A FULL-COST ANALYSIS OF FUTURE TECHNOLOGY OPTIONS FOR ELECTRICITY GENERATION IN ZAMBIA

By

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A dissertation submitted to the University of Zambia in fulfilment of the requirements for the Degree of Master of Engineering in Renewable Energy

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DECLARATION

I, **Howard Mwaala,** hereby declare that this thesis has been written by myself and acknowledgements properly made. The work has not been submitted for any other degree or professional qualification but done in pursuit for honours degree in Master of Engineering as required by the University of Zambia.

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APPROVAL

This dissertation by **Howard Mwaala** entitled "A full-cost analysis of future technology options for electricity generation in Zambia" has been approved as partially fulfilling the requirements for the award of the degree of Master of Engineering in Renewable Energy of the University of Zambia.

ABSTRACT

The aim of this research is to facilitate informed decision making for an optimal cost-based allocation of future electricity generation resources in Zambia. Such a study is cardinal in order to find out which energy technologies are economically viable from a long-term perspective for our unwarranted developing economy in Zambia that still bases its energy production predominantly on wood fuel, hydropower and coal. The research approach adopted in this dissertation is based on a profound literature review of Zambia's electricity market, coupled with the development of a full-cost approach based on levelized cost of electricity. This approach is used to empirically evaluate the performance of new-build technologies that include coal, nuclear, natural gas, hydropower, bioenergy, geothermal, solar Photovoltaic, Concentrating Solar Power and wind with regard to economic, environmental and social criteria. In separate evaluation of several aspects of power plants multicriteria analyses based on hierarchically structured criteria is applied, so as to address the overall assessment of power plants according to the technological, economic and sustainability aspects. In this thesis, ten types of power plants are evaluated using nine end-node criteria structured under the Analytical Hierarchy Process. Moreover, pairwise comparisons are employed for accurate subjective criteria weighting.

The findings from this research provide evidence that conventional power plants are not the optimal option for electricity generation in Zambia but that renewable energy power plants are to be preferred for new investments. According to the scenario based on the subjective criteria weighting, emphasis is laid on sustainability driving renewable energy power plants on top of the overall ranking, while nuclear and fossil fuel power plants rank in the last five positions.

The other conclusion drawn from this study is that the inclusion of indirect costs and non-monetary aspects of electricity generation makes technologies more competitive in Zambia that otherwise seem expensive from a positive-economic point of view. The dissertation recommends that the structure of the Zambia electricity market should be adjusted constantly in order to facilitate the accommodation of higher shares of renewable energy, in the eyes of Sustainable Development Goals, to decarbonise the world energy system by the year 2020 hence the emphasis for Zambia to embrace renewable energy.

Key words: Optimal, Levelized, Economic, Environmental, Sustainability

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The idea and motivation for this work emerged majorly from a lecture delivered at the University of Zambia's School of Engineering entitled "Economics of Distributed Resources". Zambia, the country of analysis is of special interest to me as my domain country that belongs to the emerging countries whose economic development is driven by wood fuel, hydropower save for the depletion of fossil resources. Given today's carbon-constrained world, it was imperative to evaluate the competitiveness of alternative energy sources.

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ACRONYMS

CAPCO	Central Africa Power Corporation
CCGT	Combined-Cycle Gas Turbine
CEC	Copperbelt Energy Corporation Plc
CFL	Consolidated Farming Limited
CPC	Copperbelt Power Company
CSP	Concentrating Solar Power
DoE	Department of Energy
ESB	Electricity Supply Board
ERB	Energy Regulation Board
ESI	Electricity Supply Industry
ETS	European Emissions Trading Scheme
HFO	Heavy Fuel Oil
IAEA	International Atomic Energy Agency
IBC	Per Capita Income Benchmark Country
IDC	Industrial Development Corporation
IMF	International Monetary Fund
IPCC	International Panel on Climate Change
IPP	Independent Power Producer
IRP	Integrated Resource Plan
ISMO	Independent System and Market Operation
KNB	Kariba North Bank
KPI	Key Performance Indicator
LCOE	Levelized Cost of Electricity
LHPC	Lunsemfwa Hydropower Company Limited
MCPs	Market Clearing Prices
MD	Maximum Demand
MYPD	Multi-Year Price Determination
NAMA	Nationally Appropriate Mitigation Action
NAP	National Adaptation Plan
NECL	Ndola Energy Company Limited
NER	National Electricity Regulator
NEP	National Energy Policy

NES	National Energy Strategy
NGCC	Natural Gas Combined Cycle
NG IM	Natural Gas Intermediate Load
NWEC	North Western Energy Corporation Limited
O&M	Operation and Maintenance
OCGT	Open-Cycle Gas Turbine
OECD	Organisation for Economic Co-operation and Development
PPA	Purchasing Power Agreement
PPP	Producer Power Parity
PPI	Purchasing Price Index
PV	Photovoltaic
R&D	Research Development
RE	Renewable Energy
REA	Rural Electrification Authority
RED	Regional Electricity Distributor
REFIT	Renewable Energy Feed-In Tariff
REMP	Rural Electrification Master Plan
RES	Renewable Energy Sources
RRT	Residential roof-top
RUS	Rural utility-scale
SAPP	Southern African Power Pool
SC	Super critical coal
sLCOE	Simplified Levelized Cost of Electricity
SOC	State-owned company
VFEB	Victoria Falls Electricity Board
WASA	Wind Atlas of South Africa
WPEP	White Paper on Energy Policy
WPRE	White Paper on Renewable Energy
ZABS	Zambia Burea of Standards
ZAMSIF	Zambia Social Investment Fund
ZCCM	Zambia Consolidated Copper Mines
ZDA	Zambia Development Agency
ZEMA	Zambia Environmental Management Agency
ZPL	Zengamina Power Limited

SYMBOLS AND UNITS

c	US Cents
c_f	Fuel costs
cfom	Fixed operation and maintenance costs
CO_2-eq.	CO_2-equivalent
c_p	Plant costs
CRF	Capital Recovery Factor
cvom	Variable operation and maintenance costs
DC_{GHG}	Day Ahead Market age Costs from greenhouse gas emissions
e	Price escalation rate
EI_{rt}	Emission Intensity Factor
$\bar{E}_{ZMW}$	Estimate Value Zambia
EX_{GHG}	Externalities from greenhouse gas emissions
EX_{net}	Net externalities
f	Capacity factor
GJ	Gigajoule
GW	Gigawatt
GWh	Gigawatt hours
H	Hours of the year
intl. $	International Dollars
IZ	Per Capita Income Zambia
Jc,t	Job Creation Potential in Construction Sector
JCP_t	Job Creation Potential
Jfp,t	Job Creation Potential in Fuel Processing Sector
Jin,t	Job Creation Potential in Installation Sector
Jmf,t	Job Creation Potential in Manufacturing Sector
Jmn,t	Job Creation Potential in Maintenance Sector
Jo,t	Job Creation Potential in Operations Sector
kg	Kilogramme
KW	Kilowatt
KWh	Kilowatt hours
kWp-y	Kilowattpeak per year

kW-y	Kilowatt-year
l	Levelization Factor
l_f	Levelization Factor Fuel
lom	Levelization Factor Operation and Maintenance
m	Meter
m/s	Meter per second
m^2	Square Meter
m^3	Cubic Meter
MC_P	Private Marginal Cost
MC_S	Social Marginal Cost
mm	Millimeter
Mt	Megaton
Mtoe	Megatons of oil equivalents
MW	Megawatt
MWh	Megawatt hours
ZMW	Zambian Kwacha
n	Number of observations
P*	Equilibrium Price
P_m	Monopoly Price
Q	Income Elasticity for Environmental Quality
Q*	Equilibrium Quantity
Q_m	Monopoly Quantity
r	Discount rate
t	Tons, Technology
T	Time in years
TWh	Terrawatt hours
USD	US Dollar
ZAR	South African Rand
η	Ratio of Energy Output to Energy Input
€	Euro
£	Pound
¢	Euro Cent
US$	United States Dollar
%	Percentage

CHAPTER 1: INTRODUCTION

1.1 Introduction

The development of sustainable energy is key in national and international policies formulation (Solomon & Krishna, 2011). Efforts towards a sustainable energy system are predominantly becoming an agenda of paramount importance for decision makers. Environmental sustainability constitutes the main energy policy objectives for a sustainable energy system (Omer, 2008).

A global transition to lower carbon economies is underway. The main driver is concern about increasing greenhouse gas emissions (GHGs) and effects on our climate. The environmental, social and economic implications of this challenge are immense and complex, necessitating new approaches to technology development, policy, planning, financing, governance and collaboration (Canada's Public Policy Forum, 2013). The energy sector is cited the largest contributor of GHG emissions. The energy sector is estimated to account for about 45% of *energy-related* CO_2 with emissions originated in electricity and heat generation alone responsible for 40%. The energy sector is followed by transport (22%), industry (20%), and the rest allocated to buildings and other sectors. Oil, natural gas and coal are finite resources that cannot be reproduced in human time frames. Recent global conventional oil reserve estimates range between 117 Gt and 182 Gt. Unconventional oil resources are much more abundant than conventional oil reserves and resources (BP, 2015).

Global average temperature has increased -16.978 Degrees Celsius since the Industrial Revolution, and the report from the U.N.'s Intergovernmental Panel on Climate Change states that there is "very high confidence" that human activities have caused a net warming of the planet (IPCC, 2007). Fossil fuels are the major source of anthropogenic cause of climate change, primarily through CO_2 emissions arising from fuel combustion from industry, transport and others, but also through fugitive and accidental releases of CO_2 and methane from coal beds, wells and pipelines, and through the emissions of black carbon from incomplete combustion charcoal burning in particular. Fossil fuel combustion also causes negative forcing from sulphur and nitrogen oxides as well as partially combusted organic carbon, which causes global warming (IPCC, 2014).

Mitigation of emissions from the production and conversion of fossil fuels into energy carriers (electricity, solid, liquid or gaseous fuel) as used by end users can be achieved by reducing climate forcing per unit energy delivered via (1) switching to lower carbon-intensity fuels, (2) higher energy efficiency, and (3) reducing fugitive emissions along the supply chain and black carbon emissions from combustion. Given the importance of heat and power production in the energy sector, large reductions in CO2 emissions can be obtained by replacing existing coal fired power plants by highly efficient natural gas combined cycle (NGCC) power plants or combined heat and power (CHP) plants.

Renewable energy (RE) can be defined as energy generated from natural resources such as solar, hydro, geophysical, or biological, in principal and practice can be replenished by natural processes at a rate that at least equals its rate of usage. The theoretical potential for RE, in total, greatly exceeds current and future energy demand. Only a small fraction of the RE technical potential has so far been exploited and, most, but not all, forms of RE supply have low life-cycle of greenhouse gases (GHG) emissions in comparison to fossil fuels. Such are the factors that are indicative of the potential for substantial GHG emissions reduction through many forms of RE deployment. RE technologies have advanced substantially in recent years. Notable recent advancements include: (1) improvements in manufacturing processes and photovoltaic (PV) cell efficiencies along with reductions in materials use, which have helped to substantially reduce the price of PV modules; (2) continued increases in the size and therefore energy capture of wind turbines deployed both on land and offshore; and (3) improvements in cropping systems, logistics, and multiple conversion technologies for bioenergy. Using bio-digesters is an innovation that has given rise to a paradigm shift from waste treatment for disposal to waste treatment for energy usage, methane gas in particular plus heat.

As a result of these and other advancements, a growing number of RE technologies have achieved a level of both technical and economic advancement to be deployed at significant scale, others are less advanced and not yet widely deployed. Hydropower technologies, for example, are advanced. Bioenergy technologies, meanwhile, are diverse and span a wide range that includes technologies such as conventional biomass-powered electric boilers and heating systems, as well as ethanol production from sugar and starch, whereas lignocellulose-based transport fuels are at pre commercial stage.

The technical advancement of solar energy has increased thanks to continuous Research and Development (R&D), and to relatively advanced Concentrating Solar Power (CSP), solar heating and wafer-based silicon PV. Geothermal power plants and thermal applications that rely on hydrothermal sources are anchored on advanced technologies, whereas enhanced geothermal systems are at demonstration phase still undergoing R&D.

With the exception of tidal barrages, ocean technologies are also at the demonstration phase and require additional R&D. Finally, though land-based wind technologies are already relatively advanced, the use of wind energy in offshore locations is increasing but less technically and commercially advanced. Because the cost of many RE technologies has historically been higher than market energy prices, public R&D programs are imperative and government policies have played a major role in defining the size and location of RE deployment. Additionally, because RE relies on natural energy flows, RE technologies must often be located at or near the respective energy resource, often harvested energy from diffuse energy flows, and may produce energy output that is variable and to some degree, unpredictable energy flows.

According to Griffin (2009), a smart energy policy must fulfill three main goals: “energy should be cheap, clean and secure”. For most developing and emerging economies this is an ambitious target, but practically the three goals cannot be satisfied at the same time. The first priority must be access to cheap energy, followed by securing the availability of energy supplies. The third goal of a smart energy policy, is the provision of clean energy, which is imperative after the two other objectives have been satisfied.

This kind of situation can be observed in Zambia. As Griffin (2009) pointed out, the more affluent a society becomes, the more important clean energy supply becomes besides energy security issues. Despite the fact that competitive industries such as mining, agriculture, food processing, manufacturing and a flourishing service sector have developed in Zambia, both energy security and clean energy supply still is a big hurdle for the country. External effects from air pollution, use of scarce water resources and CO_2 emissions from the extensive burning of hydrocarbons are an environmental concern, especially in countries like Zambia, where coal power plants are part of industrialization.

Besides environmental degradation, energy supply issues are challenges that can be observed regularly. Power outages happen frequently throughout the country especially at of peak demand and both generation and transmission systems are most of the time constantly under their maximum stress. The Zambian power system is yet to be managed sustainably amidst infrastructure wear out as maintenance time is compromised for the sake of keeping the power plants running. To manage peak demand and reduce the burden on the generation system, ZESCO, the national and monopolistic energy supplier in Zambia, supplements local power generation with imported electricity and provides the customer with live system alerts.

1.2 Background Information

The institutional arrangement of Zambia's electricity sector is depicted in Figure 1.1. The Ministry of Mines, Energy and Water Development (MMEWD) is responsible for policy development. The Energy Regulation Board (ERB) is the independent regulator. As is the case in Kenya, Tanzania and Uganda, there is a quasi-independent body charged with extending grid connection to rural areas, the Rural Electrification Authority (REA). The Office for the Promotion of Private Power Investment (OPPPI) is a distinctive feature of the Zambian set-up. OPPPI is a specialised unit within the energy ministry that aims to promote private-sector investment in generation and transmission, and to manage the attendant and complex planning, procurement and contracting processes (Energy Regulation Board, 2013).

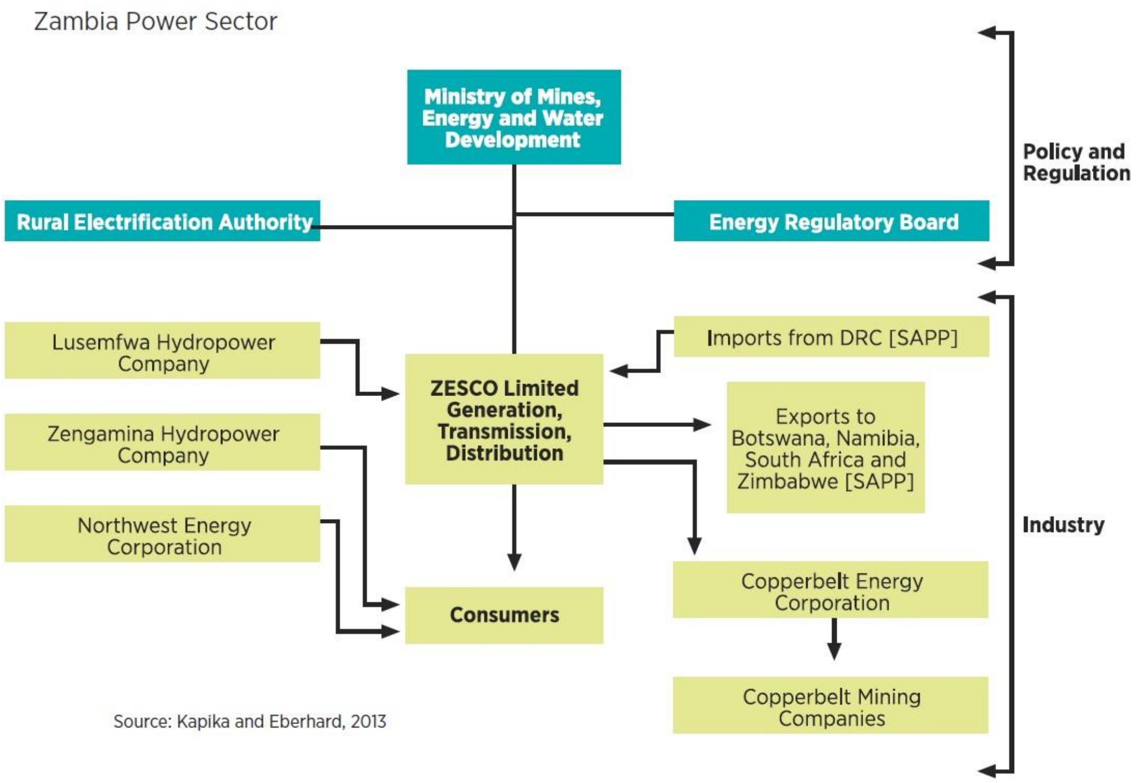


Figure 1.1: An overview of Zambia's electricity sector. Source: Kapika And Eberhard,(2013)

The Zambian Government energy targets are to: (i) improve delivery of energy services by reducing power outages and increasing electrification rates; (ii) increase the installed capacity of hydropower and other renewable energies; (iii) improve energy efficiency and conservation; (iv) liberalize the transmission network provision to private operators; (v)improve organizational management as well as the operational and financial performance of the Zambia Electricity Supply Cooperation (ZESCO); (vi) gradually phase out subsidies and raise electricity tariffs to reflect total cost recovery (Rural Electrification Master Plan for Zambia, 2009) . In the 2030 Vision, the Government aims at increasing rural electrification rates up to 51% (Zambia Renewables Readiness Assessment, 2013). The Rural Electrification Master Plan provides for a concrete roadmap to achieve this target through grid extension, individual PV systems as well as small hydropower (SHP) and biomass mini-grids. Zambia's renewable energy goals are further supported by the National Energy Policy, the Power System Master Plan and the Renewable Energy Strategy. In order to monitor progress of Zambia's energy goals, the Energy Regulation Board (ERB) and ZESCO agreed on a set of Key Performance Indicators (KPIs) (IRENA: 2013). The Government of Zambia highlights energy as being a driving force for the socio-economic development of the nation. This is evidenced through her 2030 Vision, which represents the first long-term plan of the country's aspiration to become a prosperous middle income nation by 2030. More specifically, the vision aims to provide "universal access to clean, reliable and affordable energy at the lowest total economic, financial, social and environmental cost, consistent with national development goals, by 2030" (TKN and IISD, 2012).

The aim of this research is to supplement and consolidate further informed decision making based on research for an optimal allocation of future electricity generation resources in Zambia. Such a study is important in order to discover which technologies are economically viable from a long-term perspective for a developing economy like Zambia that has energy production predominantly based on wood fuel, hydropower and coal. Sustainability of supply and the provision of quality energy services and products is key to economic growth and development. In 2014, progress was made in improving the country's power supply and petroleum infrastructure. However, as a sector, Zambia still faces challenges in the supply of energy products and services. In the quest to overcome these challenges, the Energy Regulation Board (ERB), together with key stakeholders, implemented various programmes in alternative and additional energy projects to ensure that efficient, reliable and quality energy services and products are provided by the industry. Zambia's energy sources include electricity, petroleum, coal, biomass, solar, geothermal and wind energy. The country imports all its petroleum products as crude petroleum feedstock or as finished products while hydro-electricity is mainly generated locally. According to the Ministry of Finance, the economy has been growing at an average rate of 5 percent per annum over the past 10 years (save for the 2.6% in 2016) and hence the demand for energy has also been rising (ERB, 2014). Hence, over the last decade, electricity demand has risen at an average of about 3 percent per annum mainly due to the increased economic activities in the country especially in the agriculture, manufacturing and mining sectors. The country's apparent economic growth has consequently led to a rising demand for energy products and services including alternative sources of energy such as solar (Zambia Development Agency, September 2014). The peak demand for electricity in Zambia increased from 1,100 MW in 2001 to 1,600 MW in 2009 while the country's installed generation capacity is 2,177 MW. The growth in demand is estimated to be between 150 MW and 200MW per annum (Zambia Energy Sector Profile-September 2014). Given these factors, the demand for electricity in the country is expected to exceed 2,500 MW by the year 2018 (Refer to Figure 1.2). Save for rural electrification whose progress is slow due to a general lack of a rural industrialisation policy implementation.

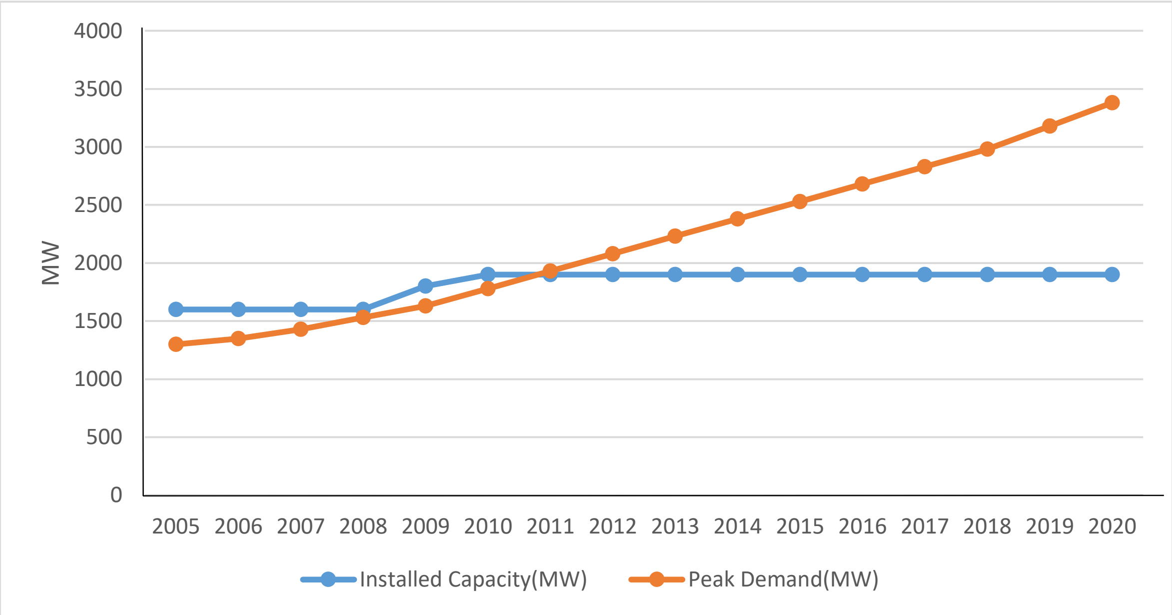


Figure 1.2: Electricity Demand Forecast in Zambia (2005 to 2020)

Source: Ministry of Energy and Water Development (2010)

There exists great potential for investment opportunities in the energy sector to meet the country's rising demand for the various forms of energy (Energy Policy in Zambia, 2015).

The research approach adopted in this dissertation is based on literature review of Zambia's electricity market, coupled with the development of a full-cost based approach on levelized cost of electricity. This approach is used to empirically evaluate the performance of new technologies as applied to coal, nuclear, natural gas, biomass, geothermal, hydroelectric, solar PV, CSP and wind amidst economic, environment and social concerns. Zambia, the country of analysis, is of special interest because it belongs to the emerging economies whose overall development is heavily dependent on wood fuels (70%), electricity (14%), petroleum products (12%), coal (2%) and others (2%). The country's electricity consumption by group are as follows: mining (54%), households (33%), government and service (6%), commerce and industry (5%), agriculture and forestry (1%) and transport (1%) (Power Sector Market Brief: Zambia, 2015). Given today's carbon-constrained world, it is interesting to evaluate Zambia's competitiveness in alternative energy sources such as Hydropower, Solar, Bioenergy, Wind and Geothermal as immediate future power sources commercial harvestables.

1.3 Research Focus

The Zambian government has recognized the need for clean and more reliable energy mix for its society and economy. A major contribution to move towards the agenda for clean energy and energy security is expected to come from renewable energy sources (RES). Although this transformation has been on the drawing board for more than a decade, Zambia has not yet managed to remove persistent obstacles to the migration to RES.

Renewable energy technology barriers in Zambia can be divided into policy institutional, financial, and technical and information, and human resource areas as described individually below.

Although the government has prioritised renewable energy for rural electrification, there are several policy and institutional barriers that limit the spread of renewable energy technologies in the country. In the absence of a level playing field in terms of policies and institutional mechanisms, renewable energy technologies cannot compete effectively with conventional projects in the rural areas. Some of the key institutional and policy barriers are as follows (ZDA, 2016):

- The renewable energy agenda and policies are scattered in many government ministries and agencies' lack of effective coordination among them is noticeable, and an effective mechanism is lacking for inter -agency coordination purpose.
- The energy policies do not envisage specific direct incentives (such as import duty and VAT exemptions, tax credit for the new power generation projects, higher power purchase price stipulated by the government, and government's low -interest loans for both the generation projects and equipment manufacturing firms) or indirect disincentives (such as widening carbon emission tax) to entice investments in renewable energy sector whose set up capital cost is huge.
- The national policies have not addressed the capacity building issues concerning renewable energy technologies in terms of components, adaptation and manufacturing, undertaking necessary research and development, provision of training and dissemination of information.
- Some of the institutions or offices established to facilitate private investments or encourage small power sector enterprises, such as OPPPI and Small Enterprises Development Board are ill staffed, low budgeted or never formalized to take a front line role.
- There is a lack of integrated development plans at the provincial and district-level to harness the potential of renewable energy-based electricity generation to support income generation activities and consequent poverty reduction.
- Absence of institutional experience in dealing with power purchase agreements for production, distribution and sale of electricity from renewable energy technologies limits the private sector's ability to invest in renewable energies.
- Complete absence of commercial and service networks and market linkages for providing maintenance and logistic support to renewable energy technologies and systems at the national/local level act as a key barrier for wide-spread replication.

Given the high inflation rates, fluctuating value of Zambian currency to the USD, and overall deficit budget scenario in Zambia, financial barriers have been identified as one major key obstacles to the private sector investments in renewable energy. Some of the significant financial barriers are as follows:

- Due to apparent huge borrowings by the government of the day in order to offset the large national budget deficit, Zambia has very high interest rate of 40-50% P.a investment loans pay back. These high interest rates crowd out private investment as needed in the renewable energy sector.

- The Zambian currency has devaluated rapidly in the past years. It will take some time to overcome investor confidence in the local currency, and the overall economic performance is not very impressive to attracting new green field investment.
- The non-cost reflective low electricity tariff in Zambia is a liability and disincentive to the energy industry. This makes it difficult to attract investment in generation and distribution of renewable energies, which tend to be higher because of the small generation capacity and upfront higher costs of the technologies.
- Some of the renewable energy technologies, such as biomass gasification and PV, are still in the earlier stage of commercialization and thus have higher capital costs outlay. Their performance and the rate of return are not yet fully proven, particularly on the Zambian market, so investors shy away from investing in these technologies.
- There is no clear and dedicated financing mechanism within the national financial institutions to support renewable energy projects. There is also lack of capacity and expertise within these financial institutions to appraise new renewable energy projects for funding.
- Due to wide spread poverty, low income communities may not afford the high costs of renewable based electricity not until their income levels rise, grid electricity must be made available in the first place to spare economic activities in rural areas.

In Zambia, there are a number of technical barriers that need to be addressed in order to enhance the factorization of renewable energy technologies in the local industry, hence build national capacity to manufacture, build, operate and maintain renewable energy based power generation technologies. Some of the key technical barriers are as follows:

- Norms and standards in terms of renewable energy performance, manufacture, installation and maintenance are weak and/or non-existent.
- Local manufacturing capacity and/or assembly of renewable energy technology components are currently lacking, although the knowledge, skills and expertise to operate renewable energy systems is available in Zambia.
- There is a limited technical capacity to design, install, operate, manage and maintain renewable energy technologies.

Given the low literacy levels, prevalent poverty and sparsely populated rural areas, information barriers have been identified as adversary to renewable energy development in Zambia. Some of the key information barriers are as follows:

- There is no sufficient statistical data available on the renewable energy resources in terms of locations, sizes, and other characteristics to better define project opportunities for investors.
- A central information-clearing house on renewable technologies does not exist. Instead, the information is scattered among various institutions and ministries.
- There is lack of information on comprehensive evaluation of renewable systems already installed in the country. Many potential investors and equipment suppliers are not fully informed about the relevant government policies and programmes.
- Awareness level among public as well as decision-makers about the potential of renewable energy resources for providing electricity and energy services is low.
- Electricity supply is considered as a social welfare service in Zambia. With the low electricity tariffs charged by ZESCO, some people prefer to wait for the government to extend the national grid to them, rather than having renewable energy technologies operated by private investors, the Zambian consumer is not ready yet to pay cost reflective tariffs. Local consumers need to be sensitized on commercial viability of reliable energy services.

Although Zambia has skilled and trained manpower in the energy sector, a number of significant human resource barriers, which may have impact on dissemination and replication of investment projects for new renewable energy have been identified as follows:

- The local capabilities in Zambia for the design, manufacturing, assembling, installing, and servicing renewable energy based power generation facilities are limited.
- There are very few training facilities in Zambia in the field of renewable energy for officials, utilities, developers and service providers. Training facilities need to be expanded to cover new technologies such as biomass gasification technology, as extended to government officials and planners, financing institutions, and utility companies.

Other major issues and barriers, both technical and non-technical, which impede large scale implementation of renewable energy technologies in Zambia include;

- Lack of attractive investment climate for private sector participation in the renewable energy sub-sector. This situation is largely attributed to the absence of a renewable energy feed-in tariff policy mechanism as well as the current none cost-reflective tariffs culture.
- Historical facts: Zambia has enjoyed surplus electricity capacity since the 1970's. This implies that there was no incentive for new capacity building let alone non-traditional renewable energy re-think. However, the current power deficit and need for rural electrification has changed the picture above.
- Obstacles include corruption, graft and a general lack of transparency in the Zambian parastatals. Further, the lack of political will and political gratification and interference of market parameters are other major reasons that impede investment into RES.
- Other impediments are discrepancies in the calculations of levelized cost of electricity (LCOE) for current and future electricity generation technologies.

The above examples highlight the major barriers to investment in the Zambia energy sector today. The energy industry in the country is volatile and yet to become a leveled playing field for private sector participation. One should also bear in mind that commitments into new fossil power stations are sunk investments for decades to come. This likely will have adverse impact on Zambia's CO_2 future emission trajectories.

Suffice rationale of this research is to verify and ascertain, whether RES are cost-effective and feasible in a smart energy policy fashion of an emerging economy in the case study of Zambia.

Therefore, the major focus in this thesis is to concentrate on the three goals for a smart energy policy for Zambia. This entails an integrated and comprehensive analysis approach of Zambia's electricity sector from an economic, social and environment perspective. The research focus is on full-cost calculations for all potential energy technologies considered relevant for Zambia's future energy supply. These include coal, nuclear, natural gas, biomass, geothermal, hydroelectric, concentrating solar power, photovoltaic and wind.

1.4 Statement of the Problem

Zambia in 2016 faced with a deficit of 560-1000 MW in its energy supply attributed to unusually low water levels in the Kariba Dam, the world's biggest man-made water body.

Demand for energy in Zambia has been rising due to a robust economy, particularly in the mining, manufacturing and agriculture activities. The Zambia Development Agency (ZDA) recorded that the demand for electricity in the country has been growing at an average of about 3%, or between 150 and 200 MW, each year (ZDA, 2016). Although Zambia has huge hydro potential, which is estimated at 6,000 MW (currently installed capacity is about 2,200 MW). Only 26% of the 15 million population has access to the natural electricity grid. About 45% of the urban population has access to electricity, and only 14% of the rural population has been connected to the national power grid.

The Zambian energy market does not have a multi-dimensional framework for an economic, social and environmental evaluation of electricity supply options. Evaluations of investments in the electricity sector must include the externalities, risks and other problem areas to reflect willingness to pay and avoid mis-allocations. There is need to develop a combined approach/framework, putting all monetary and non-monetary dimensions together in order to provide more realistic prices as a decision criteria for energy planning in Zambia.

Such a multi-dimensional approach will make different technology options comparable between one another as regards investment decision making in energy to enable a broader overview. An approach that considers cost reflective electricity tariffs in Zambia is essentially absent, hence this research in the energy scenario for Zambia made necessary and justified logically.

The world has a choice between the cost and risk of traditional energy sources and the promise and progress of clean energy. In Zambia, there is need for leadership to capture the economic, environment and security benefits of renewable energy hence de-carbonise the existing energy systems by the year 2020. Time is ripe for the country to reap the rewards of the most remarkable new market opportunities in living memory.

1.5 Research Aim

The aim of this research is to facilitate informed decision making for an optimal cost-based allocation of future electricity generation resources in Zambia.

1.6 Research Objectives

In order to achieve the research aim, objectives have been developed as proxies with the necessary background knowledge of the Zambian case. Hence, to reach a sound conclusion, a step-wise approach is applied with the following three objectives as integral parts of this thesis.

- The first objective of this thesis is to explore the unique energy structure in which Zambia's energy market evolved to what it is today. This is a necessary in order to enhance the understanding in context the future investment decisions basis. Specifically, the goal is to advance the understanding of historical developments that, encompassed different actors and stakeholders on the market that got affected by such decisions, vis-a-vis current market structure, as well as on future policy intentions that will guide investment decisions.
- The second objective of this research is to introduce and evaluate critically a common method to compare the costs of different technologies. This ought to be an evaluation of the levelized cost of electricity (LCOE) approach and an evaluation of its shortfalls. Based on this, lacking aspects will be incorporated into a more comprehensive framework that comprise environmental and social-economic dimensions to arrive at a full-cost analysis.
- The third objective of this research is to put the framework developed in the second step, done empirically, into practice and apply it for the Zambian case. As an outcome, different technology choices are made comparable.

1.7 Value of this Research

This research adds value to the research community in the following ways. Firstly, the thesis provides a clear overview of the structure of the Zambian energy market from stakeholders and policy view point, and institutional inertia.

In addition, the research provides a comprehensive approach to measure the full cost of electricity generation by including social and environmental factors as decision criteria.

