 8 august 2016).

IEA. (2014). Available from: https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapSolarPhotovoltaicEnergy_2014edition.pdf. (Accessed 08 August 2016).

Ilze, P., Stuart, P., Roelof, B. & Hein, N. (2015). A perspective on South African coal fired power station emissions. *Journal of energy in southern Africa,* 26(3):27.

International Energy Agency. (2014). Available from: http://www.iea.org/publications/freepublications/publication/Kwes2014.pdf. (Accessed 06 August 2016).

IRENA (2016). *Renewable energy benefits: Measuring the economics.* Abu Dhabi: IRENA.

IRENA (2015). *Renewable energy and jobs - annual review 2015.* International Renewable Energy Agency.

IRENA (2013). *Renewable energy and jobs.* Abu Dhabi: International Renewable Energy Agency.

IRENA and CEM (2014). *The socio-economic benefits of large-scale solar and wind: An econValue report.* IRENA and CEM.

IRP 2010 -2030 (2011). *Integrated resource plan for electricity 2010 - 2030.*

Ismail, Z. & Kollamparambil, U. (2015). Youth unemployment duration and competing exit states: What hides behind long spells of black youth unemployment in South Africa? *African development review,* 27(3):301-314.

James, B. (2012). Climate change: The opportunity cost of Medupi and Kusile power stations. *Journal of energy in southern Africa,* 23(4):67.

JIKE (2012). *City of Johannesburg case studies 2011-2012. Available at http://www.jhbcityparks.com/pdfs/coj_casestudies_20112012.pdf .accessed on 29 June 2016.* Joburg innovation and knowledge exchange.

Kampmark, B. (2015). COP21: The ambitions and flaws of the Paris agreement. *International policy digest,* 2(12):37-39.

Kannan, N. & Vakeesan, D. (2016). Solar energy for future world: - A review. *Renewable and sustainable energy reviews,* 621092-1105.

Khan, J. & Arsalan, M.H. (2016). Solar power technologies for sustainable electricity generation – A review. *Renewable & sustainable energy reviews,* 55414-425.

Kodysh, J.B., Omitaomu, O.A., Bhaduri, B.L. & Neish, B.S. (2013). Methodology for estimating solar potential on multiple building rooftops for photovoltaic systems. *Sustainable cities and society,* 831-41.

Le Roux, W.G. (2016). Optimum tilt and azimuth angles for fixed solar collectors in South Africa using measured data. *Renewable energy,* 96(Part A):603-612.

LI, A.H.F. (2016). Hopes of limiting global warming? China and the Paris agreement on climate change. *China perspectives,* (1):49-54.

Maia J, Giordano T, Kelder N, Bardien G, Bodibe M, Du Plooy P (2011). *Green jobs: An estimate of the direct employment potential of a greening South African economy. Available at www.idc.co.za/projects/greenjobs.pdf , accessed on 28th June 2016.* Johannesburg/Pretoria:

Industrial Development Corporation, Development Bank of Southern Africa, Trade and Industrial Policy Strategies.

Matshoge Tebogo & Sebitosi Adoniya Ben (2010). The mapping of maximum annual energy yield azimuth and tilt angles for photovoltaic installations at all locations in South Africa. *Journal of energy in southern Africa,* 21(4):2.

Mbadlanyana, T. (2013). The political economy of carbon tax in South Africa - a critical analysis. *Africa insight,* 43(1):77-90.

McNeill, R. (2016). *Solar PV Module Recycling — Why It's Important.* Available from: http://www.renewableenergyworld.com/articles/2016/06/solar-pv-module-recycling-why-it-s-important.html. (Accessed 10 January 2017).

Melius, J., Margolis, R. & Ong, S. (2013). Estimating rooftop suitability for PV: A review of methods, patents, and validation techniques. *National renewable energy laboratory (NREL), golden, CO.*

Mesík, J. (2015). Paris climate change agreement: A milestone or a fake? *International issues & Slovak foreign policy affairs,* 24(4):79-98.

Minnaar, U.J. (2016). Regulatory practices and distribution system cost impact studies for distributed generation: Considerations for South African distribution utilities and regulators. *Renewable and sustainable energy reviews,* 561139.

Montmasson-Clair, G., Moilwa, K. & Ryan, G. (2014). *Review of regulation in renewable energy.* TIPs.

Moyo, T. (2016). Low carbon and climate resilient investments. *Africa insight,* 45(4):129-147.

Moyo, T. (2014). Green economy/growth policies and their implementation in the context of the renewable energy sector: The case of Mozambique, South Africa and Zimbabwe. *International journal of African renaissance studies,* 9(2):39-60.

Msimanga, B. & Sebitosi, A.B. (2014). South Africa's non-policy driven options for renewable energy development. *Renewable energy,* 69420-427.

Munzhedzi, R. & Sebitosi, A.B. (2009). Redrawing the solar map of South Africa for photovoltaic applications. *Renewable energy,* 34(1):165-169.

Murombo, T. (2016). Legal and policy barriers to renewable and sustainable energy sources in South Africa. *Journal of world energy, law & business,* 9(2):142-165.

Nakumuryango, A. & Inglesi-Lotz, R. (2016). South Africa's performance on renewable energy and its relative position against the OECD countries and the rest of Africa. *Renewable & sustainable energy reviews,* 56999-1007.

Nhamo, G. & Mukonza, C. (2016). Policy, institutional and programme readiness for solar energy uptake in South Africa. *Africa insight,* 45(4):69-90.

Oluwajodu, F., Blaauw, D., Greyling, L. & Kleynhans, E.P.J. (2015). Graduate unemployment in South Africa: Perspectives from the banking sector. *South African journal of human resource management,* 13(1):1-9.

Ordóñez, J., Jadraque, E., Alegre, J. & Martínez, G. (2010). Analysis of the photovoltaic solar energy capacity of residential rooftops in Andalusia (Spain). *Renewable and sustainable energy reviews,* 142122-2130.

Pandey, A.K., Tyagi, V.V., Selvaraj, J.A., Rahim, N.A. & Tyagi, S.K. (2016). Recent advances in solar photovoltaic systems for emerging trends and advanced applications. *Renewable and sustainable energy reviews,* 53859-884.

Parkinson, G. (19 February 2016). Available from: http://reneweconomy.com.au/2016/greens-unveil-rooftop-solar-plan-for-australian-council-buildings-11316. (Accessed 13 August 2016).

Pollet, B.G., Staffell, I. & Adamson, K. (2015). Current energy landscape in the republic of South Africa. *International journal of hydrogen energy,* 40(46):16685-16701.

PTiP. (2014b). *PTiP Innovations.* Available from: http://www.ptip.co.za/index.php/technology-overview/module-design. (Accessed March 29).

PTiP. (2014a). *PTiP Innovations.* Available from: http://www.ptip.co.za/index.php/technology-overview/advantages-of-technology. (Accessed March 29).

PTiP News. (2014b). *PTiP Innovations.* Available from: http://www.ptip.co.za/index.php/thenews/entry/inauguration-of-ptip-demonstration-plant-in-techno-park-stellenbosch-on-3-february-2014. (Accessed March 29).

PTiP News. (2014a). *PTiP Innovations.* Available from: http://www.ptip.co.za/index.php/thenews/entry/ptip-solar-panels-beat-the-grid-for-affordable-electricity. (Accessed 2017 March 28).

Reichelstein, S. & Yorston, M. (2013). The prospects for cost competitive solar PV power. *Energy policy,* 55117-127.

Reinecke, J., Leonard, C., Kritzinger, K., Bekker, B., van Niekerk, J.L. & Thilo, J. (2013). Unlocking the rooftop PV market in South Africa.

REN 21 (2013). *Renewables 2013: Global status report. Paris: REN21.* REN 21.

Ren21. (2015). Available from: http://www.ren21.net/wp-content/uploads/2015/07/GSR2015_Keyfindings_lowres.pd. (Accessed 09 August 2016).

Rogerson, C.M. & Rogerson, J.M. (2015). Johannesburg 2030: The economic contours of a 'linking global city'. *American behavioral scientist,* 59(3):347-368.

Rutovitz. J & Harris S. (2012). *Calculating global energy sector jobs: 2012 methodology.* University of Technology, Sydney: Institute for sustainable futures.

Saygin, D., Kempener, R., Wagner, N., Ayuso, M. & Gielen, D. (2015). The implications for renewable energy innovation of doubling the share of renewables in the global energy mix between 2010 and 2030. *Energies (19961073),* 8(6):5828-5865.

Sharma, V. & Chandel, S.S. (2013). Performance and degradation analysis for long term reliability of solar photovoltaic systems: A review. *Renewable and sustainable energy reviews*.

Solargis. Available from: (http://solargis.info/pvplanner/#tl=Google:hybrid&bm=satellite). (Accessed 31 October 2016).