Furthermore, the outcome of this research provides the investor and other stakeholders with an up-to-date cost analysis. At the same time it is accommodative that the empirical outcome will be subject to change rather sooner than later in a fast developing energy market. Costs get affected strongly by varying input factors such as fuel costs, learning curves, economies of scale, and these can be higher for some technologies than for others. Thus, the outcomes of this thesis will be under constant updates regarding the accuracy of the input data used for cost calculations.

Suffice to put it on record that this research is timely for Zambia, where the pressure on the power sector like other emerging economies, is rising. Be it at the request of the international community to contribute to climate change abatement or, at the other side, be it internal pressure from a steadily growing demand for electricity, emerging economies all face similar investment decision problems regarding their power sectors. A methodology that includes the internalization of externalities into the LCOE, here displayed through the case of Zambia is valuable an exercise for the research community, results of which might be transferable to similar countries, a value addition mark for this thesis.

1.8 Dissertation Organisation

The first chapter provides the reader with the necessary background information of the Zambian energy market and includes a description of the impediments to renewable energy deployment. Based on this, the research focus/problem statement and position statement explained, the overall research aim is derived and objectives are identified. Chapter 1 also includes an explanation of the value addition of this research to both the research community and stakeholders.

In the second chapter, the evolution of the Zambian energy market is described based on a broad literature review. The market transformation, regulations and relevant stakeholders identified are described. Socio-economic aspects including market size, technology and energy mix, externalities and access to power are covered. The chapter ends with an illumination of current policies that will guide the future development of the energy market.

Chapter 3 introduces the analytical hierarch tree, alternative scoring criteria, Levelized Cost of Electricity approach to the reader and provides a discussion of benefits and flaws of the methods. The framework is extended with an inclusion of indirect costs of electricity generation and of non-monetary aspects of energy planning to allow for a full cost comparison among different generation technologies.

In chapter 4, relevant generation technologies for the Zambian electricity market are individually assessed, based on the methodology developed in chapter 3. Research findings are presented, contrasted and discussed. Subsequently, the stability of the obtained results is tested through a sensitivity analysis with regard to selected parameters.

In the last chapter, conclusions are drawn and outlined based on the context and performance results obtained from the previous chapters. Based on this, recommendations for the stakeholders in the energy market are derived and introduced. Finally, this chapter also includes a critical self-reflection and provides suggestions for further research that emerged throughout the research process, bibliography and appendixes done, academic freedom exercised and demonstrated scholar brilliance and rights herein reserved.

CHAPTER 2: LITERATURE REVIEW

2.1 Literature Review

Power plant evaluation involves a number of criteria whose selection and weighting is decided in accordance with the socioeconomic and political framework besides the area in which they are established. Apart from the power plant impact on the living standards as presented by Chatzimouratidis and Pilavachi (2007), (2008a, b), several other aspects could be evaluated for the overall assessment of different types of power plants. Capacity (Chang and Tu, 2007), efficiency (Bee´r, 2007; Cook and Green, 2005), availability (Ogaji et al., 2002) and maintenance (Wang et al., 2007) for specific types of power plants along with long-term scenarios for energy and the environment (Pimentel et al., 1994; Trevisani et al., 2006) have been addressed. There are also studies for thermo-economic (Franco and Casarosa, 2004; Hamed et al., 2006) and techno-economic (Kaldellis et al., 2005) analysis, each one focusing on a particular type of power plant. Nevertheless, in this research, there are no papers addressing all these factors comprehensively for all most popular types of power plant available today. This thesis, has addressed technological, economic and sustainability aspects comprehensively for ten types of power plants.

As several criteria and subcriteria are applied in the overall evaluation of the types of power plants, trade-offs between the performance of alternatives against several criteria are necessary. One of the most popular and solid method for synthesizing these scores is the Analytic Hierarchy Process (AHP), initially developed by Kablan (2004); and Saaty (1980), (1990), (1994). The AHP is a powerful tool that can be used for the hierarchical decomposition of this complex problem and the synthesis of the end node subcriteria scores and weights that result in the overall evaluation of power plants. This method presupposes the creation of a hierarchy tree where all criteria and subcriteria are presented according to their importance. Evaluation of criteria weights and the scoring of the power plant types against the criteria can be either objective, if true data exist, or subjective by pairwise comparisons when no data exist or these data do not express someone's intuition. Data may considerably change in future due to a number of factors including the development of new technologies and innovations. Power plant evaluation and rank changes, according to alternative sets of criteria weights, are presented by the use of a sensitivity analysis where four alternative scenarios (in addition to the reference scenario) are analyzed (Chatzimouratidis and Pilavachi, 2008c). These scenarios include main criteria weight changes in steps of 25%, that is ‘‘technology and sustainability’’ and ‘‘economic’’ criteria weights are 100%–0%, 75%–25%, 50%–50%, 25%–75% and 0%–100%, respectively (including the reference scenario).

Power plant efficiency, availability and capacity are very important for power plant evaluation because they depict if energy is used in the right way, covering human needs as well (Elkarmi and Mustafa, 1993; Massachusetts Institute of Technology (MIT), 2006; Wijayatunga et al., 2006). Along with the reserves to production (R/P) ratio, which describes the time period that available fuels will last according to the current and future electric power production, they are indicators for sustainable development. Sustainable development assures that the generations to come will have the necessary energy without inheriting environmental and health problems (Pohekar and Ramachandran, 2004). Today, the assessment of almost every problem involves the analysis of its economic parameters. Moreover, when the problem relates to the power generation, attention should be paid to the design and analysis of every aspect that affects its overall cost. The partial costs of power plant evaluation are capital costs, operational and maintenance costs, fuel costs and external costs (Organisation for Economic Co-operation and Development (OECD), 2003; US Department of Energy (US DOE), 1997). In a globalized economy where almost everyone can generate and sell electricity, it is important to carefully evaluate and minimize these costs in order for the power plant to be viable. One cannot determine the best power plant for a particular region of our planet nor for the rest of the 21st century because local features of each region should be seriously taken into account in order to realise optimum regional solutions. The decision maker assigns criteria weights according to several parameters like available resources, local community priorities and future prospects at the specific time of power plant evaluation. The sensitivity analysis is a powerful tool for power plant evaluation according to different sets of values for the above parameters (Chatzimouratidis and Pilavachi, 2008c).

There are known challenges with comparing the cost of electricity generation from different sources, particularly as more renewable generation sources are added to the grid. The levelized cost of electricity (LCOE) is a commonly used metric particular to enable comparison across generation sources that have different useful lives, fuel costs, and use profiles. The LCOE is a fairly basic calculation that looks at the sum of the costs over a generation source's lifetime (including a reasonable return on investment) divided by the sum of the electrical energy produced over the timeframe; the value is given in cost per kilowatt-hour. The costs are standardized to the capital costs, operation and maintenance, utility scale capacity factors, and land use (NREL, 2016).

2.2 Structure of the Zambian Power Market

The Zambian power market has evolved over 110 years. Hydro power is the most important energy source in the country after wood based fuel contributing about 10 percent to the national energy supply. Zambia has about 6,000 MW unexploited hydro power potential, while only about 2,200 MW has been developed. On the other hand, the demand for power in the various sectors of the economy has grown rapidly over the years. However, there has not been any major addition to the country's generation capacity in the last 30 years despite the huge potential in hydro resources. It is estimated that Zambia possesses 40 percent of the water resources in the Southern African Region.

To provide context to the reform process in Zambia, it is helpful to trace the history of Zambia's power sector, the development of which spanned three countries, as largely driven by the need for reliable electricity supply to the mining industry, significantly influenced by the World Bank (which has been the industry's most important funder for over half a century). Indeed, as for all of the countries in this volume, it can be argued that power-sector reform is not an event but an ongoing process.

Consequently, the energy sector was subject to a variety of changing legislations and regulations. The electricity supply and demand market conditions have changed substantially. Therefore, it is helpful to give an overview on the historical evolvement of the Zambian energy market and its institutional inertia in order to understand the current picture and variety of stakeholder interests in the market. This is followed by a description of socio-economic market characteristics, and of new developments and policies guiding the market.

2.2.1 Historical Market Development Before 1994

The history of electricity supply and demand in Zambia dates back as far as 1906. In that year, Zambia's first power station, a thermal plant, was built in Livingstone, the country's southernmost town, and home to the Victoria Falls. Later, several stand-alone generating stations were installed on the Copperbelt in the period leading up to World War II (Mihalyi, 1977). Hydropower only began to be harnessed when a 2MW generator was installed at Mulungushi power station in 1925, followed by two other 6MW generators in 1927. This hydropower was used to supply electricity to the lead and zinc mine at Kabwe (Broken Hill) (Mihalyi, 1977).

Surprisingly, despite proposals to exploit the Victoria Falls that date as far back as 1895, it was only in 1938 that a hydro–electric plant was installed on the third gorge below the falls. From then on, hydropower was on hold. A further 6MW unit was installed at Mulungushi in 1941, and four years later, two generators rated at 6MW each were commissioned at Lunsemfwa power station, 47km north east of Mulungushi, to supplement supply to the lead and zinc mines at Kabwe. The 1950s saw three important developments in the sector. Firstly, interconnected grid supply was initiated through the connection of four power stations with a combined capacity of 120MW on the Copperbelt. Secondly, in 1956 hydropower was being imported, when a transmission line was laid from Katanga in the neighbouring Democratic Republic of Congo (then the Belgian Congo) to Kitwe on the Copperbelt. This led to the establishment of the Rhodesia Congo Border Power Company by the mining companies, for the purpose of operating the transmission line and distributing power on the Copperbelt.

This company was renamed the Copperbelt Power Company (CPC) in 1964. Thirdly, an event that has left a lasting impression on the country and region's power sector was the decision by the government of the Federation of Rhodesia and Nyasaland to construct a dam on the Zambezi River at Kariba Gorge, that would straddle northern and southern Rhodesia and create a reservoir from which to supply hydro-electricity to the mines on the Copperbelt (Jarosz, 1992).

The construction of Kariba dam began in 1954, and in 1962, the 666MW Kariba South Bank power station was commissioned. At the time, Lake Kariba was the largest reservoir in the world (Jarosz, 1992). Kariba South Bank power station came to be owned and operated by the Central African Power Corporation (CAPCO), set-up by the governments of Northern Rhodesia (Zambia) and Southern Rhodesia (Zimbabwe) in 1963. CAPCO was established to be responsible for bulk power generation and transmission, and so it also owned the power lines and high voltage substations en route to the Copperbelt. In Northern Rhodesia, CAPCO, which supplied almost all of the country's power requirements, had two industrial clients: the Central Energy Corporation supplying Lusaka and surrounds and CPC on the Copperbelt.

In 1967, three years after Zambia's independence, work began on the first indigenous large hydropower project, the 600MW Kafue Gorge power station, and was completed in 1972 (Mihalyi, 1977). In 1973, work began on a dam 250km upstream of the Kafue River to increase capacity at Kafue Gorge by a further 300MW. By 1977, capacity at Kafue Gorge had been increased to 900MW and Zambia was home to another new reservoir at Itezhi-Tezhi (World Bank, 1985). Meanwhile, the second (60MW B Station) and third (40MW C Station) plants at Victoria Falls were commissioned in 1969 and 1973 respectively (Mihalyi, 1977).

At the beginning of December 1969 the Zambian government formed the Zambia Electricity Supply Corporation (ZESCO) a parastatal company responsible for the generation, transmission and distribution of electricity throughout the country, with the exception of the areas that were being supplied by CAPCO. The following year, the Zambia Electricity Supply Act of 1970 became effective, and by statutory order of the minister responsible for electricity, the rights, obligations and assets of existing electricity utilities became vested in ZESCO. Thus on 1st July 1970, ZESCO acquired the Central Energy Corporation, the Northern Electricity Supply Corporation that supplied small towns by isolated diesel generating stations and the Victoria Falls Electricity Board (VFEB), which owned the power stations at the falls. Two years later, on 1st July 1972, ZESCO acquired municipal operations in Livingstone and Ndola undertaken by the VFEB and Ndola Council Electricity respectively (World Bank, 1985). Later the same year, five other similar operations were taken over on the Copperbelt, and by 1985, ZESCO supplied the entire country with the exception of the Copperbelt mines and the lead and zinc mines at Kabwe (World Bank, 1985).

The last major generating plant constructed in Zambia was the 600MW Kariba North Bank power station (KNB). Ordinarily, the construction would have been undertaken directly by CAPCO, but the Unilateral Declaration of Independence by Southern Rhodesia in 1965, which Zambia did not recognise, meant that Southern Rhodesia’s appointments to the CAPCO board, and to the Higher Power Authority to which the board reported, were also not recognised (IBRD and IDA, 1970). As a result CAPCO could not be authorised to procure funds for the project. To overcome this, the Zambian government formed the Kariba North Bank Company (KNBC) to procure a loan from the World Bank and to own the power station. KNBC in turn contracted CAPCO to construct the power station and on completion CAPCO agreed to lease the facility for a consideration adequate to meet KNBC’s debt service and reasonable administration costs (International Development Association, 1974). The Kariba North Bank power station was commissioned in 1977, the year that two additional generators at Kafue Gorge also came into service. With these additions, total installed capacity in Zambia reached 1 608MW well above its maximum demand at the time. In fact, as late as 1982 Zambia's maximum demand was reportedly only 846MW.

In a curious arrangement, ZESCO sold all the electricity it generated to CAPCO which it sold to onward distribution to ZESCO's customers throughout the country (International Development Association, 1974). This arrangement ceased in 1977 when the relationship between ZESCO and CAPCO was restructured. Thereafter it was agreed that:

- ZESCO would cease purchasing power from CAPCO;
- The benefits and costs of the Kariba Complex would be shared equally between the two parties;
- CAPCO's transmission costs in Zambia would be reimbursed by ZESCO;
- Power supply to CPC would be undertaken by ZESCO; and
- That the arrangement where ZESCO had hitherto been purchasing power from CPC for its northern area operations would be replaced with a rental (wheeling) charge for use of CPC's transmission network on the Copperbelt (World Bank 1985).

In 1982, CPC became the Power Division of the newly formed and majority state-owned mining conglomerate, Zambia Consolidated Copper Mines (ZCCM), but in 1987, CAPCO was dissolved by the simultaneous passing of the Zambezi River Authority Act in the parliaments of Zambia and Zimbabwe. The Act provided for CAPCO's electricity generation and transmission activities to be taken over by ZESCO and KNBC, and its responsibilities related to dam infrastructure reverting to a new entity, the Zambezi River Authority.

Technically, ZESCO had performed well since its establishment, and the quality and reliability of electricity service was maintained to high standards (ESMAP, 1988). But by 1988, these standards were at risk. Demand was declining due to a reduction in power exports and local consumption growth was flat, the combination of which created a strain on ZESCO's finances. The Zambian economy was in an overall state of decline, limiting access to the foreign exchange required to ensure adequate maintenance of its plants, besides ZESCO faced increasing difficulty in attracting and retaining key staff (ESMAP, 1988). These difficulties were compounded by the fact that tariff levels were insufficient to provide adequate cash reserves for operations and maintenance, tariff adjustment procedures were lengthy and lacked in-built flexibility required in an environment of rapidly rising inflation, coupied with low employee productivity had made billing and metering problematic

(ESMAP, 1988). Despite the fact that these risks had been flagged in 1988, by 1993 the company was headed for 'financial disaster' (Ranganathan and Mbewe, 1995).

In 1991, the government changed hands. The United National Independence Party (UNIP) that had led Zambia since independence in 1964, and which had followed statist policies of economic management, was voted out of power. The Movement for Multi-Party Democracy, a party that had based its campaign on economic liberalisation and greater private-sector involvement in the economy, came to power. With the paradigm shift in economic management came a flurry of new economic policy statements. Hence in 1994, the government published the National Energy Policy (Ministry of Energy and Water Development, 1994), the first such statement wholly dedicated to the energy sector.

2.2.2 Energy Restructuring Process after 1994

The 1994 energy policy's stated objective was as follows:

> *Promoting optimum supply and utilisation of energy, especially indigenous forms, to facilitate the socioeconomic development of the country and maintenance of a safe and healthy environment which would require establishing a viable institutional structure (Ministry of Energy and Water Development, 1994)*

To achieve this objective, the policy outlined five measures specific to the electricity sector. The most far-reaching of these was the first, which stated that the electricity industry would be restructured to improve service delivery by:

- Liberalisation so that other companies could be involved in the electricity business;
- Ensuring that the operations of ZESCO would be commercialised; and
- The immediate privatisation of ZESCO's distribution function.

The policy also called for the removal of bottlenecks to accessing electricity by, for example: reducing connection charges and deployment of low-cost technologies; the promotion of the electrification of productive areas and social institutions; the development of the country's hydro-potential and taking advantage of Zambia's strategic location in the region; and a review of existing legislation so as to conform to the changed economic landscape (Ministry of Energy and Water Development, 1994).

Pricing received special mention in the policy stating that it should be based on fairness and equity that entailed:

- Allocating costs among consumers according to the burden they impose on a delivery system;
- Assuring a reasonable degree of unit charge stability and avoiding large price fluctuations from year to year;
- Providing a minimum level of service to persons who are unable to afford the full cost; and
- Providing a real return on the investment.

Specifically for the electricity sector, it was stated that tariffs would be based on long-run-marginal costs that took into account investment costs; operational costs; incentives for efficiency, reliability, safety and environmental standards; and profit.

The policy sought to clarify institutional roles and responsibilities with the extraction of government from operational activities in the energy sector. The government through the Ministry of Energy and Water Development would:

- Provide and articulate policy guidelines for the energy sector;
- Develop and implement policy;
- Monitor developments in the energy sector;
- Integrate the energy sector into the national and regional developments and
- Regularly review energy related legislation to bring it in line with developments in the sector and the economy as a whole.

The policy also called for the establishment of an independent regulatory body that would:

- Receive representations from consumers and other interested parties on energy price adjustments and levels;
- Ensure that energy price adjustments and levels are justified;
- Consider appeals from individuals and institutions not satisfied with services provided by any energy company;
- Arbitrate between the various stakeholders in the energy sector, and ensure that the interests of energy users and the public are safeguarded; and
- Regulate against monopoly practices.

The World Bank was instrumental in the development of the policy which was crafted at a time when power-market reforms were seen as important for increasing economic productivity (ESMAP, 1996). It was therefore not surprising that a key gathering of African ministers of energy and finance with utility managers got held in Johannesburg in 1995, at which meeting the Zambian energy minister and ZESCO's managing director, echoed the Zambian policy with the following statement:

> *Most sub-Sahara African power sectors need to reform. The challenge is, once pricing issues have been addressed, how to ensure that efficient pricing will be sustainable. Experience around the world suggests that the only way efficient pricing can be sustainable is by reforming the sector along market lines, removing governments from the business of producing and selling energy; allowing the private sector under competitive conditions to enter the sector, and, when competition is unlikely, regulating private companies as if they were under competition (i.e. incentive regulation). However, all of this requires a well-defined legal, institutional and regulatory framework (ESMAP, 1996).*

With the policy released, the government proceeded swiftly with its implementation, and repealed the 1970 Zambia Electricity Supply Act, which had been the foundation of ZESCO's establishment and its statutory monopoly. In its place, the 1995 Electricity Act became law. The provisions of this Act are elaborated on later in the chapter but fundamentally its effect was to liberalise the power sector. The 1995 Energy Regulation Act was enacted simultaneously, and led to the establishment of one of the first independent regulatory institutions in English-speaking sub-Saharan Africa. The Energy Regulation Board (ERB) became operational in 1996.

2.2.3 Privatisation of Mining and Electricity-Sector Assets

In 1996, as part of the economic reform programme, the government initiated the sale of its majority interests in its mining and some of its electricity assets (Coakley 1997). The most significant of these electricity assets was ZCCM's Power Division, the privatisation of which was now possible since the 1995 Electricity Act had liberalised the sector. There was considerable international interest in the Power Division, and in 1997, it was purchased for US$50 million by a consortium (led by the UK's National Grid Company and the US-based Cynergy Corporation) and renamed the Copperbelt Energy Corporation (CEC) (Craig, 2001).

With this, the first private player entered Zambia's electricity market since 1970. In 1995 to 1996, ZCCM's power consumption, which was supplied by CEC, was approximately 5 000GWh with a peak demand of 500MW. This meant that CEC was purchasing a significant two-thirds of ZESCO's total generation (Coakley, 1997). This arrangement was anchored on a bulk-sale agreement entered into between CEC and ZESCO at the time of privatisation. Later, in 2006, the National Grid Company and the Cynergy Corporation divested from CEC and their interests were taken up by a consortium of mainly local investors known as the Zambia Energy Corporation.

Also included in the assets earmarked for privatisation were the Mulungushi and Lunsemfwa power stations. These two plants were acquired by Lunsemfwa Hydro Power Company (LHPC) in 2001, which was owned by a consortium comprising Eskom (51 percent), local investors Degarnier (29 percent), and Wand Gorge Investment (20 percent). In 2008, Eskom disposed of its interests in LHPC to local investors and the management team. At the time of writing this report, LHPC with an installed capacity of 38MW was the only private generator of electricity in Zambia.

2.2.4 The Attempt to Privatise ZESCO

By 1998, ZESCO's performance got poor. Although its transmission network was generally regarded as efficient, generation availability was low, and distribution was characterised by high leakages. Commercially, performance was described as 'extremely poor' with an unsatisfactory rate-of-return on assets and an inability to settle debts that was exacerbated by very low tariff levels and overstaffing. ZESCO's financial position was too weak to finance new investments, and this made increasing access to electricity, which at the time reached just 14 percent of the population, almost impossible (World Bank, 1998).

It was not surprising therefore that ZESCO's performance began to feature ever more prominently on both the World Bank's and International Monetary Fund's (IMF) programmes in Zambia. After continued poor performance despite government-led turn-around initiatives including a performance contract signed with ZESCO in 1996 which emphasised 'commercial operation and efficient technical supply (World Bank 1998). The World Bank and IMF made the privatisation of ZESCO one of the conditions that would enable Zambia obtain debt relief under the Highly-Indebted Poor Country (HIPC) Initiative. The two multi-lateral institutions stated that:

- Attention was also focused on the need to complete the program of divestiture in order to reduce the fiscal burden of public enterprises and extend the provision and quality of essential services. In that context the privatisation of ZESCO, the national power company, was particularly important in order to improve efficiency, reduce tariffs, and facilitate future economic growth (IMG and IDA, 2000b).

A study was thus commissioned to investigate options for the privatisation of ZESCO from which government would make a decision by the end of 2000 (IMF and IDA 2000b). The study was completed early in 2001 and proposed that ZESCO be privatised in two stages: namely, via a ten-year master concession plan followed by the outright sale or further concessioning of unbundled business units. The study recommended that during the master concession plan:

- ZESCO should be unbundled into generation, transmission, distribution, and rural electrification business units;
- Rural electrification should operate under a negative sub-concession under the master concession period once the master concessionaire has developed a program plan in conjunction with the Ministry of Energy and Water Development. (Under a negative sub concession, the concessionaire would be paid a combination of an up-front and annual fee.) The disposal of remaining assets at the end of the master concession should be as follows:
- Outright sale of small hydro power stations (Lusiwasi, Musonda Falls and Chishimba Falls) with preference for local investors;
- Joint-venture sale of a majority stake in Victoria Falls and Kafue Gorge Power stations;
- Concession of the high-voltage grid and wholesale marketing functions; and
- Concession or joint-venture sale of majority stake in the distribution subsidiary (Nexant Inc, 2001)

Meanwhile, the ERB had in 1999 initiated its own investigation into options for restructuring the power sector. Subsequently it presented its report to the government in November 2002. The ERB recommended what was termed the ‘semi-competitive model’. This entailed the vertical unbundling of generation, transmission and distribution, and allowed for horizontal separation across the three functions. It made provision for an independent system operator, a power pool for short-term electricity trading and wholesale competition through contracting among generators, distribution companies and large consumers (Kapika, 2004).

But popular resistance to privatisation was rising. An editorial in the Zambian daily, *The Post*, made the following observation (Kapika, 2004):

> *Despite having liberalized its markets, as dictated by the IMF and the World Bank, Zambia has still not started benefiting from it. Why should we privatize Zambia National Commercial Bank, Zesco Limited (electricity) and Zamtel (telecommunications) simply because the IMF and the World Bank want us to do so, even when the great majority of Zambians are opposed to it because they believe it is not in their best interest?*

By 2003, privatisation was became increasingly risky politically, and after intense negotiations with the World Bank and the IMF the government agreed to put the divestiture in ZESCO on hold. It was decided instead to pursue a plan to commercialise ZESCO in the hope that this would achieve the same objectives as privatisation. It was also agreed that the performance of ZESCO against the plan would be reviewed in 2005 and if it proved unsatisfactory, privatisation would be placed back on the agenda (IMF and IDA, 2005). The commercialisation plan entailed the following broad measures:

- Legal: Amendment of ZESCO's articles of association and the composition of its board to ensure independence from political interference and enhance commercial operations; Amendments to the Electricity and Energy Regulation Acts in order to impart greater regulatory independence to the ERB; Development of a framework that would allow ZESCO to enter into partnerships with the private sector.
- Commercial: Formulation of a business plan; Collection of outstanding electricity bills; Operations without government financial support; constrain government guarantees on ZESCO's concessional debt to a limit of US$40 million until the end of 2005; Settlement of outstanding tax liabilities. (IMF and IDA, 2005)

In 2005, Zambia obtained a debt relief under the HIPC initiative. This was made possible partly by the fact that progress as measured against the ZESCO commercialisation plan was deemed satisfactory (IMF and IDA, 2005). A year earlier on 15 June, government had announced the merger of ZESCO with KNBC (Chambwa, 2004). ZESCO's dominant position in the power sector was now well established, privatisation was abandoned as well as unbundling.

2.2.5 Generation Capacity Installed Before 2010 and Demand Forecast

With an estimated 6000MW of potential capacity, Zambia has an abundance of hydro resources. It is not surprising then that installed generating capacity is almost entirely based on hydropower. As shown in Table 2.1, Zambia's total installed capacity in 2010 stood at 1889MW. Hydrological constraints, and the state of hydroelectric equipment, mean that available generation capacity is lower.

Table 2.1: Installed generating capacity, Zambia 2010.

Ownership	**Plant**	**Installed capacity (MW)**	**Type**
ZESCO	Kafue Gorge Kariba North Bank Victoria Falls	990.0 720.0 108.0	Hydro
	Lusiwasi Musonda Falls Chishimba Falls Lunzua	12.0 5.0 6.0 0.8	Small hydro
LHPC	Lunsemfwa Mulungushi	18.0 29.0	Small hydro
Total capacity		1 888.8	

Note: A fire at Kariba North Bank in 2009 resulted in one generating unit being out of service for repairs.

Source: ZESCO (2010).

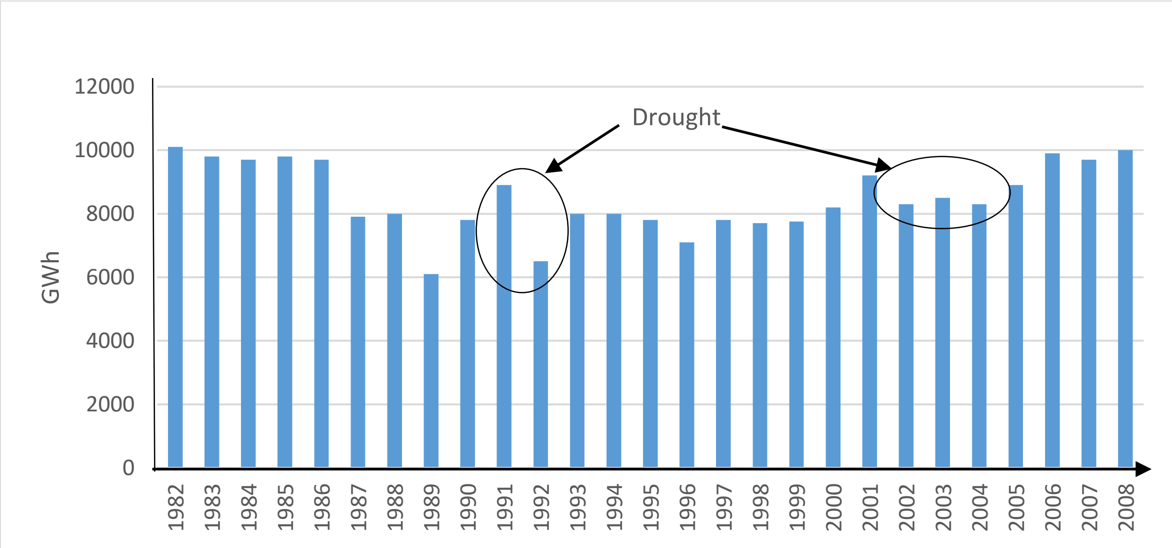


Figure 2.2: Gross electricity generation (GWh), Zambia, 1982–2008 (ZESCO: 2015).

Zambia's dependence on hydropower puts the country at risk in the event of drought. Over the period 1982 to 2008, the most disastrous drought event occurred in 1991 to 1992 (Tiffen and Mulele, 1994) when gross generation output decreased by nearly 30 percent (see Figure 2.2). There were also intermittent droughts over the first five years of the new millennium (Nyambe and Feilberg, 2009).

Other than in 1991 and 1992, the impact of drought has not been as severe as experienced by the East African countries discussed in this volume. This is due to water storage capabilities and electricity imports from Southern African Power Pool countries that have helped in alleviating the shortfalls in power generation.

As expected in a developing country, the load forecast for the period 2010 to 2030 (Figure 2.3) shows strong growth with maximum demand and energy growth averaging at 4.5 percent and 3.9 percent per annum respectively. It is noteworthy that the forecast maximum demand for 2010 (at 1.801MW) was perilously close to actual installed capacity, and if this level of demand materialises, the reserve margin would be insufficient for prudent system operations.

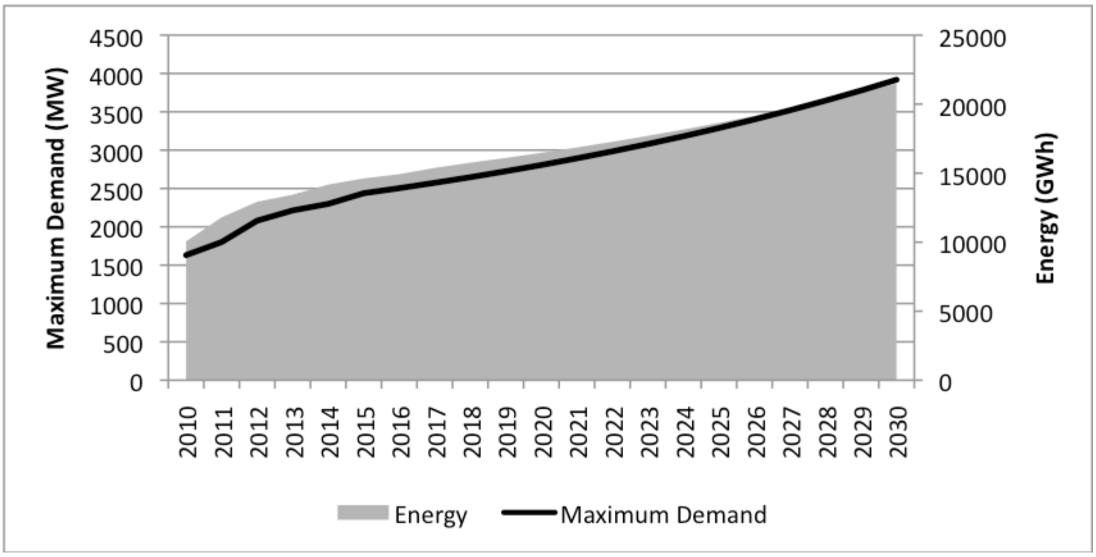


Figure 2.3: Load forecast, Zambia, 2010–2030 (ZESCO: 2015).

2.2.6 Industry Structure and Ownership

There are currently five domestic players in the electricity supply industry in Zambia i.e; ZESCO Limited, Copperbelt Energy Corporation (CEC), Lunsemfwa Hydro Power Company (LHPC), North Western Energy Company (NWEC) and Zengamina Power Limited (ZPL). ZESCO Limited is state-owned, a vertically integrated utility company involved in the generation, transmission, distribution and supply of electricity throughout the country. CEC is a private company that owns part of the transmission and distribution network on the Copperbelt province. CEC purchases bulk power from ZESCO and supplies this power efficiently to the mines in the Copperbelt province. LHPC is an independent power producer (IPP) located in the Central province involved in the generation, distribution and supply of electricity. NWEC is also a privately owned utility that is involved in the distribution and supply of electricity to the non-mining areas within and around the Lumwana mine area in the North Western province. ZPL, a privately owned off-grid utility company that is involved also in the generation, distribution and supply of electricity to the Kalene area in the North-Western province (ERB, 2010b).

The players and operators in the petroleum industry in Zambia are Tanzania–Zambia Mafuta (TAZAMA) Pipeline; Indeni Petroleum Refinery; Ndola Fuel Terminal (NFT); Oil Marketing Companies (OMCs), Transporters and Dealers (service station operators) (ERB, 2012).

2.2.7 Relevant Policies

The **National Energy Policy (NEP)** of 1994 was revised in 2008. The development plans under the NEP include the following:

- **Poverty Reduction Strategy Paper (PRSP)** highlighting the importance of harnessing renewable energy resources, with the main focus on hydropower.
- **Fifth National Development Plan (FNDP)** (2006-2010) tailored to take into account the objectives of Vision 2030 which aims to transform the country into a 'prosperous middle-income nation'. The NEP 2008 is formulated according to the objective of the Vision 2030, sustainable supply of energy to meet the national development goals emphasised.
- **Sixth National Development Plan** (2011-2015) was launched with specific goals for the energy sector, including increasing capacity by 1,000 MW as compared to 2010 levels, improving rural and city/town electrification to 15% and 40% respectively, and increasing the capacity of petroleum bulk storage facilities to enable the storage of 30 days of strategic stock at any one time. There are also plans to further implement the Rural Electrification Master Plan (REMP), build capacity in the engineering sector for energy efficiency, develop an **Energy Efficiency Plan**, and further develop the environmental technology industry in the country, with an incentive framework energy efficiency plan.
- There are also several policy measures for investigating Renewable Energy (RE) potential, strengthening the institutional framework for RE research and development, and the provision of financial and fiscal stimulation of RE deployment.
- Through the National Energy Strategy (NES) (2009-2030) and the REMP, financed by Japanese government, there are targets set for household coverage and the different modes and energy mixes of rural electrification that include mini grids, grid extension, hydro and interconnections to Southern Africa Power Pool (SAPP). The REMP, together with other planned energy initiatives, are expected to go a long way in addressing the energy needs of the country, particularly the basic energy needs of poor households that may have limited access to such services.

2.2.8 Key Legislation and Regulation

The National Energy Policy (NEP) of 1994 (revised in 2008) created new legislation aimed at increasing private sector participation and protection of consumer interests. The legislation includes: the Electricity Act (1995) amended in 2003, the Petroleum Act (1995), and the Energy Regulation Act (1995). The current legal framework for energy resource management and development is governed by various Acts of Parliament such as the following:

i) *The Zambian Constitution:* The constitution promotes universal human rights and equitable distribution of the national cake.

ii) *The Electricity Act:* The amended Electricity Act No. 21 of 2003 is an Act to regulate the generation, transmission, distribution and supply of electricity and to provide for matters connected with or incidental to the foregoing.

iii) *The Energy Regulation Act:* The amended Energy Regulation Board Act No. 23 of 2003 establishes an Energy Regulation Board and defines its functions and powers; provides for the licensing of undertakings for the production of energy or the production or handling of certain fuels; and repeals the National Energy Council Act and the Zambia Electricity Supply Act.

iv) *The Petroleum Act:* The amended Petroleum Act No. 13 of 1994 regulates the importation, conveyance and storage of petroleum and other inflammable oils and liquids.

v) *The Rural Electrification Act:* The REA Act No. 20 of 2003 establishes the Rural Electrification Authority and defines its functions; it also establishes the Rural Electrification Fund.

vi) *The Zambia Development Agency Act:* The Zambia Development Agency (ZDA) Act No. 11 of 2006 aims to foster economic growth and development by promoting trade and investment in Zambia through an efficient, effective and coordinated private sector-led economic development strategy; to establish the Zambia Development Agency as a one-stop shop that will ensure, among other matters, client focus, dialogue with the private sector and create confidence in public sector support for business; to provide for the functions and powers of the agency; to attract and facilitate inward and after-care investment; to provide and facilitate support to micro and small business enterprises; to promote exports and globalization; to mitigate bureaucratic procedures and requirements as faced by both local and foreign investors; to facilitate industrial infrastructure development and local services provision; to promote greenfield investments through joint ventures and partnerships between local and foreign investors; to promote and encourage education and skills training and transfer so as to increase both capacity and productivity in business enterprises; to encourage measures to increase Zambia's capacity to trade and enable business to participate in a competitive global environment; to ensure that the private sector takes advantage of and benefits from international and regional trade agreements; and to provide for matters connected with or incidental to the foregoing.

2.3 Socio-Economic Aspects

2.3.1 Market Size

The combined total power generation channed out from both ZESCO and Independent Power Producers (IPPs) power plants declined by 7.0 percent (1,013 GWh) in 2015. Electricity channed out reduced from 14,453 GWh in 2014 to 13,440 GWh in 2015. The reduction in electricity generation was attributed to poor rainfall experienced during the 2014/2015 rainy season which resulted in low water levels, thereby impacting negatively on the capacity to generate power from hydro power plants (ERB 2015 Energy Report).

In order to mitigate the challenges experienced in 2015, the Zambian government tendered for the emergency inland power generation of around 200 MW from thermal power plants utilising Heavy Fuel Oil (HFO), gas and other resources. The Government also facilitated the importation of emergency power from various sources within the region. Further, the Government announced a ban on local manufacturing and importation of incandescent bulbs and inefficient lighting devices in Zambia. The ban would be implemented gradually starting with the importation of such products effective January 2016. The ban on the sale of incandescent bulbs was effected in June 2016, and it was envisaged that their use would be completely phased out by December 2016.

Consistent with the Southern African Development Community (SADC) Ministers' declaration to move to cost reflectivity by 31st December 2019, the Zambian government in August 2015 provided a policy direction on the first phase movement of electricity tariffs to cost reflectivity for all customer categories. By September 2017 cost reflective tariff increase will be 75%. Meanwhile, the Government through the Industrial Development Corporation (IDC) commenced the procurement process for the planned installation of at least 600 MW of solar power plants in order to redress the power deficit challenges. The IDC in 2015 planned to develop two solar power plants of 50 MW each to be awarded to two different developers. Further, a new Lunzua power plant, owned by ZESCO and situated in Northern Province, was constructed and commissioned with a rated capacity of 14.8 MW adding to the existing capacity of 0.75 MW.

It is in public domain that current generation capacity does not suffice to cover Zambia's electricity demand. To overcome the existing supply/demand gap, the Zambian government has committed to increase the capacity of the existing generation portfolio. New capacity is to be delivered by both ZESCO and IPPs. Investments into capacity expansion become necessary and some projects are currently under construction. In order to understand the trade-offs that this situation implies, an overview about the technology mix existent in the supply chain is helpful. This is provided in the following chapter.

2.3.2 Generation Technology Mix

Overall, the generation technology mix is not very diversified in Zambia's industry. The Electricity Supply Industry (ESI) in Zambia is dominated by hydro generation which account for 94.1 percent of national installed capacity and the balance of 5.9 percent is from diesel, HFO, and Solar Photovoltaic (PV) generation plants. Hydro generation accounted for 2,269 MW of the total national installed capacity, followed by diesel at 92MW, whereas HFO accounted for 50 MW and solar PV 0.06 MW. In 2015, the total installed generation capacity increased to 2,411 MW, from 2,396 MW as recorded in 2014, representing an increase of 0.6 percent. The increase in generation capacity was attributed to the construction and commissioning of ZESCO's Lunzua small hydro power plant with a rated capacity of 14.8 MW.

Further, the energy mix has remained predominately hydro dependent (94%) and therefore prone to changes in rainfall patterns and climate change in general. In an effort to improve the energy generation mix, the ERB has developed the Renewable Energy Feed-in Tariff regulatory framework that will support investments in renewable energy. On the other hand, the government reached an advanced stage in the development of Renewable Energy Feed-in Tariff strategy and the adoption of the Global Energy Transfer Feed-in Tariff (GETFiT) framework, a cost reflective tariff top up mechanism.

Generation from Large Hydro Power Plants

ZESCO own four large hydro power plants and their installed capacities were as follows: Kafue Gorge (990 MW), Kariba North Bank (720 MW), Kariba North Bank Extension (360 MW), and Victoria Falls (108 MW) in 2015. The total generation channed out from these power plants declined by 6.9 percent from 13,638 GWh in 2014 to 12,697 GWh in 2015. The decrease in generation channed out was on account of poor rainfall experienced during the 2014/2015 rainy season as pointed earlier which resulted in low water levels and consequently reduced generation capacity from hydro power plants.

Generation from Small and Mini Hydro Power Plants

ZESCO own five (5) small and mini hydro power plants with installed capacities as follows: Lusiwasi (12 MW), Chishimba falls (6 MW), Shiwang'andu (1 MW), Musonda falls (5 MW) and Lunzua (14.8 MW) power plants. Generation channed out from small and mini hydro power plants increased significantly by 13.4 percent, from 107.1 GWh recorded in the previous year to 121.5 GWh in 2015.

Generation from Diesel Power Plants

ZESCO own nine (9) diesel power plants whose installed capacities are: Zambezi (1.8 MW), Kabompo (2.0 MW), Mwinilunga (1.4 MW), Lukulu (0.5 MW), Shang'ombo (1.0 MW), Luangwa (2.6 MW), Mufumbwe (0.8 MW), Chavuma (0.8 MW), and Itezhi-Tezhi (1.0 MW). The total installed capacity for diesel power stations 11.9 MW in 2015 compared to 11.3 MW in 2014. Total generation channed out from diesel plants increased significantly by 35.8 percent in 2015, from 17.3 GWh in 2014 to 23.5 GWh in 2015.

Generation from Independent Power Producers

In 2015, there were three (3) operational IPPs, namely: Lunsemfwa Hydro Power Company (LHPC), Ndola Energy Company Limited (NECL) and Zengamina Power Limited (ZPL). Total installed capacity from these IPPs was 106.8 MW, which was the same as in 2014. This was disaggregated as follows: LHPC (56 MW), NECL (50 MW) and ZPL (0.75 MW). Generation channed out from IPP's power plants decreased significantly by 13.5 percent from 692.1 GWh recorded in 2014 to 598.4 GWh in 2015. The decrease in generation channed out was mainly attributed to a reduction in generation capacity of LHPC because of poor rainfall experienced during the 2014/2015 rainy season which impacted on its capacity to generate power from its hydro power plants. LHPC's generation sent out reduced significantly by 27.1 percent, from 297.0 GWh in 2014 to 216.5 GWh in 2015. NECL also recorded a marginal decrease in generation channed out of 3.4 percent, from 393.4 GWh in 2014 to 380 GWh in 2015.

Electricity Exports and Imports

Zambia, through ZESCO, engages in cross border trading of electricity through the Southern African Power Pool (SAPP) and bilateral markets. In 2015, ZESCO recorded a significant increase in power imports of 6,034.4 percent. Power imports increased from 12.8 GWh in 2014 to 785.2 GWh in 2015. The increase in imports was attributed to the power deficit experienced in 2015 which necessitated emergency power imports. Nevertheless, power exports dropped by 6.4 percent, from 1,256.2 GWh recorded in 2014 to 1,175.9 GWh in 2015.

2.3.3. Electricity Consumption by Economic Sectors

National electricity consumption increased by 6.8 percent, from 10,720.5 GWh in 2014 to 11,449.9 GWh in 2015. The increase in consumption was mainly attributed to increased demand from the mining sector. Consumption from the mining sector increased by 6.4 percent, from 5,871.3 GWh recorded in 2014 to 6,245.6 GWh in 2015. This is depicted in Table 2.2.

Table 2.2: Consumption of electricity by economic sectors in 2014 and 2015.

Sectors	**Consumption (GWh)**		**Proportion (%)**	
	2014	**2015**	**2014**	**2015**
Mining	5,871.3	6,245.6	54.8	54.5
Domestic	3,250.8	3,482.0	30.3	30.4
Finance & Property	487.4	516.9	4.5	4.5
Manufacturing	479.2	530.8	4.5	4.6
Agriculture	241.4	260.4	2.3	2.3
Others	99.1	98.5	0.9	0.9
Trade	107.4	109.8	1.0	1.0
Energy & Water	73.2	89.1	0.7	0.8
Quarries	62.2	68.2	0.5	0.6
Transport	31.3	33.4	0.3	0.3
Construction	17.2	15.2	0.2	0.1
Total	**10,720.5**	**11,449.9**	**100.0**	**100.0**

Source: ZESCO,2015.

The mining and domestic sectors collectively consumed 84.9 percent of the total energy in 2015. The mining sector consumed the highest energy amongst all sectors at 6,245.6 GWh (54.5%). This was followed by the domestic sector, which includes residential customers at 3,482.0 GWh (30.4%).

2.3.4 Performance of Power Utility Companies in 2015

It is the ERB's mandate to regularly undertake economic and technical audits of the undertakings in the electricity sub-sector. The technical audits relate to safety, environmental concerns, and maintenance of equipment among others. Meanwhile, the economic audits focussed on staff productivity, cash management, and customer metering, among others.

2.3.4.1 ZESCO

The ERB uses the Key Performance Indicators (KPIs) framework to monitor ZESCO's performance. The KPI framework is aimed at checking the efficiency of ZESCO's operations both technically and financially. The KPI framework is an incentive based regulatory tool that is embedded in the tariff determination framework. Therefore, the utility company is penalised or rewarded for poor or good performance respectively. On a quarterly basis, ZESCO is required to submit data and a self-assessment report to the ERB detailing performance against benchmarks agreed in the KPI framework for evaluation.

ZESCO's performance during the year under review is depicted in Table 2.3. The utility company in 2015 attained an overall KPI score of 46.0 percent compared to 40.0 percent in 2014.

Table 2.3: Performance of ZESCO on KPIs in 2014 and 2015.

No.	Indicator	Assigned weight	2014	2015
1	Metering Customers	10%	0%	5%
2	Cash Management	20%	2%	0%
3	Staff Productivity	15%	8%	11%
4	Quality of Service Supply	20%	10%	0%
5	System Losses	10%	0%	10%
6	Power Generation	10%	10%	10%
7	Safety	5%	0%	0%
8	Customer Complaints	10%	10%	10%
	Total	**100%**	**40%**	**46%**

Source: ZESCO,2015.

In 2015, ZESCO registered improvements on the following KPIs: customer metering, staff productivity, and system leakages. The utility company registered a deterioration in cash management, and quality of service while performance remained the same on power generation, safety, and loaded customer complaints KPIs.

Technical Performance Audits

ZESCO's infrastructure in all the 10 provinces was audited during the period under review covering a total of 236 sampled facilities. ZESCO's overall compliance rating stood at 76.0

percent in 2015 compared to 72.9 percent in 2014, indicating an increase of 3.1 percentage points. The compliance ratings for the different facilities are shown in Table 2.4

Table 2.4: ZESCO's compliance ratings.

No.	Facility	Number of Facilities Audited	Compliance Rating (%)
1	Large hydro power stations	3	96.0
2	Substations greater than 33 kV	69	67.0
3	Substations less than or equal to 33 Kv	153	53.0
4	Mini hydro plants	4	82.0
5	Diesel plants	7	79.0
	Total	**236**	**76.0***

* weighted average

Source: *ZESCO,2015.*

The improvement in the compliance levels has been attributed in part to the investments by ZESCO in upgrading its distribution infrastructure under the Distribution Expansion and Rehabilitation Project.

2.3.4.2 Copperbelt Energy Corporation Plc

The Copperbelt Energy Corporation Plc (CEC) is an independent power company listed on the Lusaka Stock Exchange. It is also a member of SAPP. CEC operates and maintains a network mainly comprising generation, transmission and distribution assets that supplies power to Zambia's mining companies based on the Copperbelt province. CEC also exports power to the Democratic Republic of Congo (DRC). Table 2.5 highlights CEC's performance during the period 2013 to 2015.

Table 2.5: CEC's performance, 2013 – 2015.

Business element	2013	2014	2015
Electricity sales to the mines (GWh)	4,281	4,208	4,092
Transmission losses (%)	2.8	2.9	2.9
Stand-by generation capacity (MW)	60	80	80
Electricity generation (GWh)	0	0	7.17

Source: CEC,2015.

In 2015, CEC's electricity sales to its mining customers reduced to 4,092 GWh down by 2.8 percent from 2014 when sales were 4,208 GWh. Transmission leakages remained the same in 2014 and 2015 at 2.9 percent. Further, 7.17 GWh of energy was generated by CEC from its diesel power stations.

During the period under review, CEC faced two major challenges. Firstly, power supply from ZESCO was reduced by 30 percent on account of insufficient rainfall experienced during the 2014/2015 rainy season, resulting in reduced generation from ZESCO's hydro power plants. Secondly, other than CEC reported instances of theft of its overhead copper conductors.

2.3.4.3 Ndola Energy Company Limited

Ndola Energy Company Limited (NECL) is an IPP that supplies power to its sole customer, ZESCO, under a PPA arrangement. The company operates a 50 MW HFO power plant which was commissioned in November 2013.

In 2015, NECL's electricity sales to ZESCO reduced by 3.4 percent, from 393.39 GWh recorded in 2014 to 379.95 GWh in 2015.

During the year under review, NECL faced challenges that included grid voltage and frequency fluctuations outside the operating range of the power plant; and the absence of independent fuel test laboratories in the region to test the fuel oil.

2.3.4.4 Lunsemfwa Hydro Power Company Limited

Lunsemfwa Hydro Power Company Limited (LHPC) is an IPP that supplies power solely to ZESCO under a PPA arrangement. The company owns and operates two hydro power plants namely: Mulungushi and Lunsemfwa with a total installed capacity of 56 MW.

During the period under review, LHPC's electricity sales to ZESCO reduced significantly by 27.1 percent, from 297.0 GWh recorded in 2014 to 216.5 GWh in 2015. The reduction in sales was attributed to the poor rain fall experienced in 2014/2015 rainy season which led to failure to fill the two (2) reservoirs namely Mita Hills and Mulungushi dams, which only filled to 32.0 percent and 72.5 percent respectively.

Technical Performance Audits

In 2015, the average compliance level for LHPC infrastructure was 75.6 percentage points compared to 81.2 percent attained in 2014. This represented a 5.6 percent drop in compliance level.

2.3.4.5 Zengamina Power Limited

Zengamina Power Limited (ZPL) is a private company that owns and operates an off-grid mini hydro power plant which was officially commissioned in July 2007 and has an installed capacity of 0.75 MW. The company has a generation, distribution and supply licence. The company is situated in Ikelenge, North-Western Province and is owned by the North-West Zambia Development Trust (NWZDT). The company generates and supplies power to Ikelenge Mission Hospital, Ikelenge District and surrounding areas.

In 2015, generation sent out from the company increased by 9.2 percent, from 1,759.67 MWh in 2014 to 1,921.62 MWh in 2015. The growth in generation channed out was attributed to the growing demand for electricity. Over the last five years, the company has grown its customer base from 250 in 2010 to 510 in 2015, representing a 104.0 percent increase. Household's customers make up the biggest single category accounting for up to 90 percent of total metered and unmetered customers, followed by standard commercial customers and others.

Technical Performance Audits

The technical compliance audits conducted in 2015 revealed that the compliance level dropped from 74 percent in 2014 to 56 percent in 2015.

Challenges Faced

In 2015, ZPL continued to face several challenges. These included the following non cost reflective tariffs, low income base of potential customers, inability by the company to obtain commercial loans and expand its operations, a weak technical protection regime which makes the power plant prone to lightning and loss of equipment during the rainy season, and inability to attract qualified technical staff to operate the plant.

2.3.4.6 North Western Energy Corporation Limited

North Western Energy Corporation Limited (NWEC) has a license to distribute electricity in the North Western Province of Zambia. NWEC distributes electricity to non-mining customers in Lumwana (Barrick), Kabitaka and Kalumbila sites. Power is supplied by ZESCO at various substations established by NWEC. Operations commenced at Lumwana in 2010 and in 2015 at Kabitaka and Kalumbila. The supply arrangements at Lumwana are governed by a PPA between ZESCO and NWEC. At Kabitaka and Kalumbila, ZESCO supplies and bills power using the ERB approved ZESCO maximum demand tariffs. Since its inception in 2008, NWEC has connected over 3,000 households to its distribution network.

Technical Performance Audits

During the period under review, an audit was conducted at NWEC' s facilities in Lumwana and Kalumbila mine township comprising the Lumwana 2 x 10 MVA, 33/11kV substation and the Kalumbila 1 x 3.5 MVA, 33/11kV substation. The overall compliance levels of the substations increased by 7.0 percentage points from 83.0 percent in 2014 to 90.0 percent in 2015.

Challenges Faced by NWEC

NWEC continued to face the following challenges during the period under review:

- Lack of recapitalization finance to expand the current business operations;
- Low market penetration and low opportunities for Public Private Partnerships especially with regard to new projects; and cost reflective tariffs
- Household's customers' unwillingness to pay for electricity owing to political patronage.

2.3.5 Power quality performance in 2015

Power Quality refers to technical parameters used to describe the electricity supplied to consumers. These parameters are used to determine the extent to which the needs of consumers are met in the utilisation of electricity.

In 2015, the ERB monitored 25 sites for power quality on a pilot basis. These were selected out of a total number of 337 sites that are required to be monitored as per Zambian Power Quality standards. Of these 25 sites, the average compliance rate of the power quality standards was 62.0 percent for the period under review. The ERB has provided that all sites must reach a compliance target of 75.0 percent by December 2016. The results from the parameters that were monitored for power quality in the 25 pilot sites revealed that the performance was below the ERB set target.

Operational Performance of the Electricity Network

During the period under review, the Zambian power system experienced a total of six (6) disturbances which affected most parts of the country, thereby adversely affecting the safety, security and reliability of the system. Of the six (6) disturbances, five (5) occurred on the ZESCO system, while one was on the CEC.

2.3.6 Renewable Energy Regulatory Framework REFiT Strategy

The Ministry of Energy and Water Development (MEWD) using a consultative process with all key stakeholders and with the assistance of the United States Agency for International Development (USAID) and the Southern Africa Trade Hub (SATH) developed a Renewable Energy Feed-in Tariff (REFiT) strategy. The REFiT strategy is envisaged to expand the deployment of renewable energy by creating a platform to provide effective processes for licensing and technology-based standardized PPAs in order to increase private sector involvement in power generation with a view to diversifying the energy sector.

Having a dedicated REFiT strategy shall aid the development and expansion of the renewable energy sector in Zambia. A decentralized approach to REFiT allows for alternative ownership and management models and provides an opportunity to empower local entrepreneurs and communities. The REFiT Strategy has the potential to transform the energy sector in profound and tangible ways.

The REFiT strategy is envisaged to be implemented in phases. The first phase shall span a three (3) year period from the time of official launching and will focus on low-cost options. Further, it will also focus on the use of technology specific differentiated tariffs based on the avoided costs of marginal energy supply. The following broad objectives are provided for under the first three (3) year period:

i) To provide for a REFiT generation allocation of initially 200 MW divided into 100 MW hydropower and 100 MW non-hydropower;
ii) To provide for a REFiT micro-generation allocation of initially 10 MW; and
iii) To provide a platform for the second REFiT phase.

Further, the REFiT strategy provides for ZESCO as the off-taker of power from REFiT projects. Under the renewable energy programme the following technologies are provided for: solar energy; biomass energy/fuel; wind energy; and geothermal energy.

The key stakeholders identified in the strategy are the Department of Energy (DoE); the ERB and ZESCO. DoE will be the custodian of the REFiT programme and developer of the strategy for renewable energy procurement within the context of integrated resource planning. The ERB will create an enabling environment for the REFiT programme through the development of appropriate regulatory instruments. ZESCO is designated as the off-taker and will sign PPAs with qualifying and licensed renewable energy generators from the REFiT programme. ZESCO will also connect licensed renewable energy generators to the transmission and distribution network, consistent with the agreed cost estimates, timelines and standardised grid connection agreements.

REFiT regulatory framework

To support the REFiT strategy, the ERB developed the following regulatory support mechanisms in 2015:

i) REFIT Guidelines: Support Mechanisms and Regulations;
ii) REFiT Rules;
iii) REFiT Standard Power Purchase Agreements; for REFiT projects;
iv) REFiT Generation Licence;
v) REFiT Grid connection Guidelines; and
vi) Model Grid Connection Agreement.

Solar Photovoltaic Tariffs

The ERB computed indicative cost-reflective tariffs for solar PV projects applicable for Phase 1 of REFiT, as summarized in Table 2.6.

Table 2.6: Solar PV plant size range tariffs.

Project size	**Tariff in US¢/kWh**
500 kW but less than 1 MW	17.82
1 MW but less than 5 MW	16.76
5MW but less than 10 MW	15.74
10 MW but less than or equal to 20 MW	14.25

Source ERB,2015.

The tariffs set in the table above are the maximum that will be allowed under the REFiT programme. However, to support price discovery below these maximum tariffs, competitive bidding will be allowed consistent with the agreed REFiT procurement mechanisms and implementation agreements.

Development of Draft Solar Energy Product Standards

The ERB working in close collaboration with the Zambia Bureau of Standards (ZABS) spearheaded the development of Draft Zambian Standards (DZS) and review of existing standards for solar energy products. The development of the draft standards was made through the Solar PV Technical Committee which reviewed international standards and also undertook extensive local stakeholder consultations. The technical committee commenced the development of the two standards namely:

i) DZS: Solar Photovoltaic (PV) Panels - Specifications.
ii) DZS: Static Inverters for Solar Photovoltaic Systems.

Further, the Committee also revised and published the following standards for public comments:

i) DZS 403: Batteries For Use in Photovoltaic Systems – Specification;
ii) DZS 404: Charge Controllers for Photovoltaic Systems Using Lead-Acid Batteries – Specification;

iii) DZS 405: Photovoltaic Systems Design and Installation – Code of Practice; and

iv) DZS 407: Lighting Devices for Use in Photovoltaic Systems – Specification.

2.3.7 Investments in the Electricity Sector

Electricity Generation Projects

ZESCO and other IPPs have continued with investments in power generation in order to meet the growing demand for electricity. Table 2.7 shows generation projects under implementation.

Table 2.7: Electricity generation projects.

No.	Project Name	Description/Details/Status
1	Itezhi-Tezhi project (120 MW)	The Itezhi-Tezhi power project was under construction at Itezhi-Tezhi Dam on the Kafue River. The project was being developed through a joint venture between ZESCO and Tata Africa Holdings of India. The first phase of the project was commissioned in 2015. The second phase of the project was expected to be commissioned in 2016 now commissioned.
2	Rehabilitation and uprating of Musonda Falls mini hydro power plant	Musonda Falls is one of ZESCO's mini hydro power plants, located on the Luongo River in Luapula Province. The power plant had an initial installed capacity of 5 MW. During the period under review, the plant was under rehabilitation to upgrade it to 10 MW. The project is expected to be completed in 2016.
3	Construction of Lunzua power plant	Lunzua hydropower plant is owned by ZESCO and is located in Mbala District, Northern Province. Construction of the 14.8 MW Lunzua hydropower plant was completed and commissioned in 2015
4	Development of Kafue Gorge lower hydro power project	Kafue Gorge lower hydro power project is located in Kafue Gorge, about 65 km upstream of the confluence of the Kafue and the Zambezi Rivers and 9 km downstream of the existing 990 MW Kafue Gorge hydropower plant. Once developed, the power plant will have an installed capacity of 750 MW. The project is estimated to cost US$1.94 billion and will be developed under a Private Public Partnership (PPP) on Build, Own, Operate and Transfer (BOOT) basis with ZESCO. In 2015, the Engineering, Procurement and Construction (EPC) contractor was procured.
5	Development of Kabompo hydro power project (40 MW)	Kabompo hydropower project is located in Mwinilunga District and was under development by CEC. In 2015, civil works were underway. The 33/11 kV Kabompo Gorge substation and 33 kV line were partially handed over by the contractor. An implementation agreement was signed with the Government and CEC was in discussion with ZESCO for a PPA.

6	Construction of Maamba Thermal Power Plant (300 MW)	Maamba Collieries Limited is constructing a thermal power plant at Maamba coal mine in Sinazongwe District. The power plant is estimated to cost US$750 million. The project was commissioned in 2016.

Source ERB,2015.

2.3.8 Planned Power Generation Projects

Mambilima and Mumbotuta hydro schemes

The Governments of Zambia and DRC signed an Inter-Governmental Memorandum of Understanding for joint exploitation of Mambilima and Mumbotuta hydropower sites in July 2015. The Joint Technical Committee (JTC) between ZESCO and Societe' Nationale D'electricite' (SNEL S.A.R.L), reviewed the previous feasibility studies of 1977 and 2001 in October 2015. The terms of reference for engaging consultants were also prepared.

The reports were presented to the Project Implementation Unit for approval. The CEC also conducted preliminary feasibility studies for the Mambilima and Mumbotuta hydropower sites.

Upgrading of Mulungushi power plant

LHPC commenced feasibility studies in order to increase the capacity at Mulungushi power plant from the current 32 MW to about 45 MW. The project will involve the installation of an additional machine at Mulungushi power plant to increase the capacity from 32 MW to 40 MW and installation of 5 MW generating unit at the Mulungushi dam discharge site.

Muchinga Power Generation Project

In 2015, the draft Environmental Impact Assessment Report for Muchinga power generation project by Muchinga Power Company was submitted to Zambia Environmental Management Agency (ZEMA) for review. After the review, ZEMA had requested for a resettlement action plan submittion.

Further, the Government invited Muchinga Power Company and LHPC to initiate the project Implementation Agreement (IA) negotiation. By end of 2015, the developers were still studying the IA template from the Office for Promoting Private Power Investments (OPPPI).

Ndola Energy Company Limited Heavy Fuel Oil power plant

NECL planned to develop an additional HFO power plant in Ndola with an estimated generation capacity of 55 MW. All the power generated will be fed into the national grid. In 2015, NECL had already spent US$ 8.5 million towards the project.

Kalungwishi Hydro Power Project

The project involves the construction of two (2) power stations with a combined capacity of 247 MW located at Kabwelume Falls (96 MW) and Kundabwika Falls (151 MW). The project will also involve the construction of a 220 km, 330 kV transmission line to Kasama substation where power will be injected into the national electricity grid. Lunzua Power Authority (LPA) was contracted by an international competitive bidding process to develop the project at a total cost of US$650 million. The Implementation Agreement was signed on 22nd August, 2011 and the developer was in the process of finalizing the Environmental Impact Assessment (EIA) and other preparatory activities. The project is expected to be commissioned in 2019.

EMCO Thermal power plant

EMCO Energy Zambia Limited (EMCO) thermal power plant will be located in Sinazongwe with a capacity of 340 MW. The project is estimated to cost US$600 million. EMCO signed an Implementation Agreement with the government on 20th September, 2012 and amended it in 2014. The PPA with ZESCO was signed in June 2014. During 2015, the developer undertook an Environmental Social Impact Assessment (ESIA) study and had commenced the process of procuring coal mine and power plant contractors.

Chavuma and Chanda Falls Hydro Schemes

The power plant projects comprising Chavuma Falls (14 MW) and Chanda Falls (1 MW) located in Chavuma on the Zambezi River and Kashiji River respectively in the NorthWestern Province of Zambia. The projects will be developed on Build, Own and Operate (BOO) basis. The power plants will improve quality of electricity supply in the North-Western province by displacing diesel generation. The power generated will be infected into the national grid through the transmission lines that were being constructed by ZESCO. The projects are estimated to cost US$ 51 million and US$8.1 million respectively. In 2015, the developer was still undertaking field investigations and designs. Meanwhile, negotiations for the Implementation Agreement are progressing.

Consolidated Farming Limited Bagasse power plant

Consolidated Farming Limited (CFL) is a private company based in Lusaka. CFL plans to design, finance, construct, commission, own, operate and maintain a bagasse fired power generation plant with a design rated capacity of 24 MW in Nampundwe of Shibuyunji District. This was expected to be commissioned in 2016.

CFL and ZESCO agreed to enter into a PPA for a duration of eight (8) years commencing when the plant gets commissioned.

2.3.9 Facilitating Investments in The Electricity Sub-Sector

Investment Endorsements

To encourage investment in the electricity sub-sector, the ERB is mandated to issue an Investment Endorsement to prospective power project developers. An Investment Endorsement is a document that guarantees a developer that a license will be issued by ERB upon completion of the project subject to meeting prescribed conditions. When applying for an Investment Endorsement the developer must submit the following information to the ERB:

i) Detailed project description including technical drawings;
ii) Estimated cost and economic justification of the project;
iii) A decision letter from ZEMA; and
iv) Draft PPA agreed with the off-taker.

The Investment Endorsement is valid for one (1) year subject to renewal.

In 2015, ERB issued one (1) Investment Endorsement to CFL and two (2) Investment Endorsements renewals to MCL and EMCO. The three (3) Investment Endorsements were issued for generation of power as follows:

i) MCL**: -** for the development of a 300 MW (2 x 150) maximum capacity, coal fired power plant located in Maamba of Sinazongwe District in Southern Province;
ii) CFL**: -** for the development of a Bagasse Fired Thermal Power Plant based in CFL's sugar plantation in Nampundwe of Shibuyunji District, in Lusaka Province with a rated capacity of 24 MW; and
iii) EMCO**: -** for the development of a 340 MW (2 x 170) coal fired power plant located in Sinazongwe District of Southern Province.

2.3.10 Other Developments

There are a number of other developments in the sub-sector ranging from increasing access to electricity in rural areas, initiatives to encourage solar power generation, to proposed amendments to the current tariff determination methodology. These developments are aimed at addressing generation and supply challenges in the sub-sector.

Access to Power

Access to power depends on the availability of two factors: physical electricity generation and means to transport generated electricity to points of usage. Hence the need for investment in transmission lines infrastructure.

Access to power is an important topical subject in Zambia. Given the size of the country and the concentration of power generation in the Southern region, power is transported through a national transmission grid and regional distribution grids. Currently, only 26% of the Zambian population has access to electricity. The electrification gap stems essentially from the country's socio-political history, where access to electricity was mainly a privilege for the urban population. Consequently, in the 1990s there was not much drive behind building new grid connections, due to low demand and limited financial capacity of the poor rural population. However, this has changed in the past 15 years following the establishment of the Rural Electrification Authority (REA).

In 2015, the REA continued with activities such as grid extension projects, solar energy projects, development of mini hydro plants and feasibility studies. In particular, REA intended to develop two (2) solar mini grid projects in Lunga and Chunga areas of the Luapula and Central Provinces respectively. The Authority also commissioned studies for various forms of alternative energy sources such as wind and biogas. REA also commenced the implementation of Kasanjiku mini hydro project located in Senior Chief Ntambo's area of North Western Province for which the EPC contractor was identified.

Scaling Up Solar

The Industrial Development Corporation (IDC) is an investment company wholly owned by the Zambian government as incorporated in 2014. Its mandate is to play a catalytic role in supporting Zambia's industrialisation as well as facilitate the provision and raising of long term finance for projects. IDC also serves as an investment holding company for State Owned Enterprises (SOEs) and an active shareholder in government led energy investments.

The IDC plans to develop 600 MW of solar photovoltaic (PV) power generation plants for the country. As an immediate first step towards meeting this objective, the IDC rapidly developed two (2) solar PV power projects of approximately 50 MW each which feed a total of 100 MW of solar PV power into the national grid by the end of 2016. The projects got awarded to two different private sector developer partners for financing, construction and operation as IPPs. The two projects ran as special purpose vehicles while the IDC retain 20 percent shareholding in each project on behalf of the government. Both projects are located in the Lusaka South Multi-Facility Economic Zone (LS-MFEZ).

In 2015, two projects were identified namely: Mosi-oa-Tunya and West Lunga. Working with the International Finance Corporation which is a member of the World Bank Group, the IDC conducted open and competitive Request for Pre-qualification (RFP). The IDC received 49 applications from which 11 bidders were shortlisted to participate in the tender. The process of bid evaluation was done at the end of 2015.

Legislative Reviews and Multi-Year Tariff Framework

In 2015, like the previous year, the ERB made proposals to amend the current legislation on tariff determination. The proposals were aimed at enhancing the ERB’s regulatory efficiency. Specifically, the ERB proposed the introduction of a Multi-Year Tariff Framework (MYTF) and an automatic cost-pass-through framework that is intended to address the needs of the evolving and expanding ESI in Zambia. The current tariff determination framework requires that the licensee makes a tariff application when need arises. The proposed framework will provide for more efficiency and predictability. The proposed MYTF will undergo stakeholder consultation before finalisation and implementation once the legislation has been amended.