Sooriyaarachchi, T.M., Tsai, I., El Khatib, S., Farid, A.M. & Mezher, T. (2015). Job creation potentials and skill requirements in, PV, CSP, wind, water-to-energy and energy efficiency value chains. *Renewable and sustainable energy reviews,* (52):653-668.

Sovacool, B.K. & Rafey, W. (2011). Snakes in the grass: The energy security implications of Medupi. *Electricity journal,* 24(1):92.

StatsSA. (2011). Available from: http://www.statssa.gov.za/?page_id=1021&id=city-of-johannesburg-municipality. (Accessed 11 June 2016).

Subburaj, A.S., Pushpakaran, B.N. & Bayne, S.B. (2015). Overview of grid connected renewable energy based battery projects in USA. *Renewable and sustainable energy reviews,* 45219-234.

Sustainability Outlook. (2011). *A solar resource database and PV assessment tool for India.* Available from: http://sustainabilityoutlook.in/content/solar-resource-database-and-pv-assessment-tool-india. (Accessed 10 December 2016).

Sustainable Energy Africa (2014). *SALGA local government energy efficiency and renewable energy strategy. Status quo report.* Cape Town: Sustainable Energy Africa.

Tcholakov, Y., Wiley, E., Hornung, T., Walker, X., Mello, A., Hall, D.V., Mattar, C., Williams, K., Castelblanco, D., P-Desrosiers, C., Singh, S., Guinto, R., Essafi, S. & De Leon, S. (2015). The road to Paris: What is at stake for health in COP21 negotiations? *World medical journal,* 61(3):114-119.

The Power store. (2017). *The Power Store.* Available from: http://www.thepowerstore.co.za/pENERSOL%20300/EnerSol-300W-Solar-Panel.aspx. (Accessed 11 November 2016).

Tobin, P. (2015). The politics of climate change: Can a deal be done? *Political insight,* 6(1):32-35.

Trading Economics. (2016). Available from: http://www.tradingeconomics.com/south-africa/unemployment-rate. (Accessed 24 July 2016).

UNEP and SETAC (2009). *Life cycle management. How business uses it to decrease footprint, create opportunities and make value chains more sustainable.* UNEP and SETAC.

van Ravenswaay, J.P., Roos, T.H., Surridge-Talbot, A.K.J., Xosa, S. & Sattler, C. (2014). Development of a solar fuels roadmap for South Africa. *Energy procedia,* 691838-1848.

Vorrath, S. (2016). *RenewEconomy.* Available from: http://reneweconomy.com.au/solar-vote-strengthens-poll-finds-growing-demand-for-pv-policy-support-53717/. (Accessed 17 August 2016).

Ward, S. & Mohammed, L. (2009). Sustainable urban energy planning: A handbook for cities and towns in developing countries. *ICLEI e local governments for sustainability, UN-habitat and UNEP, Nairobi*.

Wagner, N. (2016). (Solar) light at the end of the tunnel? Research news. *Agriprobe,* 13(2):38-39.

Walwyn, D.R. & Brent, A.C. (2015). Renewable energy gathers steam in South Africa. *Renewable & sustainable energy reviews,* 41390-401.

Webb, S. (2014). *City power Johannesburg: Response to potential load shedding.* 64th AMEU Convention 2014.

Wei, M., Patadia, S. & Kammen, D.M. (2010). Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US? *Energy policy,* 38(2):919-931.

Weir-Smith, G. (2014). An overview of the geographic data of unemployment in South Africa. *South African geographical journal,* 96(2):134-152.

Winkler, H., Franke, B., Eltrop, L. & Telsnig, T. (2012). How applicable are standard solar irradiation maps? Insights from case studies.

World Bank Group. (2016). Available from: http://ppp.worldbank.org/public-private-partnership/agreements/concessions-bots-dbos. (Accessed 14 August).

World Resources Institute. (2014). Available from: http://www.ghgprotocol.org/city-accounting. (Accessed 16 July 2016).

Yaiche, M.R., Bouhanik, A., Bekkouche, S.M.A., Malek, A. & Benouaz, T. (2014). Revised solar maps of Algeria based on sunshine duration. *Energy conversion and management,* 82114-123.

Yu, D. (2013). Youth unemployment in South Africa revisited. *Development southern Africa,* 30(4/5):545-563.

Zahedi, A. (2011). Maximizing solar PV energy penetration using energy storage technology. *Renewable and sustainable energy reviews,* 15, no. 1(1).