Zambia Distribution Code

The ERB developed the Zambia Distribution Code (Distribution Code) which was intended to complement the Electricity Regulations (Grid Code), Statutory Instrument No. 79 of 2013, in facilitating non-discriminatory access to the electricity distribution network in Zambia. This will ultimately result in improved efficiency in the operation of electricity network and is expected to encourage more investment in the electricity sub-sector.

The Distribution Code aims to address the challenges arising from the envisaged developments in the ESI, especially the expected increased integration of the private sector investment in embedded generation and distribution facilities.

Specifically, the envisaged developments in the ESI, among other things include:

i) The development of embedded generators connecting directly into the existing distribution network;
ii) Integration of renewable energy based generation into the distribution network; and
iii) Net metering to allow domestic customers with renewable energy based generation to supply part of their generation into the distribution network.

The development of the Distribution Code took into account the evolving structure of the ESI in Zambia. It is expected, however, that the change in structure will be aimed at achieving increased access, greater competition and enhanced efficiency in the ESI. The Distribution Code will therefore form an integral part in achieving the goals of liberalisation.

2.3.11 Regional Developments - Southern African Power Pool

The Southern African Power Pool (SAPP) is a cooperation of electricity companies in Southern Africa under the auspices of the Southern African Development Community (SADC). Members of SAPP have created a common power grid between their countries and a common market for electricity in the SADC region. SAPP was founded in 1995 and has 16 electricity companies drawn from 12 member countries. In Zambia, the members of SAPP are ZESCO, CEC and LHPC. SAPP was created with the primary aim to provide reliable and economical supply of electricity. According to SAPP, the demand for electricity in the region rose to about 4 percent in 2015.

SAPP Installed Capacity, Demand and Supply

As at 31st December 2015, SAPP had available installed capacity of 57,917 MW and an operating capacity of 43,964 MW against a demand of 51,821 MW. This represented a shortfall of 7,857 MW. According to SAPP, the projected peak demand will equal operating capacity by 2019, according to plan.

SAPP Power Trading

On 1st April 2015, SAPP implemented its newly developed competitive market trading platform for live trading. The new trading platform named the SAPP-Market Trading

Platform replaced the SAPRI system that SAPP had been using for its Day Ahead Market (DAM) trading since 2009.

In general, the bids for electricity surpassed sale offers. Between January and December 2015, buy bids rose steadily from 252,420 MWh to 560,102 MWh. Meanwhile, on average the second half of the year showed more sale offers than the first half of the year. The month of August 2015 recorded the highest sale offer at 274,825 MWh. The competitive markets on SAPP are the DAM and Post Day Ahead Market (PDAM).

In terms of Market Clearing Prices (MCPs), the average monthly MCPs increased to USc 6.7/kWh in 2014/15 compared to the USc 5.7/kWh recorded in 2013/14. The months of July to October 2014 or 2015 recorded sustained high MCPs for the period under review. Meanwhile, the month of April 20 recorded the lowest market prices.

2.3.12 Options for New Builds

Although Zambia is endowed with new and renewable energy resources, efforts to harness these resources have been minimal. The government recognizes the need for promoting renewable energy and clearly stated its intentions in the National Energy Policy of 2008. A renewable energy strategy is being devised to assist in increasing the deployment of renewable energy. Zambia possesses a favourable resource base for a variety of other technological options that have not been mentioned or deployed on a larger scale to date. These include solar, geothermal, mini/macro hydros, wind, and biomass. The resource potential of each of these alternatives is herein introduced briefly.

Zambia is endowed with one of the most favourable levels of direct normal solar irradiation (DNI) in the world. The country has an average solar insolation of 5.5 $KWh/m^2/day$ (2001-3000 $KWh/m^2/year$) but solar penetration has remained relatively low due to high initial set up cost. The resource potential can be used for CSP and PV technologies. As such the PV market in Zambia is dominated by donor funded projects, government, NGOs and mission institutions for schools clinics, staff households and water supply. Via the support for the education sector projects, the Basic Education Support to Infrastructure Projects (BESIP) and the Zambia Social Investment Fund (ZAMSIF), the World Bank is currently the largest single financing agency of PV sales in Zambia. Annual sales are in the range of US$ 2 million to US$ 3 million, with as much as 70 percent being through large donor financed procurements. Sales in the household market segment are non-significant.

Investment opportunities in this area include local production of solar system components, setting up isolated grid and sale of solar panels and related accessories.

Another potential technology that could deliver electricity in Zambia is Geothermal Energy. Zambia has more than 80 hot springs. The Zambian hot springs associated with zones of major deep seated fault and fracture systems along which water of mainly meteoric origin circulate to great depths and is heated through normal geothermal gradients. Of the 80 hot springs, 35 were rated high in terms of surface temperature; flow rate, proximity to power lines; ease of access and relative energy potential. These springs have not been tapped for industrial or energy provision purposes owing in large part to set up cost factors. At present there is only one small geothermal generation plant. The plant was installed, following an initiative with the Italian Government in the mid 1980's. Kapisya hot springs was developed to the extent that 2 x 120 kilo watts turbines were installed in 1987.

Recent estimate indicate that the plant can be upgraded to produce 2 MW of electricity. Efforts are being now being made by ZESCO to revive the plant. The government is working on making the 22 km access road an all-weather road so that construction can commence.

Another most important potential technology that could deliver electricity in Zambia is Mini / Micro Hydro power. Zambia has a number of potential sites on smaller rivers suitable for local small-scale power generation especially in the Northern and the North-Western parts of the country because of their topography, the geology of the ground, and the highest rainfall in the country save for climate variability.

Wind energy in Zambia is relatively low. Wind data collected at 10 meters per second (m/s) above the ground indicate speeds of between 0.1 to 3.5 meters per second with an annual average of 2.5 m/s. These wind speeds are not particularly suitable for electricity generation, but are well suited for water pumping for household use and irrigation purposes. There are specific areas where wind regimes are said to be as high as 6 m/s in the Western Province of Zambia. The Department of Energy has plans to develop a wind atlas to identify areas where electricity can be generated from wind.

Investment opportunities therefore lie in the supply of equipment for wind measurement; production of wind mills for water pumping and more advanced technology that can facilitate the production of electricity.

Last but not the least, biomass is a source of energy that can be used to generate bulk electricity. ERB (2013) has estimated the power potential from biomass for Zambia at 498 MW, based on assumption that 30% from current cereal production and agricultural residues are available as fuel material. This estimate is based on current levels of production and does not even include a raw material supply structure that is especially targeted for the use of biomass. Another advantage of biomass is the fact that load factors above 70% are possible in biomass power plants which would make their performance comparable to other centralized power plants.

However, large scale production of biomass could lead to competitive situations with other agricultural activities, complex requirements on logistics and substantial need for land areas.

2.3.13 Market Failures

During 2014 - 2016, the electricity sector faced a number of challenges. In particular, there was a substantial shortfall in supply of electricity that was exacerbated by a reduction in hydro electricity generation due to poor rainfall experienced during the period 2014/2015 rainy season. This increased power outages which impacted on all aspects of the economy posting 92.8 % GDP (2016) growth amidst high production costs. In July 2015, ZESCO Limited (ZESCO) increased the extent of load shedding to at least eight (8) hours a day for the majority households, commercial and industrial consumers. Further, ZESCO requested the mining industry to reduce its load by 30 percent. This was in order to manage the power deficit of around 560 - 1,000 MW for the period September to December 2015, representing between 21.4 percent and 38.2 percent of peak demand of 2,616 MW. The electricity sub-sector continued to experience the challenge of non-cost reflective tariffs which is a major barrier to power development projects in Zambia. Further, the energy mix remained predominately hydro dependent (94%) and therefore prone to changes in rainfall patterns and climate change in general. However, there is now a political will to increase electricity tariffs to 75% by September 2017.

Zambia's migration to fossil fuels and nuclear reliance has its downside. It is the primary cause for a considerable amount of pollution as borne by society at large. Negative externalities include air pollution, health effects and climate variability and change damages. Apart from GHG emissions, other expected externalities occurrences include releases of SO_2, NO_x, particulates and radiation, radioactive waste disposal, water contamination, employee fatalities and transmission losses.

From that perspective, an aggregated consideration of externalities from a country's aging power fleet is meaningful done so to channel investments into preferable technologies. Consequently, externalities have to be evaluated individually for new power stations and for each technology. As external costs come on top of the costs paid by a power producer and thus affect the final price paid by the consumer, it is advisable to look at electricity prices first in the Zambian case for viability assessment.

2.3.14 Electricity Prices

Due to the ZESCO monopolistic market structure in Zambia, electricity prices are not determined via the market mechanism. To limit possible monopoly rents from situations where ZESCO reduces its output and charges a higher price than in equilibrium, electricity prices in Zambia are subject to approval by the ERB. For that matter, ERB's goal is to ensure cost-reflective pricing. A process of pubic consultation helps to adjust the average standard price and the way it should increase. This mechanism is called Multi-Year Price Determination (MYPD) (ERB, 2014).

If compared internationally the standard average price in Zambia is still at a very low level. So far, the government's target of a cost-reflective electricity price has not been reached and current standard average prices still do not cover all direct costs of electricity generation. Save for IMF conditionality to affect a 75% increase.

Electricity Tariff Reviews

The ERB received three (3) tariff applications from ZESCO, CEC and NWEC in 2015.

In August 2015, ZESCO lodged an application to the ERB for a tariff adjustment in conformity with the Electricity Act – Section 8(2), Chapter 433 of the Laws of Zambia. The application was to increase electricity tariffs for its various customers, except the mines. The major justification for the tariff application was the need to move towards cost reflective tariffs. The key rationale being that ZESCO had signed PPAs with IPPs at tariffs which were higher than the average tariffs that existed in 2015. The average tariff ZESCO was paying, as an off-taker, to purchase power from IPPs ranged from USc 7/kWh to USc 13.23 /kWh and yet the average retail tariff in 2015 was USc 6/kWh.

The ERB reviewed the application from ZESCO and made a determination in December 2015. The ERB approved tariffs for the various customer categories are depicted in Tables

8A/8B. There is now another application by ZESCO to phase new tariff increment of 50% by 1st May and another 25% by September 2017.

Table 2.8A: Approved electricity tariffs.

Category	Consumption	Unit	Tariffs (K) Previous	Approved
Metered Residential(Prepaid) (capacity 15 kVA)	R1 - Consumption band up to 300 kWh per month	Energy charge/kWh)	0.15	0.15
	R2 - consumption above 300 kWh in a month.	Energy charge/kWh)	0.51	1.54
		Fixed Monthly Charge	18.23	18.23
Commercial Tariffs (capacity 15 kVA)	Commercial	Energy charge/kWh)	0.31	0.88
		Fixed Monthly Charge	55.09	156.47
Social Services	Schools, Hospitals, Orphanages, churches, water pumping & street lighting	Energy charge K/kWh	0.28	0.81
		Fixed Monthly Charge	47.91	139.41

Source: ERB, 2015.

Note: Tariffs are exclusive of taxes

Table2.8B: Approved electricity tariffs.

Category	Consumption	Unit	Tariffs (K) Previous	Approved
Maximum Demand Tariffs	MD1- Capacity between 16 - 300 kVA	MD charge/kVA/Month	13.97	48.05
		Energy charge /kWh	0.20	0.70
		Fixed Monthly Charge	136.82	470.65
		Off-peak MD charge/ kVA/Month	6.98	24.03
		Off-peak energy charge/kWh	0.15	0.52
		Peak MD charge/kVA/ Month	17.46	60.06
		Peak Energy Charge/ kWh	0.25	0.87
	MD2- Capacity 301 to 2,000 kVA	MD charge/kVA/Month	26.13	89.9
		Energy charge /kWh	0.17	0.58

		Fixed Monthly Charge	273.62	941.25
		Off-peak MD charge/ kVA/Month	13.07	44.95
		Off-peak energy charge/kWh	0.13	0.43
		Peak MD charge/kVA/ Month	32.67	112.37
		Peak Energy Charge/ kWh	0.21	0.72
	MD3- Capacity 2,001 to 7,500 kVA	MD charge/kVA/Month	41.75	115.23
		Energy charge /kWh	0.14	0.38
		Fixed Monthly Charge	579.74	1,600.10
		Off-peak MD charge/ kVA/Month	20.87	57.61
		Off-peak energy charge/kWh	0.1	0.28
		Peak MD charge/kVA/ Month	52.19	144.04
		Peak Energy Charge/ kWh	0.17	0.47
	MD4-Capacity above 7500 kVA	MD charge/kVA/Month	41.98	115.87
		Energy charge /kWh	0.12	0.32
		Fixed Monthly Charge	1,159.50	3,200.22
		Off-peak MD charge/ kVA/Month	20.99	57.93
		Off-peak energy charge/kWh	0.09	0.24
		Peak MD charge/kVA/ Month	52.48	144.83
		Peak Energy Charge/ kWh	0.14	0.4

Source: ERB, 2015.

North Western Energy Corporation Limited

In November 2015, NWEC applied to the ERB to vary the tariffs for its various customers in order to make them consistent with ZESCO's application of August 2015. NWEC, in its application, argued that the load shedding and the new ZESCO proposed tariffs would lead to reductions in consumption of power by their residential customers. Further, if NWEC was to adopt the proposed new R1 and R2 tariffs by ZESCO, most of its customers would fall into a lower tariff band (K0.15/kWh) which would drop their revenues significantly.

Copperbelt Energy Corporation Plc

In December 2015, CEC applied to the ERB to vary the tariffs for its residential customers in CEC village housing complex in Kitwe to make them consistent with the proposed ZESCO's residential tariffs.

2.3.15 Future Policy Plans

With regard to Zambia's energy planning, there are several topics that are currently discussed and that could considerably influence the costs of different technologies. These include, Zambia's role in global GHG abatement, new economic tools of pricing externalities such as carbon tax, plans for rural development and a general transition of the industry to a less carbon-intensive structure, otherwise convert to renewable clean energy by the year 2020 (SDGs).

Zambia's Role in Global GHG Abatement

This section presents Zambia's Intended Nationally Determined Contribution (INDC) to the 2015 Agreement on climate change in response to decisions adopted at the 19th and 20th sessions of the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC). Zambia's INDC includes both mitigation and adaptation components based on her national circumstances. The successful implementation of Zambia's INDC will result in an estimated total emission reduction of 38,000GgCO_2eq which translates to 47% (internationally supported efforts) against 2010 as a base year. This emission reduction is conditional and subject to the availability of international support in form of finance, technology and capacity building. The total budget for implementing both components is estimated at US$ 50 billion by the year 2030, out of this USD 35 billion is expected to come from external sources while $15 billion will be mobilized from domestic sources.

National Circumstances

Climate variability and change has become a major threat to sustainable development in Zambia. The country is already experiencing climate induced hazards which include drought and dry spells, seasonal and flash floods and extreme temperatures. Some of these hazards, especially the droughts and floods have increased in frequency and intensity over the past few years and have adversely impacted food and water security, water quality, energy and livelihoods of the people, especially in rural communities.

Recent climate trends based on records from 1960 to 2003 indicate that mean annual temperature has increased by 1.3°C, since 1960, an average rate of 0.34°C per decade. On the other hand, the mean rainfall over Zambia has decreased by an average rate of 1.9 mm/month (2.3%) per decade since 1960. The future trends in the country are towards a higher average temperature, a possible decrease in total rainfall, and some indication of heavy events of rainfall. An assessment of potential climate impacts shows that they will seriously undermine the efforts to improve the livelihoods of Zambians if left unaddressed. The assessment further analyzed the negative impacts of climate change on key economic sectors including water, agriculture, forestry, wildlife, tourism, mining, energy, and health. Further studies have estimated GDP loss over a 10-20 year mid-term planning horizon for agriculture productivity and its associated effects on poverty levels, the potential impact of an energy crisis, the higher cost of treating climate related diseases such as malaria and malnutrition, and the loss of natural resources which provide critical ecosystem services to urban, peri-urban and rural communities.

The aggregated estimated total GDP loss by sector was in the range of USD 4,330-5,440 million with the following sector GDP losses: Agriculture (2,200 – 3,130), Energy related (270 – 450), Health (460), and Natural Resources (1,400).

In view of these challenges, Zambia has in the recent past developed various climate change-related policies, strategies, projects and programs in response to climate change impacts. These include: the National Policy on Environment (NPE, 2007); the National Climate Change Response Strategy (NCCRS, 2010); National Forestry Policy of 2014; National Energy Policy of 2008, The National Agriculture Policy of 2014; Transport Policy of 2002; National Strategy for Reducing Emissions from Deforestation and Forest Degradation (REDD+, 2015); Second National Biodiversity Strategy and Action Plan (NBSAP2); the National Adaptation Plan of Action on Climate Change (NAPA, 2007); Technology Needs Assessment (TNA, 2013); Nationally Appropriate Mitigation Actions (NAMAs, 2014); Second National Communication (SNC, 2015).

These policies, strategies, programmes and projects are aligned with the Revised Sixth National Development Plan (RSNDP) and the Vision 2030 which seek to promote "A prosperous middle income country by 2030", both of which support development of a low carbon and climate-resilient development pathway. In addition, Government ratified the Kyoto Protocol in 2006 among other things to facilitate implementation of the Clean

Development Mechanism. The country is also in the process of developing its National Adaptation Plan (NAP) for long term adaptation planning and mainstreaming of climate change into national development planning process. The development of the Seventh National Development Plan (SeNDP, 2017-2021) is also underway which will take into account climate change issues

An assessment undertaken as part of the INDC preparation for the mitigation component revealed that mitigation policies/actions/programs converge into three programs which have mitigation and adaptation effects: Sustainable Forest Management, Sustainable Agriculture and Renewable Energy and Energy Efficiency.

Similarly, adaptation measures identified based on vulnerability assessment of seven key economic sectors (agriculture, water, forestry, energy, wildlife, infrastructure and health) comprise three goals/programs that have strong synergies with mitigation. These are: Adaptation of strategic productive systems (agriculture, forests, wildlife and water); Adaptation of strategic infrastructure and health systems; and Enhanced capacity building, research, technology transfer and finance.

Introduction of a Carbon Tax

One policy instrument to include externalities from carbon emissions into the market price for electricity is the introduction of a carbon tax. With such a tax, a certain amount of money has to be paid for each unit of CO_2 emitted. In that way lower emissions, greater energy efficiency and the use of cleaner, low carbon technologies will be triggered in the ESI. The political challenge is to design a carbon tax in a way such that it is equal to marginal external damage costs from GHG emissions in the long-run, while confronting affected sectors immediately with the full price could make them uncompetitive on international markets. The best way to avoid this is believed to be an increasing tax rate, starting from a relatively low level. Different carbon prices have been modered to find such an optimal tax rate (Vorster et al. 2011). In South Africa, they found that a gradual tax rate increase, starting from 100 ZAR/tCO_2-eq. and gradually increasing to 750 ZAR over the next four decades would be most efficient. Their calculations reveal annual potential savings of 600Mt of CO_2equivalents by 2050 based on the carbon tax regime.

Development of Rural Areas

In Zambia, there is still a big disperities in terms of development between rural and urban areas. When it comes to access to electricity, about 86% of the rural population are not yet connected to the electricity grid. In Samfya, some rural population are connected to mini grid solar plant (Figure 2.4)

Figure 2.4: An electrified house under the Mpanta (60 kW) mini grid solar plant in Samfya

The Rural Electrification Authority (REA) is mandated to increase the electricity access rate in rural areas. The Authority focuses on resource mobilization and promotion of private sector participation in order to narrow the financing gap for rural electrification programmes.

One practical challenge is that about half of the disadvantaged households are situated in informal dwellings that cannot be economically electrified. Before these households can be electrified, the residents must either move to formal dwellings or their dwelling must be formalized, providing security of tenure even to public infrastructure.

Transition of the ESI

The last important aspect that will be guided by future policies concerns the transition of the energy industry. Energy planning in the IRP is an interactive process, were both latest market data and contributions from the scientific community are included in the revisions of the IRP policy document. One factor that is subject to change over time is future energy demand. Nel (2012) argues that energy demand is driven by changing energy intensity ratios and economic growth of an economy. Thus, changes in the structure of the economy, for instance a further shift towards the tertiary sector, is an important indicator for policy development and provide benefits that attenuate pressures from economic growth.

Other parameters that will change in coming IRP iterations are the LCOE for different generation technologies. These depend on global learning curves, technological breakthroughs, price developments for capital and commodities and on external shocks, such as the Fukushima accident has shown for nuclear technology, in which case risks must be re-evaluated. Thus, it is easy to understand that policies and political targets concerning a transition of the ESI are not always straightforward affronts. Though, besides existing environmental concerns, the net energetic balance has to be taken into account when evaluating the attractiveness of every technology under consideration.

Policy discussions are important dynamic factors that influence the conditions under which technologies are to be evaluated. Consequently, they must be accounted for when developing a framework for an evaluation of different generation technologies. This framework will be developed in the next chapter.

CHAPTER 3: RESEARCH METHODS

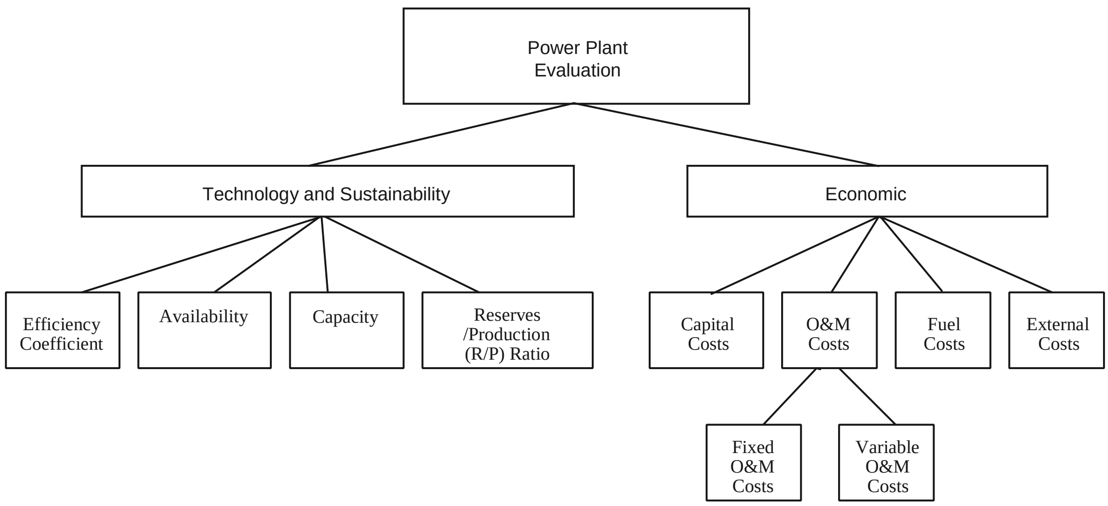
3.1 Research Methods

This chapter introduces the analytical hierarch tree, alternative scoring criteria, Levelized Cost of Electricity approach and provides a discussion of the benefits and flaws. Consequently, the goal of this chapter is to develop a multi-dimensional framework for a social economic evaluation of electricity supply options in Zambia. However, to keep the scope focused throughout this work, main emphasis will be put on the key aspects of electricity generation technologies.

3.2 Hierarchy Tree Approach

This section presents hierarchy tree approach as illustrated in Figure 3.1. The goal, which is the choice made of the best power plant according to the criteria and subcriteria at the top of level 1. There are two main criteria presented in level 2 of the hierarchy, that of technology/sustainability and economic sense. These are further divided into several subcriteria.

The criterion of technology and sustainability is divided in four subcriteria, namely ‘‘efficiency coefficient’’, ‘‘availability’’, ‘‘capacity’’ and ‘‘reserves-to-production ratio’’. The economic criterion has four subcriteria, namely ‘‘capital costs’’, ‘‘operation & maintenance (O&M) costs’’, ‘‘fuel costs’’ and ‘‘external costs’’. All these subcriteria are described in detail due course. The subcriteria of both the technology/sustainability and economic criteria are presented in the third level of the hierarchy tree. Finally, O&M costs consist of fixed and variable costs (level 4). Level 5 comprises the ten types of power plants.



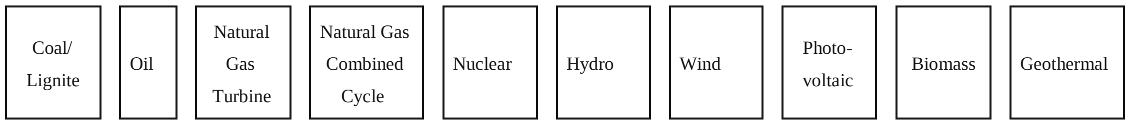


Figure 3.1. The hierarchy tree for optimization of technology/sustainability and economic criteria of the ten types of power plant.

3.2.1 Alternatives' Scoring Against Each Criterion

Alternatives' scoring against each criterion is mainly based on the IAEA database, which offers a common base of average values. Different sources of data (apart from partially available data for some types of power plant) make different assumptions, which sometimes may lead to wrong evaluations. Average values that apply at present were used for evaluation. As forecasting of several data is quite risky, only sensitivity analysis can help the decision maker analyze divergence of current figures in the future.

3.3 Technology and Sustainability

Technology and sustainability factors are grouped together, because the more technically sound a power plant the more is its contribution to sustainable development. These factors are the power plant efficiency coefficient, the availability, the capacity and R/P ratio. The greater the value of a subcriterion, the better the performance of the power plant type.

3.3.1 Efficiency Coefficient

The efficiency coefficient is the ratio, expressed as a percentage, of the output energy to the input energy. Efficiency refers to how much useful energy (electricity, in this case) we can get from an energy source. It is generally accepted that efficiency improvement that is consistent with high plant reliability and low-cost of electricity is economically beneficial (Bee´r, 2007).

A 100 percent energy-efficient machine would change all its energy input into useful energy. It would not waste any energy. However, some energy is always lost when one form of energy is converted to another. Because a percentage of input energy is lost during its conversion to electricity, efficiency is always not 100 percent. No machine is 100percent energy efficient. The lost energy is usually in the form of heat, which dissipates into the air and cannot be used again economically. For example, a boiler is 75 percent efficient when its product (steam) contains 75 percent of the heat theoretically contained in the fuel consumed. All automobile engines have low efficiency (below 30 percent) because of the total energy content of fuel converted to heat; only a portion provides motive power, while a substantial amount is lost in radiator and car exhaust. The average efficiency coefficient of the ten power plant types is presented in Table 3.1 according to the International Atomic Energy Agency (IAEA) (2002).

Table 3.1: Average efficiency coefficient for the ten types of power plant.

Type of power plant	**Efficiency coefficient (%)**
Coal/lignite	39.4
Oil	37.5
Natural gas turbine	39
Natural gas combined cycle	54.8
Nuclear	33.5
Hydro	80
Wind	35
Photovoltaic	9.4
Biomass	28
Geothermal	6

Source: IAEA, 2002.

3.3.2 Availability

The availability of a power plant is the amount of time that it is able to produce electricity over a certain period, divided by the amount of time in the period. A power plant can be out of service due to maintenance or repairs (Ogaji et al., 2002) or due to weather conditions such as the lack of sunlight or wind (Persaud et al., 1999). Occasions where only partial capacity is available are not taken into account.

The quality of the equipment, its maintenance, the type of fuel, the design of the plant and how the plant is operated are crucial components in its availability. Everything else being equal, plants that run less frequently have higher availabilities because they require less maintenance. Most steam-electric power plants, such as coal, geothermal, oil, natural gas, biomass and nuclear power plants, have availabilities between 80percent and 96percent. Newer plants tend to have a significantly higher availability, but preventive maintenance is as important as improvements in design and technology. Photovoltaic, wind and hydro power plants have lower availabilities ranging between 20percent and 50percent. The availabilities for the ten types of power plant are presented in Table 3.2 (IAEA (2002)).

Table 3.2: Average availability for the ten types of power plant.

Type of power plant	***Availability (%)***
Coal/lignite	*85.4*
Oil	*92*
Natural gas turbine	*91*
Natural gas combined cycle	*91*
Nuclear	*96*
Hydro	*50*
Wind	*38*
Photovoltaic	*20*
Biomass	*80*
Geothermal	*95*

Source: IAEA, 2002.

3.3.3 Capacity

The capacity of a power plant is the amount of electricity that it produces over a given period, divided by the amount of electricity it could have produced if it had run at full power over that period. Capacity should not be confused with availability. Furthermore, the two criteria have different quality features (the one refers to time and the other to amount of electricity) and different values (previous Tables 3.1 and 3.2 refer) for the ten types of power plant, so both of them should be incorporated in the overall evaluation. For example, Oil, NG Turbine and natural gas combined cycle (NGCC) have 92%, 91% and 91% availability, respectively, while they have 26.2%, 16.6% and 38.2% capacity. Wind power plants have greater availability of 38% as compared to their capacity of 32.1%, while photovoltaics have less availability of 20% as compared to their capacity of 22.1%. In conclusion the two criteria cannot be considered to double count the same feature of the ten types of power plant.

Capacities vary greatly depending on the type of fuel that is used and the design of the plant. Hybrid power plants like solar-geothermal can have increased capacity (Lentz and Almanza, 2006).

The capacity is not 100% output mainly for three reasons. The first reason is that equipment could be out of service, either due to failures or due to routine maintenance. This accounts for most of the unused capacity of base load power plants. Base load power plants have the lowest costs per unit of electricity produced, because they are designed for maximum efficiency and are operated continuously at high output. Nuclear, coal and biomass plants that burn solid fuel are almost always operated as base load plants. The second reason for the plant having a capacity lower than 100% is that its output is curtailed, because electricity is not needed or because the price of electricity is too low to make production economical. Peaking plants may operate only a few hours per year or up to a several hours per day. Their electricity supply is relatively expensive. It is uneconomical, even wasteful, to make a peaking power plant as efficient as a base load serving plant, because they do not operate lengthily to pay for the extra equipment cost, and perhaps not long enough to offset the embodied energy of the additional components. The third reason is that weather conditions cannot be forecasted for a long period for photovoltaic and wind plants. In such cases the capacity is evaluated by the development of long-term patterns (Sinden, 2007) or the application of probabilistic wind speed data (Chang and Tu, 2007) unforeseen risk factors taken into account.

It is important to note that while capacity is almost entirely a matter of reliability for a fuel powered plant, it is not the case for a wind plant as this is a matter of economic turbine design. With a very large rotor and a very small generator, a wind turbine would run at full capacity whenever the wind blew and would have a 60–80% capacity. Hence forth produce very little electricity. For the economic sense a wind power plant, a large generator, thus admitting the fact that the capacity is lower as a result. Wind turbines are fundamentally different from fuel powered plants in this respect. A wind plant is ‘‘fueled’’ by the wind, which blows steadily at times but not at all times. Although modern utility-scale wind turbines typically operate 65–80% of the time, they often run at less than full capacity. Therefore, a capacity of 25–40% is common, although they may achieve higher capacities during windy weeks and months. Table 3.3 presents the capacities of the ten types of power plants (IAEA (2002); Energy Information Administration (US DOE/EIA), 2006).

Table 3.3: Average capacity for the ten types of power plant.

Type of power plant	Capacity (%)
Coal/lignite	70.8
Oil	26.2
Natural gas turbine	16.6
Natural gas combined cycle	38.2
Nuclear	90.5
Hydro	29.6
Wind	32.1
Photovoltaic	22.4
Biomass	70
Geothermal	82.5

Source: IAEA, 2002; US DOE/EIA, 2006.

3.3.4 Reserves-To-Production (R/P) Ratio

Reserves-to-production (R/P) ratio calculates the availability (in years) of a certain type of fuel according to current consumption and the annual consumption increase/decrease rate of each non-renewable energy source for electric power generation. When evaluating the amount of fuel, only well-known sources that can be really exploited are considered. Several types of model like the exponential, harmonic and mechanistic Li–Horne models are used frequently to estimate reserves and to predict the production of oil and gas (Li and Horne, 2007). Non-economical extraction or exploitation of fuel is not considered. Table 3.4 presents the average R/P ratio for the ten power plant types (BP, 2005; World Nuclear Association (WNA, 2006).

Table 3.4: Average Reserves-to-Production (R/P) ratio for the ten types of power plant.

Type of power plant	**Reserves-to-Production (R/P) ratio (years)**
Coal/lignite	164
Oil	40.5
Natural gas turbine	66.7
Natural gas combined cycle	66.7
Nuclear	70
Hydro	Infinite
Wind	Infinite
Photovoltaic	Infinite
Biomass	Infinite
Geothermal	Infinite

Source: BP, 2005; WNA, 2006.

Renewable sources of energy last forever. So in order to express this relation as a figure, the AHP has been used. In AHP, the relation of renewable energy to fossil fuel R/P ratio can be expressed by pairwise comparisons. Pairwise comparisons are made using a measurement scale used by the AHP. This measurement scale is presented in Table 3.5. When comparing two items A and B, their relative importance is expressed either numerically or verbally. For example, if under a certain criterion, A is strongly more important than B, then the cell of the table that is the section of row A and column B is filled with number 5 or the phrase ‘‘strongly more important’’. Besides the values 1, 3, 5, 7 and 9 defined in Table 3.5, any other intermediate values can be used to express the relative importance of elements A and B. For example, number 4 can be used to express an intermediate situation between ‘‘A is moderately more important than B’’ and ‘‘A is strongly more important than B’’ (Table 3.5 refer). Nevertheless intermediate values have no major impact on the final results.

Table 3.5: AHP measurement scale.

Intensity of importance	Definition	Meaning (A compared to B)
1	Equal importance	A is equally important to B
3	Moderate	A is moderately more important than B importance
5	Strong importance	A is strongly more important than B
7	Very strong	A is very strongly more important than B importance
9	Extreme importance	A is extremely more important than B

By using the measurement scale of Table 3.5, Table 3.6 was built where the relation of R/P ratio is now expressed in a numerical form as a result of the pairwise comparison among all types of power plants. In Table 3.6, all renewable energy sources are (subjectively) considered equivalent with regard to their R/P ratio. Small variations (e.g. 1/7 instead of 1/9) in the pairwise comparisons of the R/P ratio of renewable energy power plants do not change their overall evaluation. Greater variations would cancel the renewable character of these power plants. The renewable sources are extremely more important, than all fossil fueled and nuclear-fueled power plants, as to their R/P ratio. Finally, coal reserves are much greater in quantities than oil and moderately more than natural gas and uranium reserves.

Table 3.6: Pairwise evaluation of Reserves-to-Production (R/P) ratio for the ten main types of power plant.

Type of power plant	Coal/lignite	Oil	Natural gas turbine	Natural gas combined cycle	Nuclear	Hydro	Wind	Photovoltaic	Biomass	Geothermal
Coal/lignite	1	5	3	3	3	1/9	1/9	1/9	1/9	1/9
Oil	1/5	1	1/3	1/3	1/3	1/9	1/9	1/9	1/9	1/9
Natural gas turbine	1/3	3	1	1	1	1/9	1/9	1/9	1/9	1/9
Natural gas combined cycle	1/3	3	1	1	1	1/9	1/9	1/9	1/9	1/9
Nuclear	1/3	3	1	1	1	1/9	1/9	1/9	1/9	1/9
Hydro	9	9	9	9	9	1	1	1	1	1
Wind	9	9	9	9	9	1	1	1	1	1
Photovoltaic	9	9	9	9	9	1	1	1	1	1
Biomass	9	9	9	9	9	1	1	1	1	1
Geothermal	9	9	9	9	9	1	1	1	1	1

3.4 Economic Sense

Economics is important in every aspect of our life. When trying to make a decision for the best power plant, several costs should be taken into account. These costs are capital costs, O&M costs, fuel costs and external costs. The lower the costs, the better the performance of the power plant type and the greater the returns to investment.

3.4.1 Capital Costs

Capital costs comprise of land cost, the costs of the necessary buildings and of all the necessary equipment for the operation of the plant. Labor costs or costs for the equipment maintenance are not included in capital costs. Nuclear and coal-fired units are characterized by high capital costs but low operating costs. As such, they are candidates for base load operation only. Gas-fired generation is characterized by lower capital costs but higher operating costs, and thus may meet the requirements for operation as peaking and/or base load generation. All renewable energy power plant types and especially photovoltaics have huge capital costs.

Oil power plants have the lowest capital costs and can be combined in hybrid wind-diesel power plants to offset the high capital costs of wind power plants providing one of the most cost effective and environmental friendly alternatives for isolated consumers in areas with high wind potential, like the Aegean sea islands (Kaldellis and Kavadias, 2007; Kasseris et al., 2007) (site a second example for Zambian case study with high wind potential).

Capital costs are evaluated according to the power plant capacity in €/kW and can vary substantially, especially for renewable energy power plant types as hydropower, wind, photovoltaic and geothermal. Their average values are presented in Table 3.7.

Table 3.7: Average capital costs for the ten types of power plant.

Type of power plant	**Capital costs (€/kW)**
Coal/lignite	975
Oil	483
Natural gas turbine	612
Natural gas combined cycle	587
Nuclear	1590
Hydro	2417
Wind	1250
Photovoltaic	4167
Biomass	1667
Geothermal	2158

Source: IAEA, 2002.

***3.4.2** Operations and Maintenance (O&M) Costs*

Operational costs include wages of the employees, and the funds spent for the energy, the products and services for the power plant operation. To prolong power plant life and avoid shutdowns, maintenance is critical. The funds spent for maintenance are less than the financial damage expended for a power plant failure save for increased credibility and confidence index of the plant.

The O&M are divided into two subcategories namely, fixed and variable O&M costs. Fixed O&M costs are those costs for operation and maintenance per year that are not directly related to the amount of electricity produced by the power plant. These costs are evaluated in € per kW per year.On the other hand, variable O&M costs are directly related to the amount of electricity produced. They are measured in €cents per kWh. In some cases, the amount of electricity produced by a power plant is taken for granted, especially for power plant types used for base load. In these cases, many reports integrate fixed O&M costs with variable O&M costs, thus giving one value for O&M costs measured in €cent/kWh. In this paper, the two costs are evaluated and presented separately.

The average values for fixed and variable O&M costs are respectively presented in Tables 3.8 and 3.9.

Table 3.8: Average fixed operation and maintenance costs for the ten types of power plant.

Type of power plant	Fixed operation and maintenance costs (€/kWyr)
Coal/lignite	19
Oil	6.25
Natural gas turbine	10.83
Natural gas combined cycle	10
Nuclear	30
Hydro	72.5
Wind	25
Photovoltaic	16.67
Biomass	60.83
Geothermal	83.33

Source: IAEA, 2002.

Table 3.9: Average variable operation and maintenance costs for the ten types of power plant.

Type of power plant	Variable operation and maintenance costs (€cents/kWh)
Coal/lignite	0.183
Oil	0.233
Natural gas turbine	0.27
Natural gas combined cycle	0.233
Nuclear	0.033
Hydro	0.486
Wind	0.417
Photovoltaic	1.667
Biomass	0.708
Geothermal	0.025

Source: IAEA, 2002.

3.4.3 Fuel Costs

Fuel is any material that is capable of releasing energy when it's chemical or physical structure is changed or converted. Fuel releases its energy either through chemical means, such as burning, or nuclear means, such as nuclear fission or nuclear fusion. An important feature of a useful fuel is that its energy can be stored to be released as and when needed, and that the release is controlled in such a way that the energy can be harnessed to produce work.

Fuel costs refer to funds spent for the provision of raw material necessary (i.e. uranium for nuclear power plants) for power plant operation. Fuel costs may include extraction or mining, transportation and possible fuel processing to be used in a power plant. They also include the possible disposal cost of waste produced by its use. Nevertheless, fuel costs do not include the social, health and environmental related costs, such as gaseous and particulate emissions. These costs are included in external costs. A detailed subjective and objective evaluation of these non-radioactive emissions is presented by Chatzimouratidis and Pilavachi (2007).

Fuel costs may vary considerably in different time periods and areas as a result of several reasons, including demand, production and policy matters. In many cases, probabilistic analysis is applied to forecast fuel costs (Feretic and Tomsic, 2005). Tarjanne and Rissanen (2000) have researched performance and cost data for new base load power plants in Finland. Nuclear fuel cost includes the reprocessing of spent fuel and the disposal of nuclear waste. Nevertheless, nuclear fuel costs are much less than that of fossil fuel costs. Biomass fuel cost refers to the average cost of peat and wood according to a detailed study in energy economics conducted by Tarjanne and Luostarinen (2003).

Table 3.10: Average fuel costs for the ten types of power plant.

Type of power plant	**Fuel costs (€cent/kWh)**
Coal/lignite	1.31
Oil	1.84
Natural gas turbine	2.34
Natural gas combined cycle	2.34
Nuclear	0.27
Hydro	0
Wind	0
Photovoltaic	0
Biomass	2.05
Geothermal	0

Tarjanne and Luostarinen, 2003; US DOE/EIA, 2005.

3.4.4 External Costs

The external costs are defined as those costs incurred in relation to health and the environment and quantifiable, but not built into the cost of electricity. External costs are the funds paid for the restoration of corateral effects of power plant operation on human health and the ecosystem. They aim at restoring people's quality life degradation and they are calculated based on the life cycle external costs of power plants (Organisation for Economic Co-operation and Development (OECD), 2003). The internalization of external costs in the power generation sector can be assessed with several models and will increase the competitiveness of non-fossil generation sources and fossil power plants with emission control (Klaassen and Riahi, 2007; Rafaj and Kypreos, 2007).

An externality is produced when the economic activity of one actor (or group of actors) has a positive or negative impact on the welfare function of another actor (or group of actors) and when the former fails to be fully compensated, or to fully compensate the latter, for that impact. Externality is one type of default that causes inefficiency. This definition is most often used in the context of negative environmental externalities such as air pollution, which damages human and animal health, crops or materials. It should be noted that, under this definition, environmental pollution would not be an externality if those who suffer from the negative impacts of that pollution were fully compensated (Virdis, 2002).

In conclusion, external costs should be incorporated in the overall electricity generation cost. In that way, there will be a common base for comparison of the several power generation technologies examining every economic aspect of them. The external costs for the ten power plant types are presented in Table 3.11.

Table 3.11: Average external costs for the ten types of power plant.

Type of power plant	**External costs (€cents/KWh)**
Coal/lignite	8.40
Oil	6.75
Natural gas turbine	2.00
Natural gas combined cycle	1.33
Nuclear	0.49
Hydro	0.56
Wind	0.16
Photovoltaic	0.24
Biomass	2.65
Geothermal	0.20

Source: OECD, 2003.

3.5 Criteria weights

Criteria weights denote the importance of each criterion and subcriterion when synthesizing the scoring of the ten types of power plant against each of them. Criteria importance in each level is assessed with respect to their parent. The criteria weights are extracted subjectively, by use of the AHP and pairwise comparisons, thus avoiding the direct weight assessment that proves to be faulty in many cases. The hierarchy tree presented in the previous Figure 3.1 contains four groups of criteria in different levels. Criteria weights in each of these groups is derived by subjective pairwise comparisons.

While objective data is difficult to alter, subjective assessments can vary among decision makers with different culture, education and experiences. To overcome this obstacle, sensitivity analysis can be used to analyze how a variation of criteria weights would affect the partial and overall results. In this way, any data alterations will lead to projected results thus giving the management or the politicians the opportunity to cope with them instantly and efficiently.

3.5.1 Weights of Technology, Sustainability and Economic Factors

The two main criteria of power plant evaluation presented in Figure 3.1 are technology/sustainability factors and economic factors. The decision maker has to choose which of these two is more important and to what extent. This, of course, is subjective and there could be various assessments. In this study, technology and sustainability is assumed to be more important than economics, because the future generations to come have to be assured. Table 3.12 presents the importance of these criteria as a result of their pairwise comparison using the AHP measurement scale presented in Table 3.11.

Table 3.12: Pairwise comparison of power plant evaluation criteria.

Power plant evaluation criteria	**Technology and sustainability**	**Economic**
Technology and sustainability	1	3
Economic	1/3	1

3.5.2 Weights of Efficiency, Availability, Capacity and the R/P Ratio

There are four subcriteria of the technology and sustainability factors, namely the efficiency coefficient, the availability, the capacity and the R/P ratio. The pairwise comparisons as presented in Table 3.12.

The most important of all four subcriteria is the R/P ratio, which practically depicts the number of years for which the particular type of power plant can operate due to fuel availability. The number 9 given to cells, which are at the intersection of the R/P ratio row and the efficiency, availability and capacity columns, depicts exactly the grade of this importance.

The availability is considered equally important with the efficiency coefficient and moderately more important than the capacity, because the power plant should be able to produce electricity whenever needed.

The capacity depends among others on the policy followed by the electricity production sector. As a result, it is considered less important than the efficiency coefficient, which depicts how well the energy is exploited by the specific power plant technology.

Every criterion has of course equal importance with itself, so the elements on the main diagonal of the matrix are set to one. As in Table 3.9.4, when an element A in a row is compared with an element B in a column and the result is value x, then the comparison of the element B in the row with the element A in the column will have the reciprocal value 1/x so that consistency is assured.

Table 3.13: Pairwise comparison between the ''technology and sustainability'' subcriteria.

Subcriteria of technology and sustainability	**Efficiency coefficient**	**Availability**	**Capacity**	**Reserves-to-Production (R/P) ratio**
Efficiency coefficient	1	1	3	1/9
Availability	1	1	3	1/9
Capacity	1/3	1/3	1	1/9
Reserves-to-Production (R/P) ratio	9	9	9	1

3.5.3 Weights of Capital, O&M, Fuel and External Costs

The capital, O&M, fuel and external costs are the four subcriteria of economic factors. Their contribution to the overall cost differs significantly according to power plant type, the discount rates and fuel market prices. However, capital costs play a crucial role in the overall electricity generation cost, while high capital costs limit private investment, because of the long amortization period. Fuel costs also contribute significantly to the overall cost. O&M costs are relatively low compared to the capital and fuel costs. Finally, the external costs seem to rise greatly, in the near future these costs will be fully incorporated in the electricity production cost in the years to come in. In accordance to the foregoing considerations, Table 3.14 is constructed.

Table 3.14 Pairwise comparison between the ‘‘economic’’ subcriteria.

Economic subcriteria	**Capital costs**	**O&M costs**	**Fuel costs**	**External costs**
Capital costs	1	5	1	3
O&M costs	1/5	1	1/5	1/3
Fuel costs	1	5	1	3
External costs	1/3	3	1/3	1

3.5.4 Weights of Fixed and Variable O&M Costs

The O&M costs are divided into two subcategories, namely fixed and variable O&M costs. Fixed O&M costs are in dispensable to the power plant operations. On the other hand, variable O&M costs depend on the power plant production activities. In this paper, it is considered that power plants have a great capacity, thus minimizing their idle time. For this reason, priority is given to variable costs which are considered to be cardinal, in view of the great capacity of most of the power plants. These relations are presented in the form of pairwise comparisons in Table 3.15.

Table 3.15: Pairwise comparison between fixed and variable O&M costs.

Subcriteria of O&M costs	**Fixed O&M costs**	**Variable O&M costs**
Fixed O&M costs	1	1/5
Variable O&M costs	5	1

3.5.5 Global and Local Criteria and Subcriteria Weights

According to the evaluation presented in previous sections, the local criteria and subcriteria weights are presented in Table 3.16, while the global criteria and subcriteria weights are presented in Table 3.17. Global weights refer to the overall weights of the criteria, that is, their importance with respect to the overall goal. Local weights refer to weights of the criteria with respect to their parent node in the hierarchy tree; that is, their importance regarding their parent criterion.

Technology and sustainability factors take first priority over economic factors as a result of their pairwise comparison presented in the previous Table 3.13. R/P ratio has 55.53% global weight, meaning that its contribution to the overall score is slightly higher than all the other subcriteria together. Sensitivity analysis presents changes in the global and local weights of criteria and subcriteria that affect the overall score and ranking.

Table 3.16: Local criteria and subcriteria weights.

Power plant evaluation (100%)							
Technology and sustainability (75%)				Economic (25%)			
Efficiency coefficient (10.56%)	Availability (10.56%)	Capacity (4.84%)	Reserves-to Production (R/P) ratio (74.04%)	Capital costs (38.99%)	O&M costs (6.79%) Fixed(16.67%) Variable (83.33%)	Fuel costs (38.99 %)	External costs (15.23 %)

Table 3.17: Global criteria and subcriteria weights.

Power Plant Evaluation (100%)							
Technology and sustainability (75%)				Economic (25%)			
Efficiency coefficient (7.92%)	Availability (7.92%)	Capacity (3.63%)	Reserves-to Production (R/P) ratio (55.53%)	Capital costs (9.75%)	O&M costs (1.70%) Fixed (0.28%) Variable (1.42%)	Fuel costs (9.75%)	External costs (3.80%)

3.6 The Levelized Cost of Electricity Approach

This section refers to the second objective cited for this thesis, that of introducing and evaluating critically the levelized cost of electricity (LCOE) framework, to elaborate its shortfalls and to develop a comprehensive framework that allows comparing potential electricity generation technologies for Zambia on a common basis. The usefulness of this approach is justified by Fakir (2012) who has called for a new normative framework for energy planning governed by the following parameters: "social outcomes, reducing carbon intensity, getting more from limited finances, accounting for externalities, ensuring long-term flexible energy security and diversifying the industrial base".

The LCOE methodology, that measure direct costs of electricity generation, is herein introduced and formalized and subsequently its shortfalls pointed out. Then, non-market priced cost elements, namely externalities from electricity generation will be discussed and an approach will be developed to incorporate them into the standard LCOE analysis. This will be complemented with a quantification of risks under nuclear energy generation, being the only technology that is exposed to a higher risk class, proven by the fact that these risks cannot be fully insured on the market. Moreover, non-quantifiable aspects of energy resource planning will be discussed for each technology. This includes the aspects of job creation potential, availability of electricity, and energy security. Finally, a combined approach will be formalized, putting all monetary and non-monetary dimensions together. The chapter ends with a brief discussion of the limitations with regard to the methodology developed.

3.7 Direct costs of electricity generation

3.7.1 Levelized Cost of Electricity

The LCOE methodology is a practical tool for economic evaluation of power generation investments and it represents the most transparent framework currently in use for energy planning and policy development (IEA/NEA/OECD, 2010). The advantage of this approach is that it enables the comparison of investments that differ in physical principles, fuel types or their economic plant life. When calculating the LCOE of a power plant project, all discounted direct project costs over the life-time of the project are divided by the discounted sum total of the electricity that it generates over its life-time. From a financial perspective, LCOE can also be described by the constant level of revenues necessary per year to recover all expenses over the life of a power plant (Roth and Ambs, 2004, NREL, 2010). In the standard approach, these expenses include plant costs, operation & maintenance costs (O&M), and fuel costs. In the end, the calculation will enable comparisons of different options on a constant unit cost basis, in ZMW per MWh in this thesis.

In practice, two approaches have evolved to calculate LCOE: the simplified LCOE approach (sLCOE) and the Financial Model Approach (FMA). These differ in that the sLCOE approach gives “the minimum price at which energy must be sold for an energy project to break even (or with zero present value)” while the FMA “saves for the required revenues to achieve a certain internal rate of return” for a specific investor (Black and Veatch, 2011). This internal rate of return is based on company-specific project discount rates, tax liability, financing costs and revenue requirements. The FMA is thus preferable for integrated companies that might have to take internal investment decisions by considering several technologies. The sLCOE approach, on the other hand, is preferable by policy makers, because it makes projects comparable without accounting for specific requirements that might vary from company to company, hence it provides for a single discount rate for all projects. For these reasons, but also because company specific data are difficult to obtain by outsiders, the latter approach is used throughout this thesis. Subsequently, when referred to LCOE, it is the sLCOE approach that is meritorious.

To calculate the LCOE of a project, capital costs, O&M costs and fuel costs have to be levelized over the life-time of the power plant. Subsequently, the three cost components are reviewed separately and then combined into a complete LCOE formula.

Plant costs (c_p) are herein defined as the costs that are incurred to set up a power plant. Often, for purpose of such an analysis, the concept of overnight costs is applied, which simulates a case where the costs to install the plant occur ‘overnight’ following the investment decision, and the plant is ready to operate straight after the investment injection. Regularly, such data is available in the form of currency per unit of capacity. Have costs have to be levelized on a unit of electricity output, e.g. in ZMW/MWh, plant costs divided by the time the power plant actually produces electricity in a year. This is given by the 8760 hours of a year (H), which are multiplied by a capacity factor (f), indicating the percentage of the time the power plant actually runs to produce electricity. So far, this calculation gives capital costs per unit of electricity over one year. In reality, a power plant operates over years or even decades. This is why a capital recovery factor (*CRF*) is included in the calculations. This CRF is known as the annuity factor in finance and here defined as the portion of plant cost that the revenues must cover during a year of operation to break even the whole project by the end of its plant life. The CRF thus converts a flow of annual payments over a project life into present value. It depends on the discount rate (r) applied to the project and plant operation time (T). Capital costs can be calculated with the following formulae:

$$Capital\ costs = \left[\frac{CRF \cdot c_p}{H \cdot f}\right] \tag{3.1}$$

$$where\ CRF = \frac{r \cdot (1+r)^T}{(1+r)^T - 1} \tag{3.2}$$

The second component in LCOE is O&M costs. O&M costs occur during the operation of a power plant and can either be expressed in fix (c_{fom}) or variable (c_{vom}) terms. This depends on the data available. Like capital costs, fixed O&M costs are divided by the multiplier of *H* and *f* to capture how much occur during one year of production. What is different though is that O&M costs can be subject to increase with growing plant age, caused by technical degradation. Consequently, the sum of fixed and variable O&M costs is multiplied with a levelization factor (*l*). This *l* levelizes all O&M costs over plant life and accounts for possible cost increases by incorporating a price escalation rate (e). By considering a discount rate (*r*) and project life time (*T*), everything is expressed in net present values, other things being equal thus:

$$O\&M\ costs = \left[l \cdot \left(\frac{c_{fom}}{H * f} + c_{vom}\right)\right] \tag{3.3}$$

$$where\ l = \frac{r \cdot (1+r)^T}{(1+r)^T - 1} \cdot \frac{(1+e)}{(r-e)} \cdot \left[1 - \left(\frac{1+e}{1+r}\right)^T\right] \tag{3.4}$$

The third component in LCOE is fuel costs (c_f). These costs do only exist with technologies, where fuel is physically needed to produce electricity, hence an important price factor for fossil-based power plants while negligible for most RES. As with O&M costs, fuel prices are mostly subject to variation over time and consequently, current price levels have to be multiplied with a separate levelization factor for fuel. The formula for fuel costs takes shape as follows:

$$Fuel\ costs = \left[l \cdot \left(\frac{c_f}{H * f}\right)\right] \tag{3.5}$$

Taking all cost components into consideration, the full LCOE formula is then reshaped as follows:

$$LCOE = \left[\frac{CRF \cdot c_p}{H \cdot f}\right] + \left[l_{om} \cdot \left(\frac{c_{fom}}{H * f} + c_{vom}\right)\right] + \left[l_f \cdot \left(\frac{c_f}{H * f}\right)\right] \quad (3.6)$$

3.7.2 Underlying Assumptions

The analysis of LCOE always depends on assumptions about price escalation rates and discount rates. Most often, such estimates are based on historical data hence projections of their future developments always include some level of uncertainty. As the IPCC (2011) clarifies, *e* and *r* cannot be observed directly, hence assumptions about future real rates must be based on expectations about inflation and price determinations. This is why LCOE are often indicated as a range, based on upper-bound and lower-bound levels for *r* and/or for *e*. To account for this, a sensitivity analysis with regard to different levels of r is provided for in Chapter 4.

It is also important to make clear whether *r* and *e* are expressed in constant real terms, excluding effects of inflation, or in constant nominal terms, as a stream of values in nominal currency, including inflation considered (Black and Veatch, 2011). For the scope of this thesis, constant real rates, adjusted for inflation, are applied and results expressed as ‘real LCOE in 2017 ZMW currency’.

In addition and according to Steyn (2006), discount rates are insofar subject to debate as it is not clear whether they should reflect private risk faced by a monopolist or whether social discount rates should be applied. They would be much lower and in the order of 4-5%, as Griffin (2009) suggests. Especially if high costs arise in the future calculations, the choice of a higher discount rate may considerably affect the LCOE in favor of technologies where high further costs are predicated (IPCC, 2011). In the scope of this thesis, all cost calculations in chapter 4 are discounted for 5%. The separate sensitivity analysis will make variations of the results from other discount rates visible.

Finally, note that LCOE depend on the location of the power plant project to be evaluated. The capacity factor is a technical performance parameter that strongly depends on location, especially in the case of RES. Other technology-dependent parameters such as life-time, investment cost and O&M cost might also depend on local market conditions, wages and maturity of technology (IPCC, 2011). In the final analysis, best available locations are selected for energy projects and consequently, optimistic parameters applied. Economically, it makes sense to choose these locations first.

3.7.3 Merits

LCOE is a practical tool for economic evaluation of power generation investments and it represents the most transparent framework currently in use for energy planning and policy development (IEA/NEA/OECD, 2010). The clear advantage of this approach is that it allows for comparison of investments that differ in physical principles, fuel types or their economic plant life. It also reflects time value of money including real cost of money (including risk) and inflation. LCOE is easily understood with a common definition of economic value.

3.7.4 Flaws

LCOE is a good and practical approach to compare costs of different energy technologies on a common basis, but it comes with several serious flaws that limit the significance of the results for reality. In the standard approach, Roth and Ambs (2004) criticize that only costs directly associated to the plant-level are taken into account for economic evaluation, while indirect costs are denied from entering the equation.

As confirmed by the IPCC (2011), indirect costs miss out in the calculation of LCOE and must thus be thought about separately in a consideration of the competitiveness of a power plant. In the electricity sector, the list of such indirect costs is long and includes, inter alia, externalities (e.g. carbon price mark-up, pollution, or health costs), cost for back-up power that stems from the intermittency of some RES, grid integration and transmission costs, system cost increase from a change of the energy mix, outages of base-load power plants due to maintenance, and path dependence which refers to sunk costs of made investments.

Another flaw in the LCOE methodology is the fact that some direct cost occur far in the future, such as decommissioning costs of a power plant or waste disposal, and are often not included with the argument that given high discount rates, they do not have a significant effect on LCOE anyway (OECD/Nuclear Energy Agency, 2010).

In his concept of a smart energy policy, Griffin (2009) called upon emerging economies to caution their willingness to pay for clean and secure energy. Consequently, evaluations of investments in the electricity sector must include the externalities, risks and other problem areas described above to reflect the true willingness to pay and to avoid miss-allocations, as

Vorster et al. (2011) acknowledge. A framework including indirect costs and nonmonetary aspects of energy planning be developed as below and included to the LCOE methodology in order to provide more realistic prices as decision criteria basis for energy planning in Zambia.

3.8 Indirect costs of electricity generation

3.8.1 Economic Reasoning Behind An Inclusion Of Externalities Into Full Costs

The quantification of externalities and their inclusion into market prices for electricity is not a new concept and various studies exist, that have tried to quantify externalities occurring with electricity production. Surprisingly, only few of the studies have been directly combined with the concept of LCOE and to the knowledge of this scholar, no such combined analysis has been published recently for the case of Zambia. Blignaut (2002) advanced that the downside of a non-inclusion of external costs into market pricing is a long-term opportunity cost. The economic reasoning behind this situation is simplified in Figure 3.2.

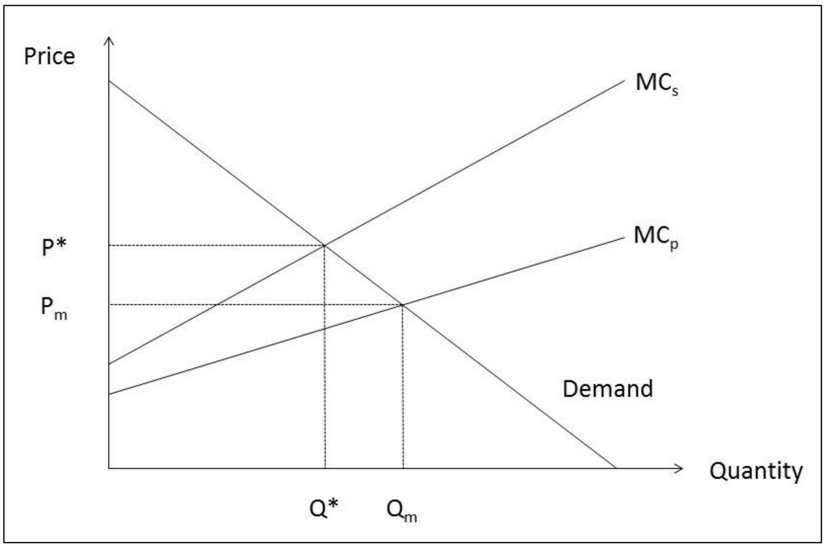


Figure 3.2: Electricity market allocation with private and social marginal costs *Source:* Own illustration, adopted from Blignaut and King (2002).

Here, the case is depicted where an electricity supplier sells an additional unit of electricity produced from coal at his marginal private cost (MC_p). In equilibrium, this leads to the quantity of Q_m demanded at price P_m. However, the true costs that society faces include externalities from burning the coal and are higher than MC_p. They are depicted by the marginal social cost (MC_s). Thus, the equilibrium including externalities is at a higher price P^* and a lower quantity Q^*. What can be concluded from this situation is that either the electricity price without externalities is too low ($P_m < P^*$) or the quantity of electricity demanded is too high ($Q_m > Q^*$). Blignaut and King (2002) acquiesce that it is also an indication for too much externalities produced and for too few incentives that exist to reduce them. To correct the root cause of this market failure, it makes sense to converse the electricity supplier to include the externalities into his pricing function.

3.8.2 Externalities Studies for Southern Africa

A meta-study on externalities from the South African electricity sector was compiled by Edkins et al. (2010c). It summarizes the research published in previous reports from Dutkiewicz and De Villiers, Van Horen (1997) and Spalding-Fecher and Matibe (2003). The study comprises all technologies used in Southern Africa, including coal, nuclear, CCGT-gas, OCGT-diesel, biomass, small hydro, wind, CSP and PV. In their study, the authors identified both negative and positive externalities. Negative externalities cover impacts from the entire life-cycle of a power plant, reaching from construction, manufacturing activities, utilization of the plant, fuel production, transport on and utilization, to waste management, while positive externalities include avoidable health costs from increased access to electricity. Unfortunately, these benefits from electrification were reported by Edkins et al. as a uniform value for all technologies per electrified customer. As a result, relative prices between technologies are not affected by this number and for this reason it is excluded from the analysis. Furthermore, it would only make sense to include these positive impacts from electrification as long as there are still households left to electrify. As soon as a 100% electrification rate is reached, it would not make any economic sense to account for these benefits over the rest of a plant’s life-time.

Impacts from climate change and outdoor air pollution are identified to be the worst adverse drivers that influence negative external costs from coal-based electricity generation. This finding was confirmed in a separate international study from Nicholson et al. (2011). However, Edkins et al. (2010c) admitted that damage costs from GHG emissions seem to be outdated in their local meta-study, if compared with international studies. He also added that international studies out-costed local studies on health impacts from acid mine drainage by a factor of 10. Finally, it’s acknowledged that their meta-study had been compiled under severe time pressure. Consequently, values for damage costs from emissions and for negative impacts from coal mining are hereby sourced from international studies.

A detailed externality study for the new Kusile coal-based power plant has been published by Blignaut et al. (2011). This study managed to overcome the flaws of previous studies in terms of evaluating global damage costs for GHG emissions and health impacts. It incorporates the latest scientific consensus on these issues. The externality estimates estabilished for coal power plants will therefore be applied in this analysis. For all other technologies, results from the local and international meta-study will be used. Where this one is flawed, as described above, the data-transfer method will be applied and estimates adopted from recent international studies.

3.8.3 Data-Transfer Method from International Studies

In order to estimate external costs from GHG emissions (EX_{GHG}) as accurately as possible in this research, estimates for damage costs from GHG emissions (DC_{GHG}) are adopted from recent international peer-reviewed publications. These are multiplied with emission intensity factors of a technology (EI_{rt}), if no concrete estimates on GHG output for a specific reference plant are available, thus:

$$EX_{GHG} = [EI_{rt} \cdot DC_{GHG}] \qquad (3.7)$$

To make data transfer meaningful, Nahman (2011) suggests that values for local pollution impacts based on estimates from other countries get adjusted simultaneously for relative income differences between countries and preferences for local environmental quality by using the following formula:

$$\bar{E}_{ZMK} = \left(E_{BC} \cdot \frac{I_{ZMK}}{I_{BC}}\right)^{Q} \qquad (3.8)$$

where ($\bar{E}_{ZMW}$) is the estimated value for Zambia, (E_{BC}) is the estimated value for the benchmark country, (I_{ZMW}) and (I_{BC}) are the per capita incomes based on purchasing power parity (PPP) rates and (Q) is the income elasticity for environmental quality.

Finally, external costs are added up and included into LCOE. Technically, this is straightforward if all data is provided on a per-unit basis (ZMW/KWh) as in the given studies. In the same way like variable O&M costs, net externalities (EX_{net}) will then be multiplied by a levelization factor *l* and added on top of the LCOE, thus:

$$Levelized\ externalities = [l \cdot EX_{net}] \qquad (3.9)$$

The difficulty which arises is to determine a reasonable value for *l* that reflects the cost development of externalities of the plant life. The smallest value that could be assumed for *l* is the inflation rate, but as all calculations in this analysis are based on real values, inflation will be factored out. An assumption for *l* would then be a value of one for reasons of simplicity.

To account for uncertainties with the quantification of externalities, lower-, median- and upper-bound values will be reported, consistent with the LCOE methodology. Where prices are available in foreign currency or real values based on a specific base year, they will be converted to ZMW in the base pricing year of the source and then inflated with the Zambian producer price index (PPI) to standardized 2017 real values.

3.8.4 Risk

Zambia's policy makers are currently faced with a decision situation to migrate to nuclear power technology. The deployment of this technology induces profound risks. However, the possibility of major accidents, as well as long-term management issues of waste treatment remain controversially discussed issues (OECD/NEA, 2003). Even though probabilities of major accidents seem to be very small, a second major accident happened in 2011 in Japan. This accident has shown that consequences from situations out of control can be immense and costly and are in great part borne by the society at large. In a responsible energy planning, it is imperative to include the risks associated with this technology into its economic evaluation. In this sense, a risk premium for the costs of a major nuclear accident must be added to the LCOE for nuclear power, in addition to other external costs from its fuel cycle. This is indeed almost an impossible task, given potentially high external costs and low probabilities for a major accident. Only two scientific studies from Rabl and Rabl (2013) and Meyer (2012) are available, who have both tried to quantify the costs resulting from nuclear accidents based on experiences from the Chernobyl and Fukushima cases. Like other externalities studies, lower-, upper- and central-bound scenarios are reported and these are included in the full-cost evaluation of nuclear power in Zambia. However, the assumptions made in these studies can be subject to debate and their relevance for the case of Zambia as discussed in the analysis part on nuclear energy, of Chapter 4.

Apart from quantifiable direct and indirect costs of electricity generation, there are also non-monetary aspects that must be evaluated during integrated resource planning.
Qualitative and quantitative methods to do so will be described in the chapters that follow.

3.9 Non-monetary aspects of integrated resource planning

3.9.1 Job Creation Potential

Job creation from a diversified of the industrial base is a macro-economic factor with distinct applications for emerging economies such as Zambia, where majority people struggle to participate in economic development. Even when job creation potential is hard to quantify in numbers, it is still a valid qualitative and social aspect for policy makers in their decision making as regards the IRP for the electricity sector. In theory, new jobs can arise from investments into any new technology. Maia et al. (2011) allude to the fact that existing jobs can be lost if the capacity of one technology is substituted with that of another. At this point, it should be recalled that Zambia committed itself to reducing its future GHG emissions compared to a baseline emissions scenario and conditional to transfer of technology from developed countries. Such a transfer of technology, policy makers argues, will induce a shift of the ESI towards new 'green' industries and ultimately create new jobs. From a policy maker's perspective, the relevance of this is that job creation is only valuable if local companies and human capital are involved in changing the value chain of Zambia's ESI.
The effects of different energy technologies (t) on job creation have been subject to research. Recently, in South Africa-specific estimates on the job creation potential of different energy technologies got published in reports from Edkins et al. (2010b), Van Wyk et al. (2011) and Maia et al. (2011). Even when differences in the underlying methodology for their projections exist, all of these studies have in common that they consistent job creation specific potential of various sub-categories such as construction ($J_{c,t}$), manufacturing ($J_{mf,t}$), installation ($J_{in,t}$), operation ($J_{o,t}$), maintenance ($J_{mn,t}$) and fuel processing ($J_{fp,t}$). The sum total of these ($\sum J_{i,t}$) gives the total job creation potential of a technology and is reported in jobs created per MW of installed capacity.

In the analysis part, best estimates for the job creation potential (JCP_t) of each technology is drawn based on the arithmetic mean of the results from these studies. This allow for a comparison of the relative job creation potential among technologies thus:

$$JCP_t(J_{i,t}) = \frac{1}{n}\sum_{i=c}^{fp} J_{i,t} \qquad (3.10)$$

3.8.2 Availability of Electricity

Electricity is a good that has to be consumed instantaneously if it is not stored in another medium. For this reason the concept of availability of electricity is another important aspect in a non-monetary evaluation of different generation technologies. Usually, electricity demand is not constant during a day, but depends on how many electric appliances are turned on at any given moment. A typical daily demand profile for electricity in Zambia is depicted in figure 3.3. It must be noted that this demand profile is not identical over time, but seasonal with week-day varieties in demand patterns. However, for the scope of this analysis, this typical demand curve for reasoning purpose.

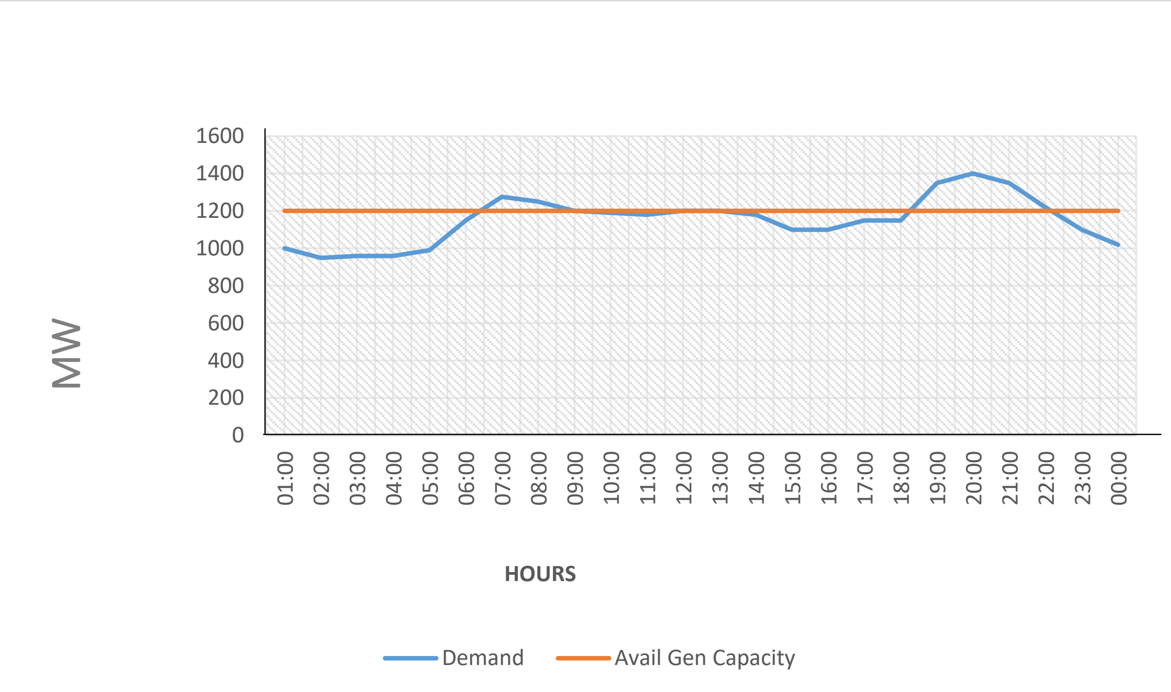


Figure 3.3: Sketch of typical hourly electricity demand patterns in 2013 *Source:* Illustration adapted from (ZESCO, 2013).

The electricity load that is exerted on the system to match demand comes from various energy sources and must be predicted in advance, and the required output of power stations must be planned and dispatched accordingly. While base load and intermediate load are relatively easy to predict and provide, peak load must be produced from very flexible power stations that are able to adjust their output instantly. In Zambia the situation will change if more renewable energy capacity is connected to the grid. In that it is imperative to assess the degrees of dispatchability and back-up power capabilities, which are expressed by capacity factors, and the flexibility to adapt power output. These aspects are discussed qualitatively in my analysis chapter. More complex discussions such as the market value of variable RES based on merit-order-effects or correlation effects are not covered here. Such analysis would only be meaningful in a competitive market where market forces influence relative prices, which is not obtaining in the case of Zambia.

3.9.3 Energy Security

Energy security is one of the three pillars of a smart energy policy as defined by Griffin (2009) and it has played a leading role in previous energy investment decisions for Zambia. Politicians have regularly called upon energy security as the main justification to upgrade power plants capacities. Zambia is in dire need to progress but the issue of global climate change imposes new responsibilities on emerging countries to re-think their concepts of energy security.

In this sense, Sovacool and Mukherjee (2011) have defined energy security as a multidimensional phenomenon consisting of availability, affordability, efficiency, technology development, sustainability and regulatory aspects of energy. An evaluation of a technology and its potential to contribute to energy security must include a consideration of these foregoing aspects. To quantify such aspects, the authors have established an exhaustive list of indicators over six dimensions, but admit that selecting a few of them might be sufficient for a reasonable evaluation settlement. Even though their framework was developed to compare energy security between different countries, indicators that allow for a comparison among technologies can be found. The dimensions are presented in Table 3.18.

Table 3.18: Selected indicators and metrics for measurement of energy security dimensions.

Dimension	Indicator	Metric
Availability	Proven recoverable energy reserves, Total renewable energy resource endowment	Reserves-to-production ratio in years, resource endowment in GW
Affordability	Social marginal cost of electricity generation	ZMW/KWh
Efficiency	Energy end-use efficiency	η, percentage of energy input to output
Technology Development	Lead time for construction of power plant	Years
Sustainability	Energy payback ratio	Number

Sources: Sovacool and Mukherjee, 2011.

3.10 A combined approach / framework

The final and comprehensive approach to evaluate all technology options consist of a combination of monetary evaluation and qualitative discussions as outlined in the previous chapters. LCOE, externalities and risks will be added and levelized on a per-unit basis of electricity output. Job creation potential and energy security will be measured with the introduction of metrics, while the availability is discussed qualitatively. For some calculations, lower, central and upper bound estimates is made where appropriate. In a summary statistics chapter, all technologies will then be compared directly with each other and the sensitivity to variations in important input factors analyzed.

3.11 Limitations

The methodology developed claims by no means to be exhaustive, given the many aspects that play a role in energy resource planning. Besides, parameters that underlie calculations and qualitative evaluations might be subject to controversy. One important example is the choice of an appropriate discount rate which reflects the diminishing value attributed to future cash flows. This choice is especially important when costs occur very far in the future. However, such ethical discussions are not included here, but it must be noted that different schools of thought have been expressed by economists such as Stern (2006), Weitzman (2010), and Nordhaus (2008). To account for possible differences in outcomes from the selection of discount rates, a sensitivity analysis with regard to this parameter is provided for in chapter 4.

Other issues that might limit the validity of the results are availability and quality of data in the Zambian case. Much of the data is provided through ZESCO and ERB, companies that are ultimately controlled by the government with possible biases towards certain technologies that seem most profitable imaginable. Over and above, some of the calculations that rely on previous studies might be subject to mistakes or impreciseness given that the data-transfer method is applicable and mistakes that occurred in previous studies are likely incorporated into this analysis. The same case applies to analysis of externalities of RES which are partially based on international data, down scaled to local circumstances. Thopil and Anastassios (2010) advocate that accurate analysis can only be performed ex-post, once RES are installed and operational.

Calculations of projections might be of limited reliability when these get based on historical events. Consequently, there is no guaranteed certainty that inferences about the future will hold true. In this analysis, such uncertainties concern the future energy demand, learning rates as well as job creation potential.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Research Findings

This chapter reviews applicable electricity generation technologies for Zambia according to the methods described in chapter 3. Research findings are presented, contrasted and discussed though out chapter 4. The results will be synthesized with regard to sensitivities from parameter variations.

4.1.1 Analysis of the Results Using the Hierarchy Tree Approach

After deciding the alternatives' scoring against each criterion and the criteria weights, their synthesis gives the overall score and ranking of the ten types of power plants. The results of the synthesis are presented in Figure 4.1 and Table 4.1.

The five types of renewable energy power plants are in the first five positions, mainly due to the high R/P weighting. The other eight end node criteria regulate the score and ranking among these five renewable energy power plants. Note that all five renewable energy power plants score between 15.34% and 12.33%; that is, there is only a 3% potential differential between the first and the fifth type of power plants.On the other hand, nuclear and fossil fuel-based power plants have considerably lower scores between 6.98% and 4.92%. Coal/lignite power plants are the best among fossil fuel-based plants with 6.59%, surpassing both natural gas and oil plants.

The analysis of the results can be carried out either by analysis of the end node criteria or by the power plant type. The first type of analysis presents how each criterion affects the overall score and ranking of power plants, while the second describes the criteria scores allocation for each power plant type.

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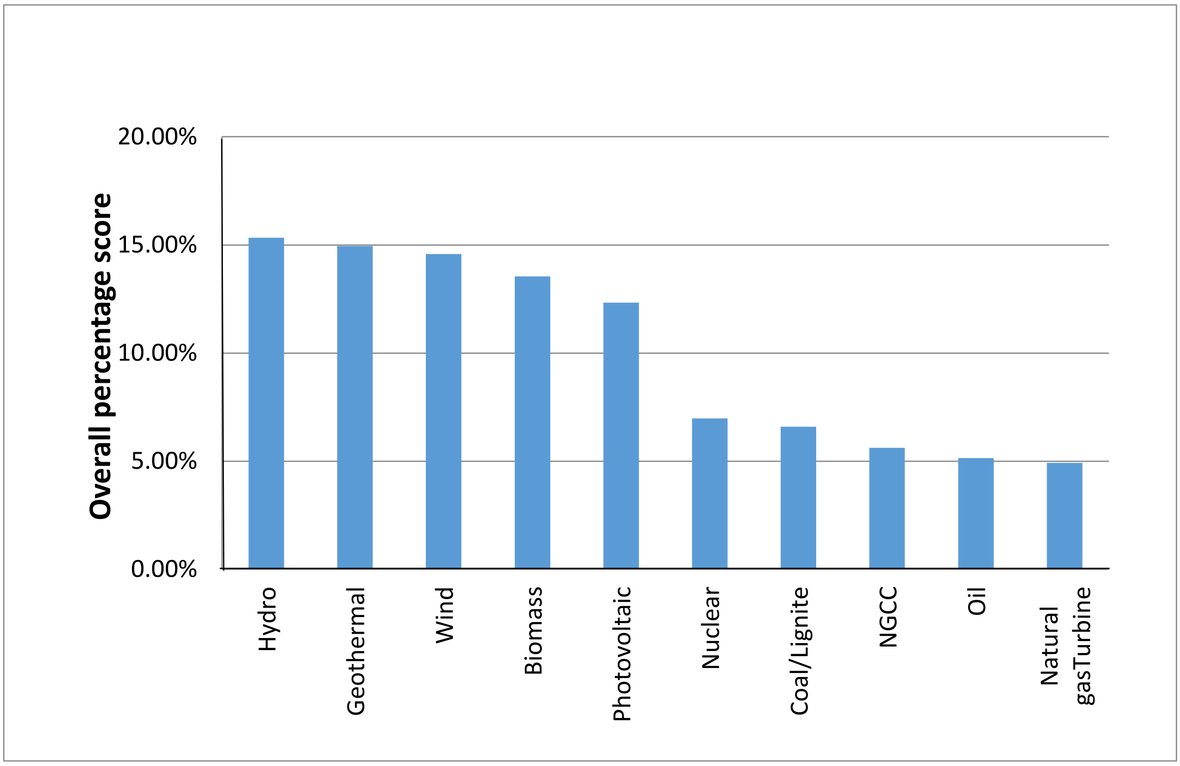


Figure. 4.1. Power plant evaluation based on technological, economic and sustainability criteria.

Table 4.1: Power plant performance per end node criterion.

	Hydro 15.34%	Geothermal 14.95%	Wind 14.58%	Biomass 13.55%	Photovoltaic 12.33%	Nuclear 6.98%	Coal 6.59%	NGCC 5.62%	Oil 5.14%	Natural gas turbine 4.92%
Efficiency coefficient	1.84	0.01	0.72	0.55	0.08	0.68	0.83	1.21	1.18	0.82
Availability	0.44	1.10	0.27	0.88	0.00	1.12	0.96	1.05	1.06	1.04
Capacity	0.15	0.76	0.18	0.62	0.07	0.86	0.63	0.25	0.11	0.00
R/P ratio	9.89	9.89	9.89	9.89	9.89	1.11	2.01	1.11	0.74	1.11
Capital costs	0.66	0.76	1.11	0.94	0.00	0.97	1.21	1.35	1.40	1.35
Fixed O&M costs	0.01	0.00	0.03	0.01	0.04	0.03	0.04	0.04	0.04	0.04
Variable O&M costs	0.13	0.19	0.14	0.11	0.01	0.19	0.17	0.16	0.16	0.16
Fuel costs	1.73	1.73	1.73	0.19	1.73	1.53	0.74	0.01	0.35	0.01
External costs	0.49	0.51	0.51	0.36	0.51	0.49	0.00	0.44	0.10	0.39

4.1.2 Analysis by Power Plant Type

The analysis by type of power plant present a different perspective of results emphasis in each criterion's contribution to a power plant's overall score. Table 4.2 presents power plant performance per end node criterion. This analysis describes advantages and disadvantages of each power plant. Presentation will be carried out according to the overall score and ranking of respective power plants.

Hydros are at the top of the overall ranking mainly because of their favourable performance as judged by the three different criteria. The most important critension is that of a renewable energy type scoring 9.89% at the ''reserves-to-production ratio'' criterion. It has the highest efficiency coefficient scoring 1.84% and zero fuel costs, which adds 1.73% to its overall performance. These three criteria contribute 13.46% out of the 15.34% of the hydro power plants overall score.

Geothermals have quite the same partial scores with hydros except for the efficiency and availabilities. Geothermals have 9.89% for the ‘‘reserves-to-production ratio’’ criterion, 1.73% for the fuel costs criterion and 1.10% for the availability criterion. Their capacities are also satisfactory. Their overall score is 14.95%.

Wind power plants are in the third position, mainly because they do not have strong performance in neither of the efficiency, availability nor capacity. They have lower capital costs than all renewable energy power plants with an overall score of 14.58%.

Biomass power plants have moderate performance for the efficiency, availability and capacity. Their overall score (13.55%) is lower mainly because of their fuel costs, especially when it is compared with the other four types of renewable energy power plants that have no fuel costs.

Photovoltaics are in the fifth position with 12.33%, mainly because they are renewable energy based plants with no fuel costs. They have zero performances for all the other criteria such as the efficiency, availability and capacity as well as the capital costs.

Nuclear power plants surpass all fossil fuel-based plants ranking in the sixth position with 6.98%. Their main advantages are the low fuel costs, the high availability and capacity and the relatively low external costs.

Coal/lignite is the best solution among fossil fuel-based power plants, mainly because of their high R/P ratio and low fuel costs. Their overall score is 6.59%. Their main disadvantage is their high external costs.

NGCC power plants have a high efficiency coefficient and rank in the eighth position with 5.62%. Oil power plants are in the ninth position with 5.14%, mainly due to their oil R/P ratio which is the lowest of all power plants. Natural gas turbine plants rank in the last 10th position with 4.92%, having the worst capacity among all plants.

4.1.3 Analysis by End Node Criteria

The analysis by end node criteria is carried out according to their weights. The end node criteria weights are presented in descending order in Figure. 4.2. Table 4.2. presents a detailed analysis of the performance of each power plant against each end node criterion.

The R/P ratio is by far the most important criterion as its weight is 55.53%. A high power plant performance for this criterion cannot be counterweighted by any of the other criteria. All five types of renewable energy power plants have a 9.89% percentage score for the ‘‘reserves-to-production ratio’’ criterion, which leads them to the first five positions. The other eight end node criteria determine the final ranking between the types of renewable energy power plant at the top five positions, and will be examined in detail later. Among fossil fuel power plants, coal/lignite has the better score with 2.01%. Natural gas-based plants and nuclear plants score 1.11%, while oil plants are in the last position with just 0.74%, as oil reserves are estimated to last for the next 40 years.

The second most important criterion is ‘‘capital costs’’ at 9.75%. The greater the capital costs the less the score for a power plant type. Photovoltaic appear to be the worst solution relative to capital costs, as they have no score for this criterion. All five types of renewable energy power plants have great capital costs and low scores for this criterion. Nuclear power plants also require huge investments. Fossil fuel power plants have the lowest requirements for capital investment, thus having scores between 1.21% and 1.40% for this criterion.

Fuel costs are of equal importance with capital costs with 9.75% weight. Except for biomass, all other types of renewable energy power plants have zero fuel costs leading to 1.73% scores. Uranium is also low-cost, hence nuclear power plant performs high according to the ‘‘fuel costs’’ criterion with 1.53%. Natural gas appears to be the most expensive fuel with 2.34 €cent/kWh. Therefore, power plants of this type have zero scores for this criterion.

Efficiency coefficient is the fourth most important criterion with a 7.92% weight. Hydros have the highest efficiency coefficient (80%) and a corresponding score of 1.84%. Among the five types of renewable energy power plants, this criterion is the one that lends hydro power plants on top of the ranking with an overall score of 15.34%. All other types of renewable energy power plants have low efficiency coefficients. NGCC plants have satisfactory efficiency coefficient of 54.8% and corresponding score of 1.21%.

Fossil fuel, nuclear, biomass and geothermal power plants have high availability and, therefore, high scores for this criterion which is of equal importance (7.92%) with the efficiency coefficient. Photovoltaic, wind and hydros have the worst availability as their operation depends on weather conditions which are unstable.

External costs are the sixth most important criterion with 3.80% weight. Fossil fuel and biomass power plants which incorporate combustion processes in their operation release harmful emissions and thus have high external costs. Their scores are conversely proportional to their external costs. Coal/lignite is the worst of all while natural gas-based plants perform better among the five types of power plants that require combustion. On the other hand, nuclear and the four types of renewable energy power plants that do not use combustion processes have better scores for this criterion.

Nuclear, geothermal, coal/lignite and biomass power plants have high capacities ranging between 70% and 90.5%. Although different in their characteristics, these four types provide high percentages of the electricity they can actually produce. Capacity weight is 3.63%. Therefore, their scores for this criterion range between 0.62% and 0.86%.

Variable O&M costs have a low weight factor of 1.42%. The lowest score for this criterion is 0.01 for photovoltaic and the highest is 0.19 for nuclear and geothermal power plants.

Finally fixed O&M costs have a very low weight factor of 0.28%. Although the fixed O&M costs range between 16.67 and 83.33€/kWyr, the scores of the power plants for this criterion range between 0% and 0.04% as a result of the very low weight factor.

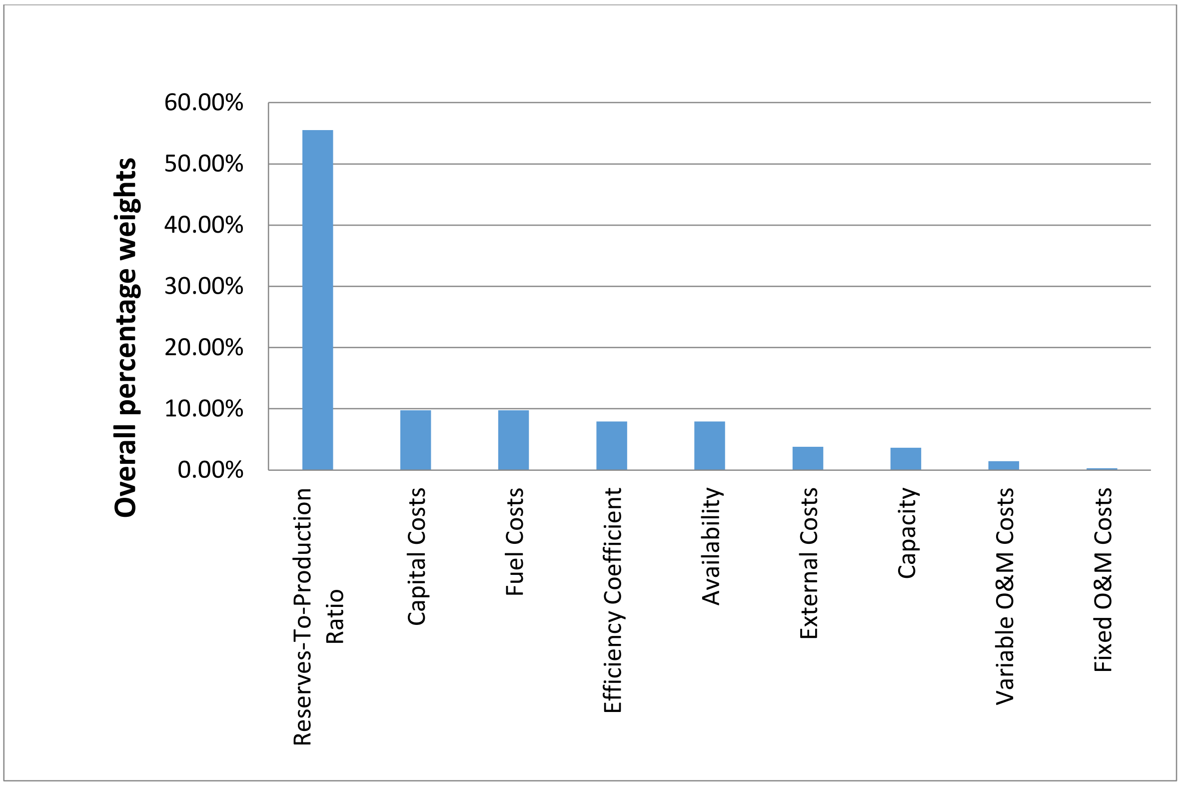


Figure 4.2. Global percentage weights of the end node criteria of the hierarchy tree.

Table 4.2: End node criteria contribution to each power plant.

	R/P 55.53%	**Capital costs 9.75%**	**Fuel costs 9.75%**	**Efficiency coefficient 7.92%**	**Availability 7.92%**	**External costs 3.80%**	**Capacity 3.63%**	**Variable O&M costs 1.42%**	**Fixed O&M costs 0.28%**
Coal/lignite	2.01	1.21	0.74	0.83	0.96	0.00	0.63	0.17	0.04
Oil	0.74	1.40	0.35	1.18	1.06	0.10	0.11	0.16	0.04
Natural gas turbine	1.11	1.35	0.01	0.82	1.04	0.39	0.00	0.16	0.04
NGCC	1.11	1.35	0.01	1.21	1.05	0.44	0.25	0.16	0.04
Nuclear	1.11	0.97	1.53	0.68	1.12	0.49	0.86	0.19	0.03
Hydro	9.89	0.66	1.73	1.84	0.44	0.49	0.15	0.13	0.01
Wind	9.89	1.11	1.73	0.72	0.27	0.51	0.18	0.14	0.03
Photovoltaic	9.89	0.00	1.73	0.08	0.00	0.51	0.07	0.01	0.04
Biomass	9.89	0.94	0.19	0.55	0.88	0.36	0.62	0.11	0.01
Geothermal	9.89	0.76	1.73	0.01	1.10	0.51	0.76	0.19	0.00

4.2 Analysis using the Levelised Cost of Electricity Approach

4.2.1 Coal

Coal is the predominant fossil fuel energy source for electricity generation in Zambia and is thus the technology that serves as a benchmark in economic evaluation of other technologies. Coal/lignite is the best solution among fossil fuel-based power plants, mainly because of their high R/P ratio and low fuel costs. Unlike other fossil fuel based technologies, coal based power plants are not capital intensive during commissioning, but very sensitive to fuel costs and their future development. Coal's main disadvantage is high external costs. Creamer (2013c) expect the future purchasing price for a metric ton (t) of coal to increase substantially for Southern Africa. Thus, it is expected here that the coal price will converge with the international export price in the long-run. Projections for future prices are based on historical coal export prices and on extrapolations of their 1logarithmic, linear and exponential regressions, as depicted in Figure 4.3.

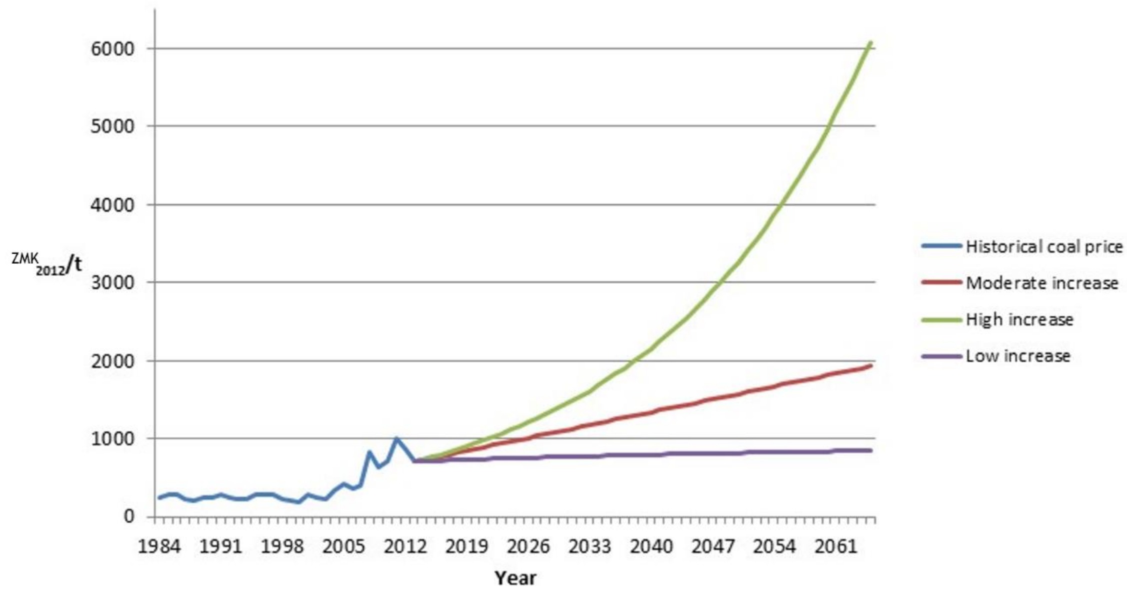


Figure 4.3: Price projections for Southern Africa sub-bituminous coal export prices *Source:* Projection based on historical coal price (Index Mundi, 2013).

Taking these as a basis, coal purchase price is then expected to increase from 349 ZMW/t in 2015 to either 848 in 1930 and 6080 ZMW/t in 2065 depending on the scenario. The corresponding price escalation rates from 2015 to 2065 are calculated based on the geometric growth formula. All other relevant parameters underlying the LCOE calculation are presented in Appendix C. When the formulas described in the previous chapter are applied, LCOE for this coal power plant range between 614.49 and 973.13 ZMW/MWh with 712.97 ZMW/MWh being the median scenario.

If externalities are added to an economic evaluation of coal power, the cost of electricity from that source is subject to an enormous increase. A study from Blignaut et al. (2011) reports external costs between 0.97 and 1.88 ZMW/KWh. Inflated to ZMW_{2016} values and converted to the unit of analysis (ZMW/MWh) costs translate to 1111.38, 1635.53 and 2159.67 ZMW/MWh respectively. These indirect costs are higher than direct costs associated with this technology and include externalities from health impacts, GHG emissions, water use and coal mining. All numbers are based on conservative assumptions, taking for example a global carbon cost of 12.78 and 20.67 USD_{2010}/tCO2-eq. as basis. The greatest portion comes from opportunity costs of water consumption which account for almost 70% of total external costs. All underlying parameters are presented in Appendix 3.

In terms of job creation potential, a new super-critical coal power plant requires on average 3.1 jobs per MW of installed capacity (Edkins et al., 2010b; Van Wyk et al., 2011). About 80% of the jobs are involved in the construction and the manufacturing of the power plant, while only one fifth is attributed to O&M of a coal power plant.

A super-critical coal power plant provides base load power, has a typical capacity factor of 85% and a hot ramp-up time of about one hour. This means that this technology provides a relatively stable amount of electricity output which can be used to satisfy a constant level of market demand. At the same time, coal power plants are impractical to cover demand peaks given their low degree of flexibility. An energy system that is based on a high share of coal, must use an international market to balance system load in times of under- or oversupply. In the long-run, more flexible or intermittent energy sources are very necessary to connect to the grid.

In terms of energy security, coal power plants perform as follows. In 2015, proven reserves amounted to 173 million tonnes, while production/usage in that year was 4.86t/day. Thus, the reserves-to production ratio is about 100 years. Social marginal costs range, according to this analysis, between 1726 and 3133 ZMW/MWh at a discount rate of 5%. The total efficiency of a coal power plant from coal input to electricity output is around 40% and the plant needs to produce energy for about 7 years to offset the energy used during its construction. Super-critical coal power plant need a construction lead time of 10 years, which is very long. The results are depicted in Table 4.3:

Table 4.3: Overview energy security indicators for super-critical coal power plant

Dimension	Indicator	Metric	Values	Source
Availability	Proven recoverable energy reserves	Reserves-to-production ratio	100	(www.cea.nic.in 2010)
Affordability	Social marginal cost of electricity generation	ZMW/MWh	1725.87 – 3132.80	calculated
Efficiency	Energy end-use efficiency	η, ratio energy input to output	0.4	(EURELECTRIC, 2003)
Technology Development	Lead time for construction of power plant	Number of years	10	(Eskom, 2013e)
Sustainability	Energy payback ratio	Life-time energy output to input	7	(Gagnon, 2005)

4.2.2 Nuclear

Zambia is among countries that have signed partnerships with the Russian government to find solutions to power deficit challenges at Atom-Expo 2016 forum in Moscow. The partnerships include joint development of atomic energy infrastructure, design and construction of power and research nuclear reactors, as well as the exploration and production of uranium deposits. According to a statement obtained by the Daily Mail from Sputnik News, Russian nuclear energy corporation Rosatom chief executive officer Sergey Kirienko said the firm signed economic potential contracts worth US$10 billion during the expo that was held from May 30 to June 1, 2016 in Moscow. Thus, Zambia should anticipate a nuclear new-build capacity.

A nuclear plant is a thermal power station that generates heat used to generate steam to drive a turbine connected to an electric generator which produces electricity. LCOE are calculated for such a power plant design. Parameters are drawn from the IRP (DoE, 2010) and from the ERC (2013) study which provides updated assumptions on capital costs. This data is complemented with estimates from Stott (2012, in Kotzé, 2012) about uranium fuel costs. Further assumptions had to be made with regard to the escalation rates for O&M costs and fuel costs. Bruynooghe et al. (2010) estimate that O&M costs will increase and a value of 0.5% above the inflation rate is assumed here.

It is also estimated that fuel prices will be subject to increase in the future, given that the IAEA (2001) forecasted a long-term scarceness and increasing exploration costs for natural uranium. Zambia has natural uranium and can also purchases nuclear fuels from South Africa, Namibia and other African countries, as well as enriched uranium from suppliers in Europe and Russia (Kotzé, 2012). Consequently, it can be concluded that some level of dependency to international market prices exists and that prices will increase by 1% per year. The data on fuel cost calculations are not transparent in the IRP, especially with regard to the enrichment process, and calculated fuel costs would result in unrealistically low values. That is why the number assumed for fuel cost will be drawn from Stott (2012 in Kotzé, 2012), who has estimated fuel cost for nuclear power plants at 40% of those from coal power plants. All data underlying the LCOE calculation are shown in Appendix D. LCOE of 658.45 ZMW/MWh result from these calculations.

Rabl and Rabl (2013) estimated the externalities of nuclear power in a post-Fukushima study. Taking into account both external costs from normal operation, which include current operation and waste management, and external costs from accidents, they obtain total external costs between 0.25 and 3.22 Eurocents/KWh, with a central estimate of 0.79 Eurocents/KWh. Adjusted to the Zambian context with the formula suggested by Nahman (2011), external costs translate to 8.02, 25.33 and 103.26 ZMW/MWh.

In addition, external costs which include the risk of an accident have been assessed in a study by Meyer (2012). She reported a range of risk-adjusted external costs between 10.7 and 34 Eurocents/KWh as realistic, averaging at 22.35 Eurocents/KWh. Adjusted to the Zambian context with Nahman's formula, these numbers translate into 300.96, 628.65 and 956.33 ZMW/MWh. It must be noted that Meyer's estimates vary by an order of magnitude of 9-36 from Rabl and Rabl's, but these two studies are the only recent studies identified that quantify risks and costs of nuclear accidents. When taking the precautionary principle as the underlying normative framework to evaluate a technology, it is compelling to contemplate all possible events and to consequently use the entire bandwidth of estimates as scenarios. Although nuclear power is also a very water-intensive technology which requires high amounts of water for thermal cooling, no water use externalities are included in the Zambian context. This is because Zambia has good rivers systems. We can adopt the once-through cooling systems which are based on river-water cooling where the water is released back to the river after usage without consuming any fresh-water. Thus, no opportunity costs of fresh water are included in the analysis for nuclear.

In terms of job creation, a new nuclear program could be beneficial for the Zambian economy. Edkins et al. (2010b) have estimated job creation potential of 2.5 jobs/MW for the nuclear industry in Southern Africa. However, Sokolov (2013, in Campbell, 2013) alludes that the establishment of an effective nuclear industry sector depends on how well legal, regulatory, technical, human, industrial, safety and security aspects are developed.

Similar to a coal power plant, nuclear power serves the base load fraction in an electricity system (Rabl and Rabl, 2013). In fact, nuclear power plants produce the most stable load output, but are also the most inflexible option of electricity generation. The main argument that is brought forward in favor of expanding the Zambia nuclear program is that nuclear is a cost-effective and CO_2-neutral option of diversifying the country's electricity supply, even more important in times when coal prices are subject to increase in a carbon constrained world. It is thus seen by many as the preferable option to increase security of supply. The associated performance parameters are depicted in Table 4.4.

Table 4.4: Overview energy security indicators for nuclear power plants in Zambia.

Dimension	Indicator	Metric	Values	Source
Availability	Proven recoverable energy reserves	Reserves-to-production ratio	>100	(NEA/IAEA, 2012)
Affordability	Social marginal cost of electricity generation	ZMW/MWh	666.47 – 1614.78	calculated
Efficiency	Energy end-use efficiency	η, ratio energy input to output	37 %	(WNA, 2013)
Technology Development	Lead time for construction of power plant	Number of years	16	(DoE, 2010)
Sustainability	Energy payback ratio	Life-time energy output to input	14 - 16	(Gagnon, 2005)

4.2.3 Natural gas

Today in 2017, natural gas is still virtually non-present as a fuel in Zambia's ESI, but it is an important option if unconventional gas is recovered in future. Instead, imported diesel fuel is used to fire nine ZESCO diesel power plants with open-cycle gas turbine technology (OCGT), which have a combined capacity of 11.9 MW. These flexible power stations are built to supply electricity during peak demand hours, system stabilization and for power supply to remote areas. If new supplies of domestic natural gas were available on a larger scale, these nine OCGT power plants could easily be upgraded into more efficient combined-cycle gas turbine power plants (CCGT) running on natural gas. Moreover, it is also possible to retrofit aging coal-fired power stations into gas power stations at economic benefits, which has been disclosed by Silverstein (2013) who claimed that a switch to gas is beneficial for climate and job creation. This has been demonstrated in the US and other countries, where shale gas supplies become increasingly important. Consequently, it is worthwhile to have a closer look at CCGT power plants as a flexible option to cover peak demand, intermediate demand as well as base load in Zambia. Subsequently, three alternative capacity factors of f = 5%, 50% and 85% will be taken as basis for an analysis of the CCGT option.

The outcome of LCOE analysis based on the parameters described in Appendix E adds up to lowest LCOE of 640.54 ZMW/MWh for a gas power plant producing base load at f = 85% to 698.25 ZMW/MWh for a CCGT plant delivering intermediate load at f = 50% and finally to LCOE of 1959.61 ZMW/MWh for peak electricity output, when the plant is only used at a capacity factor of 5%. This considerable variance in LCOE shows that the cost for electricity from a gas power plant is fuel intensive and thus fluctuates with the plant utilization (*f*).

External costs from CCGT power plants are estimated at a range of 1326.75, 1589.42 and 1840.43 ZMW/MWh. However, it must be admitted that the given external cost analysis for shale gas combustion is by no means complete, given the novelty of the technology and the resulting lack of empirical data and contributions to the scientific research body. This concerns, inter alia, estimations on external costs resulting from a diminishing value of land property close to gas wells, as Muehlenbachs et al. (2012) allude. In addition, it is a difficult task to quantify the harm to society from large amounts of fresh water necessary and from groundwater contamination which occurs during fracturing processes. While statistics on life-cycle fresh water consumption for shale gas-powered CCGT power plants have been published by Laurenzi and Jersey (2013), these have to be read with caution as they are financed by ExxonMobil Research and might be biased in favor of gas businesses. A too optimistic description of the benefits from this unconventional resource may be a result. Barth (2013), as well as Kinnaman (2011), elaborate on this deficiency more in detail. Consequently, opportunity costs of water consumption had to be estimated. To do so, the same methodology and alternative technologies as used by Blignaut et al. (2011) were applied and opportunity costs of 1.14 ZMW/KWh to solar and 1.49 ZMW/KWh to coal were detected. This seems more reasonable, given the fact that shale gas extraction is more water intense than coal mining. Resulting median full cost estimates from shale gas-powered CCGT are then 2229.96, 2278.67 and 3549.03 ZMW/MWh, depending on underlying capacity factors.

According to The Economist (2012), businesses and proponents of the gas industry generally describe job creation potential from their activities as substantial. However, it is at least questionable by how much the local rural population could directly benefit from a developing gas industry. This is also dependent on policies to be developed. Should CCGT power stations be built, Edkins et al. (2010b) and Van Wyk et al. (2011) estimate an average of 2.39 jobs per MW of installed capacity.

As described earlier, the advantage with a CCGT power plant is that it can dispatch its output of electricity in a flexible way, being the most flexible of all fossil generation options. As a result, it offers a maximum availability factor. Within 5-7 minutes, capacity can be ramped-up and the power output can be adjusted to demand (Eskom, 2009b). If gas supplies should once be secured from domestic extraction of unconventional shale gas and power stations be deployed on a larger scale, both availability and energy security will benefit from it, as shown in Table 4.5.

Table 4.5: Overview energy security indicators for gas power plants in Zambia.

Dimension	Indicator	Metric	Values	Source
Availability	Proven recoverable energy reserves	Total resource endowment	Explorations ongoing	
Affordability	Social marginal cost of electricity generation	ZMW/MWh	1967.29 – 3800.04	calculated
Efficiency	Energy end-use efficiency	η, ratio energy input to output	50%	(Godoy et al., 2010)
Technology Development	Lead time for construction of power plant	Number of years	3	(Lazard, 2012)
Sustainability	Energy payback ratio	Life-time energy output to input	2.5 – 5	(Gagnon, 2005)

4.2.4 Concentrating Solar Power

CSP is an important option to generate electricity and heat in countries with good solar irradiance. Thus, this form of electricity generation is very interesting for Zambia. Different technologies have evolved to capture sun energy, but all have in common that the solar irradiation is concentrated on a central location to heat a medium. When the heat is extracted, a conventional steam turbine can be powered from this (Coley, 2008). Many plant designs exist, which makes it difficult to compare them in terms of LCOE. In this study, a power plant using solar tower technology with 3 hour storage capacity has been selected as the reference technology. Ernst&Young and Enolcon (2013) estimate local employment potential to be the highest for this kind of technology. When considering input parameters as summarized in Appendix F, CSP in Zambia induces LCOE of 1308.66 ZMW/MWh. Like other RES, it is a capital intensive technology, but has the advantage of zero fuel costs and moderate O&M costs. In the literature, some variation concerning capital costs has been identified, therefore a conservative value of 59860 ZMW/MW has been chosen.

Externalities of the solar tower technology are very moderate and include health impacts and GHG emissions. For different scenarios of global damage costs from GHG emissions, total external costs amount to 11.26, 15.80 and 18.78 ZMW/MWh. So, full costs for CSP come down to a range between 1319.92, 1324.46 and 1327.44 ZMW/MWh. The heat carrier medium of CSP power tower technology can be based on molten salt and consequently, such power plants are not dependent on fresh water consumption.

CSP can offer substantial potential for job creation in Zambia. In Spain, local value creation increased from an initial 50% to 80% in the present, increasing the number of jobs in the country. Based on studies from Edkins et al. (2010b), Maia et al. (2011) and from the International Labour Office (Van Wyk et al., 2011), an average JCP of 17.6 jobs/MW is projected from construction and operation of a CSP plant in Zambia.

With regards to availability of electricity, CSP offers a possibility to disassemble the collection of sun-energy (heat) and the production of electricity by means of thermal storage. Consequently, the degree of intermittency of that technology is reduced. Today, it is possible to build plants that are able to store heated liquids for up to 15 hours for electricity production. Therefore, the range of CSP plants can be extended from late morning hours through most of the night, which makes it suitable to serve intermediate and peak load during these hours. Through the means of storage, output becomes highly dispatchable. Nicholson et al. (2011) categorized CSP even as a base load technology. Improving the availability of an intermittent source is also a result of a stochastic analysis of the variability of weather patterns. Energy security patterns of CSP are illustrated in Table 4.5.

Table 4.5: Overview energy security indicators for CSP plants in Zambia.

Dimension	Indicator	Metric	Values	Source
Availability	Proven recoverable energy reserves	Total renewable energy resource endowment	Exploration going on	
Affordability	Social marginal cost of electricity generation	ZMW/MWh	1319.92 – 1327.44	calculated
Efficiency	Energy end-use efficiency	η, ratio energy input to output	40 %	(Lazard, 2012)
Technology Development	Lead time for construction of power plant	Number of years	2	(Lazard, 2012)
Sustainability	Energy payback ratio	Life-time energy output to input	80	(Jacobson, 2009)

4.2.5 Solar Photovoltaic

Solar PV is another technology option to harness sun energy in Zambia. Yet, an analysis of this technology can quickly become complex: various types of solar panels have evolved until today and there is still no “gold standard” for a dominant technology between silicon-based and thin-film applications. Another argument is that solar PV can be employed on different scales, ranging from residential to utility-scale applications which can either be grid connected or isolated. Moreover, the electricity output from solar panels depends on local solar irradiation levels as well as on tilt angles in which the panels are positioned. All in all, there are many different possible combinations of parameters and consequently, Darling et al. (2011) argue that parameter distributions must be used to estimate the LCOE of this technology in a realistic way. However, this is not feasible within the scope of this research, and thus one exemplary technology in combination with typical parameters must be chosen. As most interesting options to look at, a rural utility scale PV power plant (RUS) with 10 MW capacity and a residential roof-top application (RRT) with 1 KW capacity, both located in an identical geographical location and composed of polycrystalline silicon PV panels selected as the reference projects for analysis. This makes sense as bulk energy generation options are compared throughout this analysis. Besides, both CSP and PV can be compared on a common basis if their output is measured under identical geographical conditions. Finally, it makes economically sense to install solar power plants in the most favourable places first, as earlier indicated.

All other technical parameters related to the analysis have been taken from most recent literature available and are specified in Appendix G. For such exemplary applications, LCOE range between 939.90 ZMW/MWh for RUS and 1456.28 ZMW/MWh for RRT.

During the lifecycle of a PV power plant, quantifiable externalities stem from GHG emissions and health issues during the production process of plant components. Given low GHG emission factors which range between 23 – 44 kg CO_2-eq./MWh (Peng et al., 2013) and moderate health effects of 2.32 ZMW/MWh (Edkins et al., 2010c) external costs remain low compared to other generation options. Consequently, external costs of a PV power plant in Zambia range between 2.47, 6.55 and 11.33 ZMW/MWh dependent on assumptions on GHG abatement costs.

A development of the PV sector could become a job motor in Zambia, especially additional manufacturing facilities for solar panels will be opened up. All three studies on job market potential in Southern Africa’s ESI attribute a high job creation potential to new PV power plants. On average, Edkins et al. (2010b), Van Wyk et al. (2011) and Maia et al. (2011) report a number of 30.1 jobs/MW of installed PV capacity. Maia et al. thus conclude that PV is among the top generators of new direct employment from RES.

Contrarily to CSP there are not yet any reliable large-scale storage concepts for PV generated electricity and this energy source is thus still dependent on weather conditions. Although commercial advances in storage technology are likely to be introduced soon, it is more realistic to estimate that a utility-scale PV power plant will feed its production directly into the grid in Zambia. Still, this has advantages: daily output patterns of PV can be very favorable for the load management of an electricity system. As PV electricity is generated during day-time with output peaking around noon, PV power plants can reduce the burden on the electricity system, which has then a reduced residual peak demand. This functionality has proven successful in Brazil and was described by Rüther et al. (2008). It is outlined in Figure 4.3.

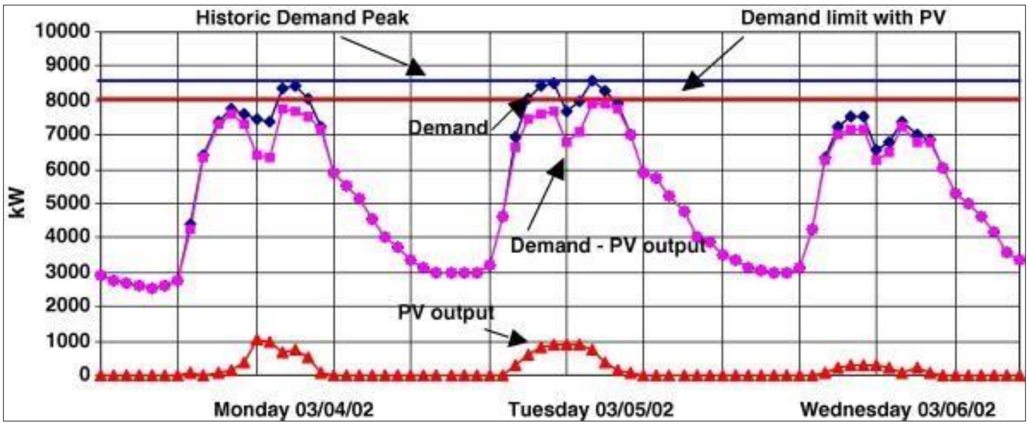


Figure 4.3: Effect of PV feed-in on peak electricity demand. Source: Rüther et al., 2008)

Even though solar PV is an intermittent source of energy, its economic value might be significant as marginal costs during peak demand hours could be lower than that of other peak generation options. Furthermore, deployment of PV on a larger scale in Zambia might be a substitute to demand reduction programs which are generally more difficult to handle for utilities and customers. This way, PV is a source of energy that scores well in many dimensions of energy security, which are listed in Table 4.7.

Table 4.7: Overview energy security indicators for PV in Zambia.

Dimension	Indicator	Metric	Values	Source
Availability	Proven recoverable energy reserves	Total renewable energy resource endowment	Exploration going on	
Affordability	Social marginal cost of electricity generation	ZMW/MWh	942.37 – 1467.61	calculated
Efficiency	Energy end-use efficiency	η, ratio energy input to output	12%	calculated
Technology Development	Lead time for construction of power plant	Number of years	2	(Lazard, 2012)
Sustainability	Energy payback ratio	Life-time energy output to input	5.7 – 26.7	(Peng et al., 2013)

4.2.6 Renewable Energy Sources Emphasised

In addition to the energy sources analyzed thoroughly in the previous chapters, there are other RES which have the potential to play a role in Zambia's future ESI. These energy sources include hydro power, geothermal, wind and different forms of biomass. For reasons of completeness, the main issues with these sources will be discussed briefly here.

Zambia has an abundance of hydro resources with an estimated 6 000MW potential capacity. It is not surprising then that installed generating capacity is almost entirely based on hydropower. Zambia's dependence on hydropower puts the country at risk in the event of drought. Hydro power is at the top of the overall ranking energy sources mainly because it is a renewable energy type with high reserves-to-production ratio, high efficiency coefficient and zero fuel costs.

Mini / Micro Hydro power is another most important potential technology that could deliver electricity in Zambia. Zambia has a number of potential sites on smaller rivers suitable for local small-scale power generation especially in the Northern and the North-Western parts of the country because of their topography, the geology of the ground, and the highest rainfall in the country.

Biomass is already an important source of energy in Zambia and it could become more important for the electricity sector. Unlike other RES, biomass power plants or co-firing in compatible coal-fired power plants would have the advantage of high load factors and lower carbon intensity. Biomass is thus one of the few RES suitable for base load generation. An additional benefit with biomass is that its collection is very labour intensive and thus beneficial for job creation.

Geothermal Energy is another potential technology that could deliver electricity in Zambia. Zambia has more than 80 hot springs. The Zambian hot springs associated with zones of major deep seated fault and fracture systems along which water of mainly meteoric origin circulate to great depths and is heated through normal geothermal gradients. These springs have not been tapped for industrial or energy provision purposes owing in large part to the cost.

Last but not least, wind energy in Zambia is relatively low. Wind data collected at 10 meters per second (m/s) above the ground indicate speeds of between 0.1 to 3.5 meters per second with an annual average of 2.5 m/s. These wind speeds are not particularly suitable for electricity generation, but are well suited for water pumping for household use and irrigation purposes. There are specific areas where wind regimes are said to be as high as 6 m/s in the Western Province for Zambia. The Department of Energy has plans to develop a wind atlas to identify areas where electricity can be generated from wind.

The economic value of a wind power station depends on a multitude of factors. Most important for the performance of a wind turbine are location and the prevailing average wind speed patterns that determine how much energy the power plant can capture. Other important factors are the choice of optimal parameters of the power plant, which include rated turbine capacity, hub height, rotor diameter, cut-in and cut-out wind speeds and other factors that influence operation and maintenance requirements for the plant. One main advantage of wind power is the low level of external effects associated with this technology. Despite all advantages, wind energy has the draw-back of being an intermittent and non dispatchable source of energy. Consequently, an energy system cannot only rely on wind energy, as the wind might just not blow at a given point of time.

4.3 Discussion of Results Using LCOE Approach

4.3.1 Summary Statistics

Throughout chapter 5.2, comprehensive impact analyses of all technologies have been carried out and were presented individually. The results obtained are now contrasted and discussed in this chapter.

The first direct comparison of technologies is made at the LCOE level: while the LCOE for coal power are indicated as a range of possible costs with a lower and upper bound, median LCOE were reported for all other technologies. This was owed to the uncertainty with the future development of the coal price in Zambia. Other fuel intensive technologies compared are nuclear and natural gas. The mechanisms of fuel pricing in the nuclear industry were found to be very intransparent. The price of natural gas was estimated to remain constant over the 30-year life-time horizon of a CCGT plant. In contrast, costs are more firm to foresee for the capital cost-intensive technologies and so median LCOE are a reasonable estimate to make with CSP and PV. This is why all LCOE figures other than coal are expressed as median cost estimates. Figure 4.6 contrasts the results from the analysis, grouped according to generation options.

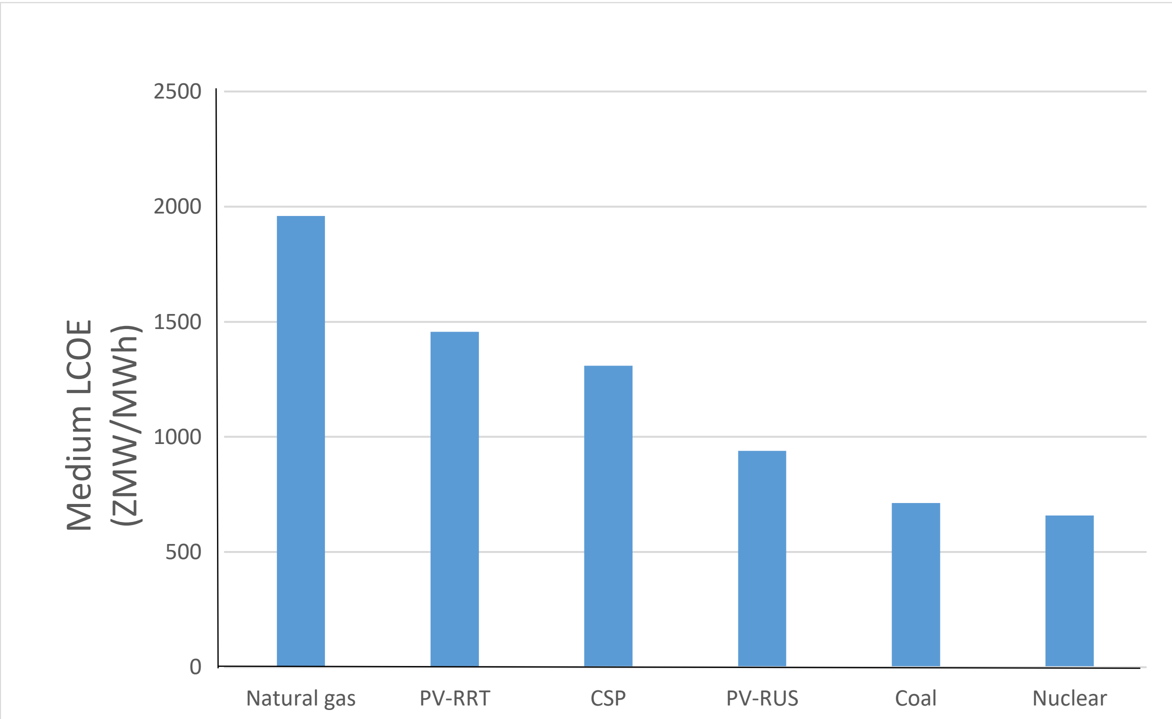


Figure 4.6: Summary median LCOE of all technology options

From figure 4.6, it can be inferred that median LCOE for nuclear and coal technologies are comparably low and almost balanced. Coal is an outlier in the sense that there is the possibility of being slightly cheaper or considerably more expensive than nuclear. The highest LCOE of all technologies is caused by the low capacity factor of the option with a resulting high share of fixed costs attributed to each unit of electricity generated. Unfortunately, natural gas is a dispatchable back-up power at present. PV RUS is cost-competitive with CSP. On the other hand, PV RRT is due to many small scale implementations the second most expensive option, but it is still considerably cheaper than natural gas.

In a second step, indirect costs of all technologies were evaluated. The results from lower, upper and median case scenarios are visualized in Figure 4.7.

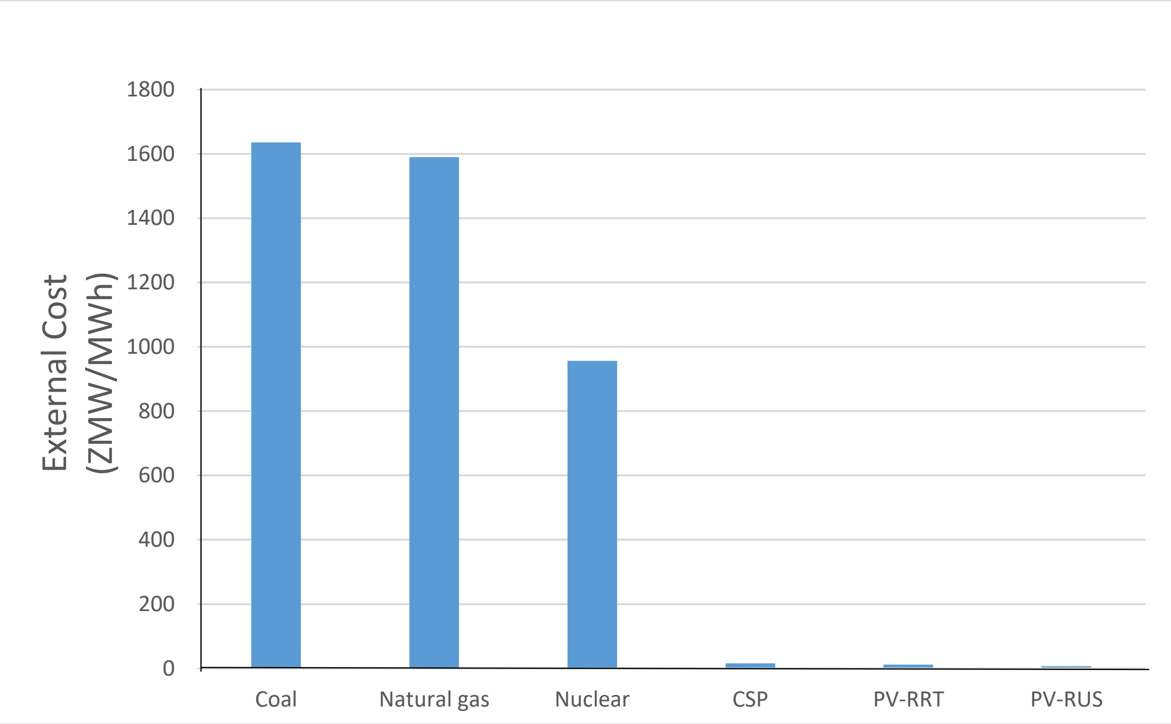


Figure 4.7: Summary external costs of all technology options

The figure shows that burning coal causes the highest externalities if median externalities estimates are compared. Yet, coal could still be topped by natural gas in the lower bound scenario, when low GHG damage costs and opportunity costs for water intaking are assumed in the externalities evaluation. In either case, both technologies impose far higher levels of external costs to the society at large than all other technologies. Next, nuclear power is a special case in terms of risk assessment and indirect costs. The large error bar in relation to other technologies is a clear sign for the difficulty to reasonably evaluate the risk of this technology. For example, Rabl and Rabl (2013) report probabilities of major accidents, which are only based on two past events in Chernobyl and Fukushima. Whether this approach allows for inferences about the frequency of future accidents can at least be doubted. In addition, their study fails to consider several other factors that might also influence the probability of accidents. These include increasing frequency of natural disasters from climate change, increasing average age of the power plant fleet and an increasing total number of plants. Also, it seems early to objectively evaluate health damages from the Fukushima accident, and Gluzman et al. (2012) point out that there even remains controversy about the number of thyroid cancers resulting from Chernobyl. All these factors bias the results and make an objective evaluation of nuclear power difficult. The last observation from Figure 4.7 is that PV-RUS, PV-RRT and CSP entail considerably lower external costs to society than all other technologies.

The logical next step is now to consolidate direct and indirect costs of the technologies to have a say about their overall economic impact and competitiveness. The outcome of this process is expressed by Figure 4.8

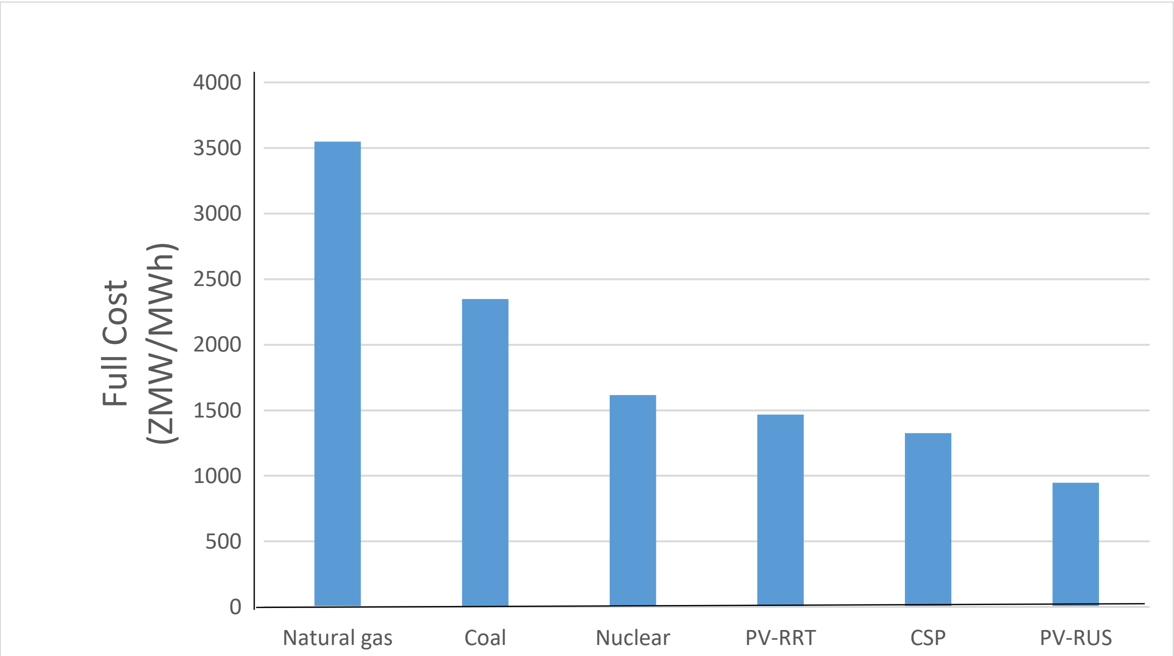


Figure 4.8: Summary full costs of all technology options

It can be noted quickly, that an accommodation of indirect costs has effects on the ranking order. In the new picture, coal becomes the second most expensive technology option in terms of median full costs, only surpassed by natural gas. Due to its large error bar, coal can either be the most expensive option or be almost competitive with high-cost nuclear. Still, median full cost of nuclear are lower than that of coal and natural gas, if one accepts the risk-evaluation from the studies cited.

PV-RUS, CSP and PV-RRT has now become substantially cheaper than nuclear. Renewable energy options are not very reactive to variations in indirect costs, a fact that improves the level of certainty of the outcome. Last but not least, intermittent technologies have become competitive with most technologies.

From a full-cost perspective in the context of Zambia, these RES gain an economic advantage over fossil-based generation technologies.

The next dimension of analysis is employment impacts for the economy from investments into new power plants. Figure 4.9 contrasts estimates for permanent job creation potential of different technology options in the value chain of the Zambian Energy industry.

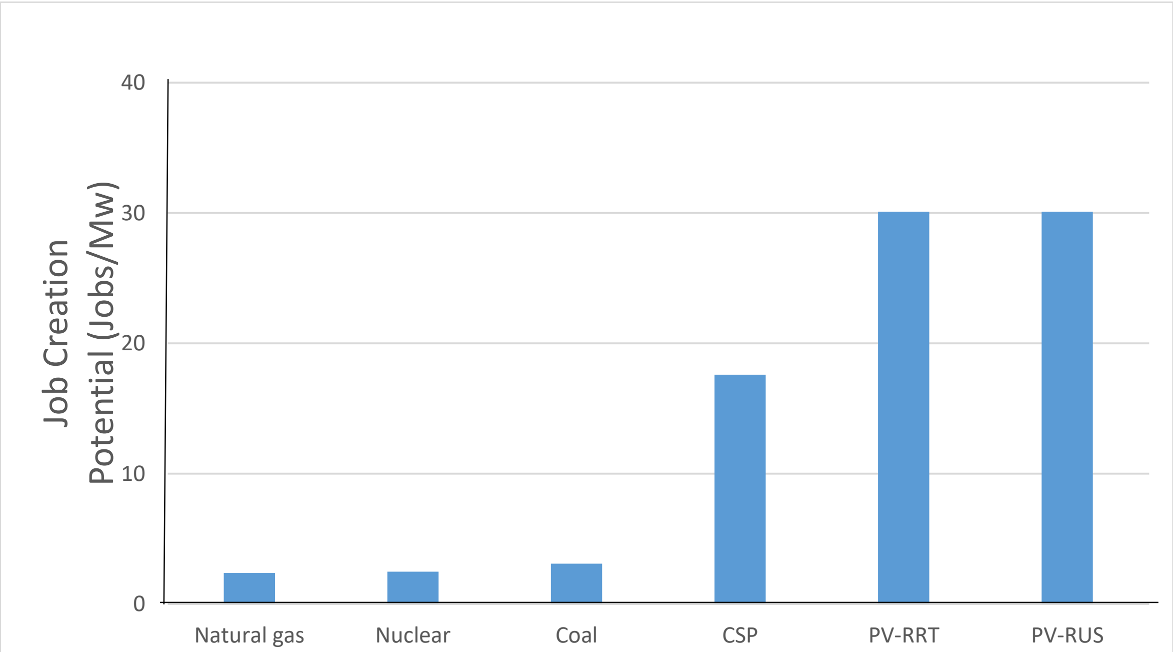


Figure 4.9: Summary job creation potential of all technology options

The graph highlights that fossil-based energy sources are more employment-efficient in terms of jobs/MW and contribute to fewer new jobs in the economy if chosen for energy investments. However, this does not express anything about the options to be preferred from a project developers' or policy makers' cost-benefit point of view, and employment creation itself is a political topic with the question of interchangeability of capital and labour at its heart. Assuming however, that employment creation for domestic jobs is a result from transfer of technology and from a localization of segments of the energy industry value chain, then new "green industries" are often praised as a preferable political goal for the government of an emerging economy. In the case of Zambia, PV, CSP and hydro are then technologies with higher value in terms of new job creation.

4.3.2 Sensitivities of Results

As mentioned previously, results of cost analyses are always sensitive to the various input parameters chosen. More specifically, full costs depend on assumptions made for LCOE and for externalities valuation. LCOE can be sensitive to variations in capital costs, O&M costs or fuel prices. When all these parameters are kept constant, results can still be sensitive to the discount rate chosen for analysis. At the other hand, external cost estimates are mainly sensitive to assumptions on a global carbon price and to opportunity costs for water consumption. While a price on carbon emissions was mentioned by Nicholson et al. (2011) as the main factor influencing externalities and consequently has been included into the analysis ex-ante with CO_2 damage costs varying between 6.71 and 204.76 ZMW/tCO_2eq.

The comprehensive statistical results of different technologies are shown in Figure 4.10.

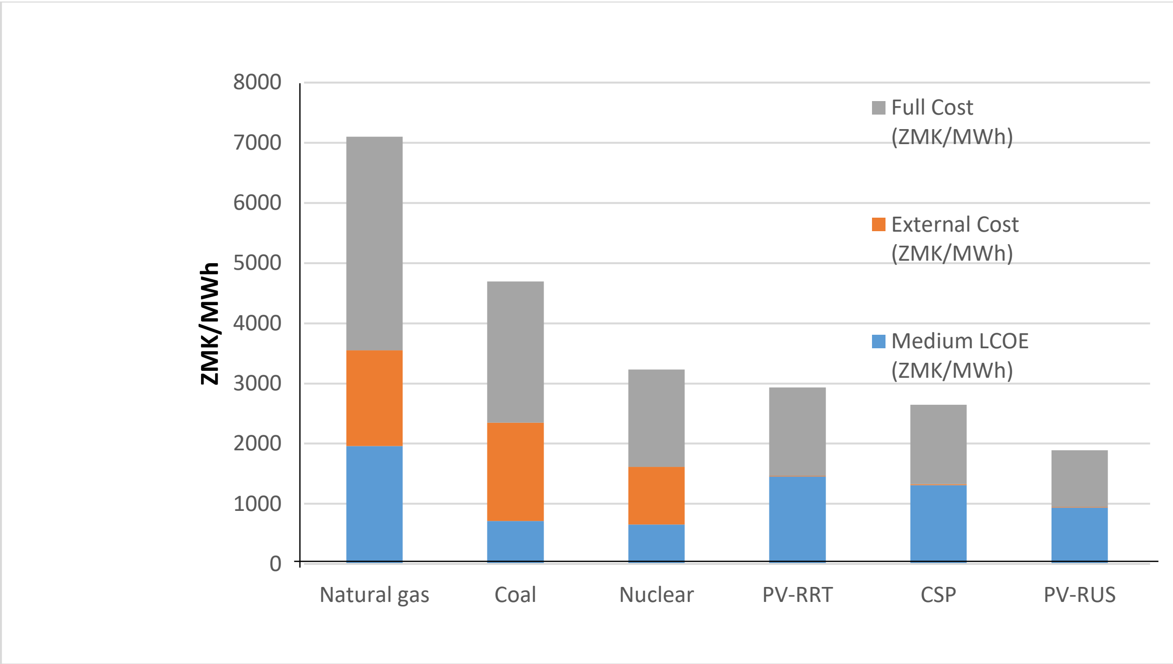


Figure 4.10: Summary statistical results

PV-RUS is the best option technology followed by CSP and PV-RRT. The next technology is nuclear which has a lot of risk factors despite the fact that it has the lowest LCOE. While natural gas is more expensive than coal. From the summary statistical results it can be concluded that renewable energy resources are more cost effective than fossil based energy systems.

CHAPTER 5: CONCLUSION

5.1 Introduction

This research was guided by the main research aim of facilitating informed decision making with regard to new investments options for the electricity sector in Zambia. To ensure the best possible improvement for the country from the status-quo, such choices need to compliance with the goals of a smart energy policy as defined by Griffin (2009), implying cost effectiveness (cheap) and long-term societal benefits (clean & secure). Based on this, three objectives were derived and conceptualized, and corresponding data and information analyzed, interpreted and synthesized throughout this work. In this chapter, the most important results from the research objectives are summarized and relevant conclusions are drawn. From this process, recommendations for Zambia stakeholders are derived and advice given on their implementation. Finally, the work is rounded off with a critical reflection on its limitations and with suggestions for further research that revealed during the research process.

5.2 Conclusions on Technological, Economic and Sustainability Criteria by AHP Application

Global evaluation of the ten types of power plant with regard to technological, economic and sustainability criteria by the application of the AHP leads to the conclusion that renewable energy power plants are the best solutions for the future. Except for biomass, all other types of renewable energy-based power plants require no fuel, thus having no fuel costs and ensuring their operation for ever. This guarantees the energy future of the generations to come. Hydro, geothermal and wind power plants rank in the three top positions. Biomass plants are fourth due to their fuel cost, while photovoltaics rank fifth because of their worst performance on technological criteria and high capital cost.

Among non-renewable energy-based power plants, nuclear plants have the best evaluation. They rank in the sixth position, mainly due to their low fuel cost as compared to the natural gas, coal/lignite and oil. On the other hand, coal/lignite is the fossil fuel with the greatest reserves that can ensure stable energy provision for many decades, despite its adverse environmental effects. Natural gas is still expensive but very promising for the future, as its combustion is less harmful for human health and the global ecosystem. A probable price drop of natural gas relative to other fuel costs will sharply increase its competitiveness in the electricity production. Oil can supplement other forms of energy for the near future, but its use for electricity production is steadily declining.

5.3 Conclusion on Research Objectives

The first objective of this work was shared background knowledge on Zambia’s electricity market.

Revealed through an in-depth literature review, Zambia’s electricity market presented itself as a rather static market, transforming at a slow pace to a more competitive, diversified, and open market setting. This nexus is mainly owed to its history, to the structures created and to locked-in investments in hydro power only that occurred over the past decades. Nevertheless, if put into the regional context of Sub-Saharan Africa or of other emerging economies, history has shown that Zambia performed well with regard to two important goals of a functioning electricity market: it guaranteed cheap prices and clean energy from renewable energy sources.

However, it can be concluded that this comparably good performance has not resulted from deliberate energy planning, but from massive and phase-wise investments into capacity expansions. In the meanwhile, growing demand in electricity has resulted in new supply/demand gaps in Zambia and decision makers consequently scheduled mitigation builds of coal power plants.

At the same time, worldwide tendencies for more sustainable energy pathways given scientific consensus about climate change gained foothold in the developed world and many governments started to focus on alternative energy systems instead. Given unprecedented worldwide transparency resulting from international trade, emerging economies become more and more urged to join industrialized countries on a more sustainable path with their energy systems cophersed to include carbon costs into their export products and services. As a result, countries such as Zambia find themselves in a situation where they face seemingly conflicting goals with regard to a smart energy policy. Often renewable energy sources seem expensive at first glance and are thus perceived as “costly” options if measured with established metrics such as the LCOE. From this perspective, it can be understood that only hydro and other marginal amounts of renewable energy capacity entered policy plans, still prioritizing other options such as coal and now Zambia wants to move towards nuclear power. Supporting mechanisms and structures for RES were developed, but often not successfully implemented, something which has led to great market uncertainties for investors. Examples for such initiatives are the REFIT program, which failed or non-implemented unbundling of services through an ISMO. This would level the market playing field for new IPPs. However, Pegels (2012) pointed out that such problems were not uncommon, and that many countries, including developed countries, seem to undergo phases of experimentation and market adaption with renewable energy policies.

All in all, it can be adhered that the Zambia market structure is in a process of gradual transformation and that stakeholders have learned from mistakes made in the past. However, if Zambia is desirous to reach its policy goals of market opening, electrification, diversification of supply sources, lowering of emission trajectories and increasing security of energy supply in due course, then the transformation would have to be considerably accelerated.

The second research objective was to develop a comprehensive framework which allows for a full-cost analysis of energy technologies, including economic, environmental and social aspects of energy planning.

Indirect costs of electricity generation and risk in the case of nuclear have been inserted to the LCOE approach. Furthermore, non-monetary aspects where formalized to account for other important dimensions in energy planning. These included the potential for job creation, availability of electricity and energy security. Consequently, the framework covers far more aspects than merely the direct costs of a technology (LCOE), which are too often used as the sole proxy in simplified argumentations in favour or against one specific technology.

While external costs were found easier to be included from a methodological point of view, other dimensions such as, job creation potential, energy security or nuclear risk were challenging to be captured in a sound approach. Thus, job creation potential was chosen to be measured in permanent jobs created over the entire value chain of a project, while some of Sovacool and Mukherjee's (2011) energy security indicators were selected by the author based on dimensions and metrics that were "measureable by numbers". Nuclear risk was incorporated through results taken out of two studies, but these were found to be incomplete in their measurements and full-cost results for nuclear are thus flawed. By grouping technologies into different load segments, the notion of "availability of energy sources" was also included also into the analysis. It can thus be concluded that framework developed in this study is more comprehensive and includes parts that allow for quantitative evaluation and parts that must be evaluated with a mixture of quantitative and qualitative aspects.

The third objective of this research was to apply the framework to relevant technology options given Zambia's resource potential. In this sense, hydro, coal, nuclear, natural gas, CSP and PV were identified as most important options and these technologies were assessed one by one. Comparing the full cost of these technologies revealed that an inclusion of external costs and risk altered the ranking between some of the technologies. Hence, the results from the full-cost analysis are rather solid with regard to this parameter.

From the examination of job creation potential and energy security indicators, it can be concluded that hydro, CSP and PV are attractive options for Zambia. As a result, a smart energy policy for Zambia should consider CSP for intermediate load, but include as much rural utility-scale PV as possible to support peak generation. This result is valid if policy makers want to realize long-term benefits for Zambia. However, a diversification of the industry might prove difficult to be realized as long as externalities are not yet included in today's market prices.

Based on these findings, recommendations for Zambia policy makers can be derived and this is discussed in the next chapter.

5.4 Recommendations

i. Decision makers should take into account all different perspectives concluding to the best solution for each case, which depends on the local cultural, social and policy aspects.
ii. Options should gain more weight in future energy planning. Especially CSP is currently undervalued in energy planning. To deal with their intermittent character, the relative full-cost advantage of these technologies could be used for investments into a reduction of their degree of intermittency. Improved storage technologies such as thermal, chemical or pumped-storage could help to do so.
iii. Higher shares of the aforementioned technologies need to be incorporated into the next IRP the logical challenge concerns the choice of policy measures that guarantee actual deployment of preferable technologies.
iv. Sensitive policies that balance the interests of all local stakeholders must be developed to ensure a successful deployment of preferred technologies, which still seem expensive from a purely market-based point of view.

v. Frameworks should be shaped and regulations should be enacted that entail market mechanisms to optimally allocate investment decisions with a focus on long-term benefits.

vi. To diversify the electricity supply, it is recommendable to open the supply market towards IPP investments.

vii. Zambian government should regulate the market frameworks and trigger an unbundling of services through adoption of the ISMO, but also that investment certainty is increased for all stakeholders.

viii. The government should help and guide investments into the desired direction. This becomes especially evident in a decision on a new nuclear program, where this work cannot recommend a build-out based on the technology, given the uncertainty and irreversibility of such an investment. Contrarily, the REBID bidding process and the adoption of a carbon tax that will eventually reflect marginal damage costs of GHG emissions seem promising tools to ensure cost-reflective pricing.

ix. Another tool to internalize externalities would be the adoption of increased levies on non-preferred technologies that compensate for the damages caused. However, this is only effective if the government invests the money obtained at the benefit of the stakeholders concerned.

x. It is also recommended that Zambia focuses on domestic capacity and skills development and fosters on transfer of technology to ensure sustainable management of its energy resources. This is a necessary condition for the development of a green industry and the attraction of parts of solar value chains in the country.

xi. In addition, electricity consumers must be actively engaged, informed and convinced about energy planning and transformation processes in the supply industry.

xii. Furthermore, it can be recommended that Zambia should engage in intensified international cooperation for a diversification of its electricity sector. The existing SAPP market structure is a decent starting point, but to realize substantial positive effects in the region, physical exchange of electricity must increase. Then, in the medium run, Zambia could also supply other markets with solar energy and benefit from better opportunities to balance domestic supply and demand. All in all, the derived recommendations can be summarized as in Figure 5.1.

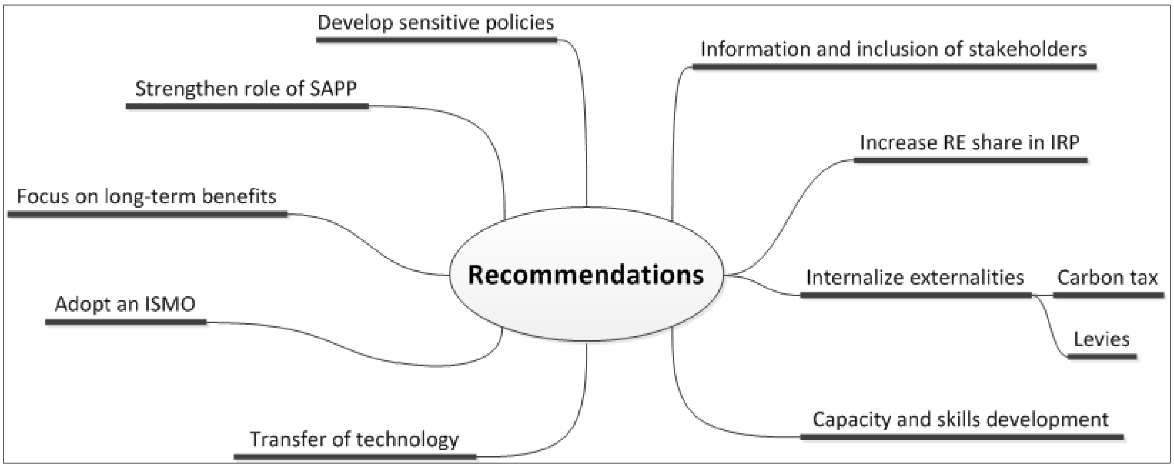


Figure 5.1: Summary of recommendations

It is hence a combination of different market-based and non-market-based measures that are recommended for Zambia to achieve a good balance between cheap, clean and secure supply of electricity. If, however, the implementation of these recommendations fails and Zambia continues to invest in seemingly cheaper coal-based or nuclear generation options, the following quote of Nicolas Sarkozy (2010, in Stiglitz et al., 2010), former French president, might highlight the consequences of such behavior:

"It is possible to go for a long time without paying the true price of scarcity and risk, while being convinced of the contrary, but sooner or later the true price has to be paid. The bill is then much heavier, as behaviors based on these erroneous economic calculations have heightened the scarcity and the risk."

As explained earlier, a research process is a dynamic process during which new challenges and questions may occur. Given the limited scope of this research, not every issue that popped up could be considered. Thus, some of the major limitations in the scope of this work are described in the last chapter and suggestions for further research are made based on them.

Xiii Finally, as fresh water is prerequisite for plant, animal and human life on earth, additional research on the true opportunity costs of fresh water consumption as harnessed from Ground Water Rivers is suggested here.

REFERENCES

Avery, J. S. 2007. *Energy, resources, and the long-term future,* Hackensack, N.J., World Scientific.

Bazilian, M., Nussbaumer, P., Rogner, H.-H., Brew-Hammond, A., Foster, V., Pachauri, S., Williams, E., Howells, M., Niyongabo, P., Musaba, L., Gallachóir, B. Ó., Radka, M. & Kammen, D. M. 2012. Energy access scenarios to 2030 for the power sector in sub-Saharan Africa. *Utilities Policy,* 20**,** 1-16.

Becker, B. & Fischer, D. 2012. Promoting Renewable Electricity Generation in Emerging Economies. *Discussion Paper 9/2012.* Bonn: Deutsches Institut für Entwicklungspolitik gGmbH.

Bee´R, J.M.,2007.High efficiency electric power generation: the environmental role. Progress in Energy and Combustion Science 33,107–134.

Black And Veatch. 2011. Levelized Cost of Energy Calculation. Energy Foundation - The China Sustainable Energy Program.

Blignaut, J., Koch, S., Riekert, J., Inglesi-Lotz, R. & Nkambule, N. 2011. The external cost of coal-fired power generation: the case of Kusile. *The external cost of coal-fired power generation: the case of Kusile*.

BP,2005. Statistical review of world energy.

BP,2015. Statistical review of world energy.

Bruynooghe, C., Eriksson, A. & Fulli, G. 2010. Load-following operating mode at Nuclear Power Plants (NPPs) and incidence on Operation and Maintenance (O&M) costs. Compatibility with wind power variability. Luxembourg.

Burkhardt, J. J., Heath, G. & Cohen, E. 2012. Life Cycle Greenhouse Gas Emissions of Trough and Tower Concentrating Solar Power Electricity Generation. *Journal of Industrial Ecology,* 16**,** 93-109.

Cassim, R., Akinboade, O. A., Niedermeier, E. W. & Sibanda, F. 2003. Sustainable Development: The Case of Energy in South Africa. *In:* CASSIM, R. & JACKSON, W. (eds.) *tkn paper.* Winnipeg: International Institute for Sustainable Development.

Canada's Public Policy Forum, Final Report, 2013

Chang,T.-J.,Tu,Y.-L.,2007.Evaluation of monthly capacity factor of WECS using chronological and probabilistic wind speed data: A case study of Taiwan. Renewable Energy 32,1999–2010.

Chatzimouratidis,A.I.,Pilavachi,P.A.,2007. Objective and subjective evaluation of power plants and their non-radioactive emissions using the Analytic Hierarchy Process. Energy Policy 35,4027–4038.

Chatzimouratidis,A.I.,Pilavachi,P.A.,2008a. Multicriteria evaluation of power plants impact on the living standard using the Analytic Hierarchy Process. Energy Policy36,1074–1089.

Chatzimouratidis,A.I.,Pilavachi,P.A.,2008b. Sensitivity analysis of power plants impact on the living standard using the Analytic Hierarchy Process. Energy Conversion and Management 49,3599–3611.

Chatzimouratidis,A.I.,Pilavachi,P.A.,2008c.Sensitivity analysis of technological, economic and sustainability evaluation of power plants using the Analytic Hierarchy Process. EnergyPolicy37,788–798.

Coley, D. A. 2008. *Energy and climate change : creating a sustainable future,* Chichester, Wiley.

Cook,W.D.,Green,R.H.,2005. Evaluating power plant efficiency: A hierarchical model. Computers & Operations Research 32,813–823.

Darling, S. B., You, F., Veselka, T. & Velosa, A. Y. 2011. Assumptions and the levelized cost of energy for photovoltaics. *Energy & Environmental Science,* 4**,** 3133 - 3139.

Dasappa, S. 2011. Potential Of Biomass Energy For Electricity Generation In Sub-Saharan Africa. *Energy For Sustainable Development,* 15**,** 203-213.

Doukas H, Patlitzianas Kd, Psarras J. Supporting sustainable electricity technologies in Greece using MCDM. Resour Pol 2006;31:129-36.

Eberhard, A. 2003. The Political, Economic, Institutional And Legal Dimensions Of Electricity Supply Industry Reform In South Africa. *Political Economy Of Power Market Reform Conference.* Stanford University: Program On Energy And Sustainable Development.

Eberhard, A. 2007. The Political Economy Of Power Sector Reform In South Africa. *In:* Victor, D. G. & Heller, T. C. (Eds.) *The Political Economy Of Power Sector Reform : The Experiences Of Five Major Developing Countries.* Cambridge: Cambridge University Press.

Ecb. 2016. European Central Bank Reference Exchange Rate, Zambian Kwacha/Euro.

Edkins, M., Marquard, A. & Winkler, H. 2010b. South Africa's Renewable Energy Policy Roadmaps. Cape Town: Energy Research Centre, University Of Cape Town.

Edkins, M., Winkler, H., Marquard, A. & Spalding-Fecher, R. 2010c.

Elkarmi,F.,Mustafa,I.,1993. Increasing The Utilization Of Solar Energy Technologies (Set) In Jordan: Analytic Hierarchy Process. Energy Policy 21,978–984.

Erb - Power Sector Market Brief, 2015.

External Cost Of Electricity Generation: Contribution To The Integrated Resource Plan 2 For Electricity. Cape Town: Energy Research Centre, University Of Cape Town.

Fakir, S. 2012. South Africa's 21st Century Energy Plan? *Supplement To The Mail & Guardian, March 16 To 23 2012.* Johannesburg: World Wide Fund For Nature.

Feretic,D.,Tomsic,Z.,2005. Probabilistic Analysis Of Electrical Energy Costs Comparing: Production Costs For Gas, Coal And Nuclear Power Plants. Energy Policy 33,5–13.

Fluri, T. P. 2009. The Potential Of Concentrating Solar Power In South Africa. *Energy Policy,* 37**,** 5075-5080.

Franco,A.,Casarosa,C.,2004.Thermo Economic Evaluation Of The Feasibility Of Highly Efficient Combined Cycle Power Plants. Energy 29,1963–1982.

Gagnon, L. 2005. Electricity Generation Options: Energy Payback Ratio. Montreal.

Gluzman, D. F., Sklyarenko, L. M., Zavelevich, M. P., Koval, S. V. & Ivanivska, T. S. 2012. Hematological Malignancies In Chernobyl Clean-Up Workers (1996-2010). *Journal Of Hematological Malignancies,* 2**,** 43-50.

Godoy, E., Scenna, N. J. & Benz, S. J. 2010. Families Of Optimal Thermodynamic Solutions For Combined Cycle Gas Turbine (Ccgt) Power Plants. *Applied Thermal Engineering,* 30**,** 569-576.

Gollier, C. & Weitzman, M. L. 2010. How Should The Distant Future Be Discounted When Discount Rates Are Uncertain? *Economics Letters,* 107**,** 350-353.

Graeber, B., Spalding-Fecher, R. & Gonah, B. 2005. Optimising Trans-National Power Generation And Transmission Investments: A Southern African Example. *Energy Policy,* 33**,** 2337-2349.

Griffin, J. M. 2009. A Smart Energy Policy : An Economist's Rx For Balancing Cheap, Clean, And Secure Energy, New Haven, Yale University Press.

Guezuraga, B., Zauner, R. & Pölz, W. 2012. Life Cycle Assessment Of Two Different 2 Mw Class Wind Turbines. *Renewable Energy,* 37**,** 37-44.

Gunn, K. & Stock-Williams, C. 2012. Quantifying The Potential Global Market For Wave Power. *4th International Conference On Ocean Engineering.* Dublin.

Hamed,O.A.,Al-Washmi,H.A.,Al-Otaibi,H.A.,2006.Thermo Economic Analysis Of A Power/Water Cogeneration Plant. Energy31,2699–2709.

Hirth, L. 2012. The Market Value Of Variable Renewables. *In:* 15.2012 (Ed.) *Nota Di Lavoro.* Milano.

Hirth, L. 2013. The Market Value Of Variable Renewables: The Effect Of Solar Wind Power Variability On Their Relative Price. *Energy Economics,* 38**,** 218-236.

Hult, T., Súri, M., Dunlop, E., Albuisson, M. & Wald, L. Integration Of Helioclim-1 Database Into Pvgis To Estimate Solar Electricity Potential In Africa. 20th European

Photovoltaic Solar Energy Conference And Exhibition, 2005 Barcelona. European Commission.

Iaea. 2001. Analysis Of Uranium Supply To 2050. Vienna.

Iea. 2012a. Co2 Emissions From Fuel Combustion Statistics.

Iea. 2012b. Coal Information 2012. Oecd Publishing.

Iea. 2012c. World Energy Statistics. Iea World Energy Statistics And Balances.

Iea/Nea/Oecd. 2010. Projected Costs Of Generating Electricity. Paris.

International Atomic Energy Agency (Iaea),2002. Reference Technology Database.

Ipcc. 2007. *Climate Change Mitigation*

Ipcc. 2011. *Ipcc Special Report On Renewable Energy Sources And Climate Change Mitigation,* Cambridge, United Kingdom And New York, Ny, Usa, Cambridge University Press.

Ipcc. 2014. *Climate Change Mitigation*

Ipcc. 2015. Final Report

Irena: Zambia Renewables Readiness Assessment 2013

Jacobson, M. Z. 2009. Review Of Solutions To Global Warming, Air Pollution, And Energy Security. *Energy & Environmental Science***,** 148-173.

Kablan,M.M.,2004. Decision Support For Energy Conservation Promotion: An Analytic Hierarchy Process Approach. Energypolicy 32,1151–1158.

Kaldellis,J.K.,Kavadias,K.A.,2007.Cost–Benefit Analysis Of Remote Hybrid Wind- Diesel Power Stations: Case Study Aegean Sea Islands. Energy Policy 35, 1525–1538.

Kaldellis,J.K.,Vlachou,D.S.,Korbakis,G.,2005.Techno-Economic Evaluation Of Small Hydropower Plants In Greece: A Complete Sensitivity Analysis. Energy Policy 33,1969–1985.

Kasseris,E.,Samaras,Z.,Zafeiris,D.,2007. Optimization Of A Wind-Power Fuel-Cell Hybrid System In An Autonomous Electrical Network Environment. Renewable Energy 32,57–79.

Kaygusuz, K. 2010. Wind Energy Status In Renewable Electrical Energy Production In Turkey. *Renewable And Sustainable Energy Reviews,* 14**,** 2104-2112.

Klaassen,G.,Riahi,K.,2007. Internalizing Externalities Of Electricity Generation: An Analysis With Message-Macro. Energy Policy 35,815–827.

Kuuskraa, V., Stevens, S., Van Leeuwen, T. & Moodhe, K. 2011. World Shale Gas Resources: An Initial Assessment Of 14 Regions Outside The United States. Arlington, Usa: Eia.

Lantz, E., Wiser, R. & Hand, M. 2012. The Past And Future Cost Of Wind Energy. *Work Package 2: Iea Wind Task 26.* Golden, Co: International Energy Agency.

Laurenzi, I. J. & Jersey, G. R. 2013. Life Cycle Greenhouse Gas Emissions And Freshwater Consumption Of Marcellus Shale Gas. *Environmental Science & Technology,* 47**,** 4896–4903.

Lazard. 2012. Levelized Cost Of Electricity Analysis - Version 6.0.

Lentz, A.,Almanza,R.,2006. Solar–Geothermal Hybrid System. Applied Thermal Engineering 26,1537–1544.

Li,K.,Horne,R.N.,2007. Comparison And Verification Of Production Prediction Models. Journal Of Petroleum Science And Engineering 55,213–220.

Energy Policy In Zambia. Grips Policy Design And Implementation In Developing Countries, 24th July 2015

Maia, J., Giordano, T., Bardien, G., Bodibe, M., Du Plooy, P., Jafta, X., Jarvis, D., Kelder, N., Kruger-Cloete, E., Kuhn, G., Lepelle, R., Makaulule, L., Mosoma, K., Neoh, S., Netshitomboni, N., Ngozo, T. & Swanepoel, J. 2011. Green Jobs: An Estimate Of The Direct Employment Potential Of A Greening South African Economy. Industrial Development Corporation, Development Bank Of Southern Africa, Trade And Industrial Policy Strategies.

Maphosa, M. 2012. Market Overview And Regulatory Landscape: The Energy Regulator’s Perspective. Nersa.

Massachusetts Institute Of Technology (Mit),2006. The Future Of Geothermal Energy—Impact Of Enhanced Geothermal Systems On The United States In The 21st Century.

Mbatha, T. 2011. South African Renewable Energy Sector - Nersa Progress And Challenges. *Naruc Renewable Energy Workshop For Regulators.* Nairobi: Nersa.

Meyer, B. 2012. Externe Kosten Der Atomenergie Und Reformvorschläge Zum Atomhaftungsrecht. Berlin.

Micklem, E. F. 2010. *Developing Wind Power In South Africa: A Sustainable Means To Satisfying South Africa's Energy Demand.* Msc In Economics And Business Administration, Norges Handelshøyskole.

Ministerial Statement On Power Deficit-Dora Siliya, November 2015

Muehlenbachs, L., Spiller, E. & Timmins, C. 2012. Shale Gas Development And Property Values: Differences Across Drinking Water Sources. *Nber Working Paper Series.* Cambridge, Ma: National Bureau Of Economic Research.

Nahman, A. 2011. Pricing Landfill Externalities: Emissions And Disamenity Costs In Cape Town, South Africa. *Waste Management,* 31**,** 2046-2056.

Nea/Iaea. 2012. Uranium 2011: Resources, Production And Demand: Executive Summary. Paris.

Nel, S. 2012. Transforming The Energy Supply Industry. *The Journal Of The Helen Suzman Foundation***,** 15-21.

Nersa. 2008. Multi Year Price Determination 2 (Mypd 2): Proposed Rule Changes. *Nersa Consultation Paper.* Nersa.

Nersa. 2009. South Africa Renewable Energy Feed-In Tariff, Regulatory Guidelines 26 March 2009. *In:* Energy, D. O. (Ed.) 32122 Ed. Pretoria: Nersa.

Nicholson, M., Biegler, T. & Brook, B. W. 2011. How Carbon Pricing Changes The Relative Competitiveness Of Low-Carbon Baseload Generating Technologies. *Energy,* 36**,** 305-313.

Niez, A. 2010. *Comparative Study On Rural Electrification Policies In Emerging Economies,* Paris, Oecd/Iea.

Nkambule, N. & Blignaut, J. 2011. The External Costs Of Coal Mining: The Case Of Collieries Supplying Kusile Power Station. *The External Cost Of Coal-Fired Power Generation: The Case Of Kusile***,** 108-139.

Nordhaus, W. 2008. *A Question Of Balance,* New Haven & London, Yale University Press.

Nrel, 2016. Levelized Cost Of Energy Calculator. . http://www.nrel.gov/analysis/ tech_lcoe.html.

Nrel. 2010. *Simple Levelized Cost of Energy (LCOE) Calculator Documentation* [Online]. National Renewable Energy Laboratory. Available: www.nrel.gov/analysis/lcoe_documentation.html.

Ogaji,S.,Sampath,S.,Singh,R.,Probert,D.,2002. Novel approach for improving power-plant availability using advanced engine diagnostics. Applied Energy 72,389–407.

Ojha, V. P. 2005. The Trade-Off Among Carbon Emissions, Economic Growth and Poverty Reduction in India. *SANDEE Working Papers.* Kathmandu: South Asian Network for Development and Environmental Economics.

Omer Am. Energy, Environment and Sustainable Development. Rev 2008;12:2265-300.

Organisation For Economic Co-Operation And Development (OECD),2003. Nuclear electricity generation: What are the external costs?

Pegels, A. 2010. Renewable Energy in South Africa: Potentials, Barriers and Options for Support. *Energy Policy,* 38**,** 4945-4954.

PEGELS, A. 2012. The Rise and Fall of The South African Feed-In Tariff. *Lund Conference on Earth System Governance.* Lund, April 18-20, 2012: Lund University.

Peng, J., Lu, L. & Yang, H. 2013. Review On Life Cycle Assessment Of Energy Payback And Greenhouse Gas Emission Of Solar Photovoltaic Systems. *Renewable And Sustainable Energy Reviews,* 19**,** 255-274.

Persaud,S.,Flynn,D.,Fox,B.,1999. Potential For Wind Generation On The Guyana Coastlands. Renewable Energy 18,175–189.

Pimentel,D.,Rodrigues,G.,Wang,T.,Abrams,R.,Goldberg,K.,Staeker,H.,Ma,E.,Brueckner,L. ,Trivato,L.,Chow,C.,U.,G.,Boerke,S.,1994. Renewable Energy: Economic And Environmental Issues. Bioscience 44,536–547.

Pohekar,S.D.,Ramachandran,M.,2004. Application Of Multi-Criteria Decision Making To Sustainable Energy Planning—A Review. Renewable And Sustainable Energy Reviews 8,365–381.

Rabl, A. & Rabl, V. A. 2013. External Costs Of Nuclear: Greater Or Less Than The Alternatives? *Energy Policy,* 57**,** 575-584.

Rafaj,P.,Kypreos,S.,2007. Internalisation Of External Cost In The Power Generation Sector: Analysis With Global Multi-Regional Markal Model. Energy Policy 35, 828–843.

Rafey, W. & Sovacool, B. K. 2011. Competing Discourses Of Energy Development: The Implications Of The Medupi Coal-Fired Power Plant In South Africa. *Global Environmental Change,* 21**,** 1141-1151.

Renfrew, C. 1984. *Electricity, Industry And Class In South Africa,* Albany, New York, Usa, State University Of New York Press.

Roques, F. A., Nuttal, W. J. & Newbery, D. M. 2006. Using Probabilistic Analysis To Value Power Generation Investments Under Uncertainty. Electricity Policy Research Group, University Of Cambrigde.

Rosnes, O. & Vennemo, H. 2012. The Cost Of Providing Electricity To Africa. *Energy Economics,* 34**,** 1318-1328.

Roth, I. F. & Ambs, L. L. 2004. Incorporating Externalities Into A Full Cost Approach To Electric Power Generation Life-Cycle Costing. *Energy,* 29**,** 2125-2144.

Rüther, R., Knob, P. J., Da Silva Jardim, C. & Rebechi, S. H. 2008. Potential Of Building Integrated Photovoltaic Solar Energy Generators In Assisting Daytime Peaking Feeders In Urban Areas In Brazil. *Energy Conversion And Management*, 49**,** 1074-1079.

Saaty,T.L.,1980. The Analytic Hierarchy Process. Mcgraw-Hill,Newyork.

Saaty,T.L.,1990. Multicriteria Decision Making: The Analytic Hierarchy Process. Rws,Pittsburgh.

Saaty,T.L.,1994. Highlights And Critical Points In The Theory And Application Of The Analytic Hierarchy Process. European Journal Of Operational Research 74, 426–447.

Saippa. 2011. *What Is An Independent Power Producer* [Online]. Available: www.saippa.org.za/main.html.

Saneri. Renewable Energy Database And The South African Wind Atlas. *In:* Doe, Ed. Colloquium on Energy Planning, 2012 Midrand.

SAPP. 2010. *Southern African Power Pool Statistics 2010* [Online]. Harare. Available: www.sapp.co.zw/docs/R9%20-%20SAPP%20Statistics%20-%202010.pdf.

SAPP. 2012. *Southern African Power Pool Monthly Reports* [Online]. Available: www.sapp.co.zw/viewinfo.cfm?id=60&linkid=2&siteid=1.

SAPVIA. 2011. *NERSA Consultation on REFIT Rates* [Online]. Cape Town: South African Photovoltaic Industry Association. Available: www.sapvia.co.za/wpcontent/uploads/2011/05/NERSA-REFIT-Public-Consultation_SAPVIA-writtenresponse.pdf.

Sebitosi, A. B. & Okou, R. 2010. Re-Thinking The Power Transmission Model For Subsaharan Africa. *Energy Policy*, 38**,** 1448-1454.

Sebitosi, A. B. & Pillay, P. 2008a. Grappling With A Half-Hearted Policy: The Case Of Renewable Energy And The Environment In South Africa. *Energy Policy*, 36**,** 25132516.

Sebitosi, A. B. & Pillay, P. 2008b. Renewable Energy And The Environment In South Africa: A Way Forward. *Energy Policy,* 36**,** 3312-3316.

Shabangu, S. 2003. White Paper On Renewable Energy. *In:* Energy, D. O. M. A. (Ed.). Department Of Minerals And Energy.

Sigauke, C. & Chikobvu, D. 2011. Prediction Of Daily Peak Electricity Demand In South Africa Using Volatility Forecasting Models. *Energy Economics,* 33**,** 882-888.

Sigauke, C. & Chikobvu, D. 2012. Short-Term Peak Electricity Demand In South Africa. *African Journal Of Business Management,* 6**,** 9243-9249.

Sinden,G.,2007. Characteristics Of The Uk Wind Resource: Long-Term Patterns And Relationship To Electricity Demand. Energy Policy 35,112–127.

Solomon Bd, Krishna K. The Coming Sustainable Energy Transition: History, Strategies, And Outlook. Energy Pol 2011;39:7422-31.

Sovacool, B. K. & Mukherjee, I. 2011. Conceptualizing And Measuring Energy Security: A Synthesized Approach. *Energy,* 36**,** 5343-5355.

Spalding-Fecher, R. & Matibe, D. K. 2003. Electricity And Externalities In South Africa. *Energy Policy,* 31**,** 721-734.

Stern, N. 2006. Stern Review On The Economics Of Climate Change. Cambridge.

Steyn, G. 2006. Investment And Uncertainty: Historical Experience With Power Sector Investment In South Africa And Its Implication For Current Challenges. *Working Paper.* Cape Town: University Of Cape Town.

Stiglitz, J. E., Sen, A. & Fitoussi, J.-P. 2010. *Mismeasuring Our Lives, Why Gdp Doesn't Add Up,* New York, The New Press.

Suri, M. 2011. Site Assessment Of Solar Resource, Upington Solar Park.

Tarjanne,R.,Luostarinen,K.,2003. Competitiveness Comparison Of Electricity Production Alternatives. Lappeenranta University Of Technology, Finland (Research Report Enn-56).

Tarjanne,R.,Rissanen,S.,2000. Nuclear Power: Least-Cost Option For Base Load Electricity In Finland. The Uranium Institute 25th Annual Symposium.

Thopil, G. & Anastassios, P. 2010. An Overview Of The Electricity Externality Analysis In South Africa Within The International Context. *South African Jounal Of Science,* 106**,** 6.

Tidball, R., Bluestein, J., Rodriguez, N. & Knoke, S. 2010. Cost And Performance Assumptions For Modeling Electricity Generation Technologies. Golden, Colorado.

Timilsina, G. R., Kurdgelashvili, L. & Narbel, P. A. 2012. Solar Energy: Markets, Economics And Policies. *Renewable And Sustainable Energy Reviews,* 16**,** 449-465.

Tkn And Iisd, "Investment Incentives For Renewable Energy In Southern Africa: Case Study Of Zambia", December 2012

Tkn And Iisd, "Investment Incentives For Renewable Energy In Southern Africa: Case Study Of Zambia", December 2012

Tradetech. 2013. *Uranium Prices And Analysis Since 1968* [Online]. Available: www.uranium.info/daily_u3o8_spot_price_indicator.php [Accessed 30 Apr 2013].

Treasure Karoo Action Group. 2012. *Fracking Facts* [Online]. Available: www.treasurethekaroo.co.za/fracking-facts.

Treasury Department 2012. Budget Review. *In:* Treasury, N. (Ed.). Pretoria.

Treasury Department. 2010. *Discussion Paper For Public Comment, Reducing Greenhouse Gas Emissions - The Carbon Tax Option* [Online]. Available: www.treasury.gov.za/public%20comments/Discussion%20Paper%20Carbon%20Taxes%2081210.pdf.

Trevisani,L.,Fabbri,M.,Negrini,F.,2006. Long-Term Scenarios For Energy And Environment: Energy From The Desert With Very Large Solar Plants Using Liquid Hydrogen And Superconducting Technologies. Fuel Processing Technology 87, 157–161.

Turkson, J. & Wohlgemuth, N. 2000. Power Sector Reform And Distributed Generation In Sub-Saharan Africa. *Energy Policy,* 29**,** 135-145.

Us Department Of Energy (Usdoe),1997. Clean Power For 21st Century Dollars From Sense: The Economic Benefits Of Renewable Energy.

Us Department Of Energy/Energy Information Administration (Usdoe/Eia),2005. Annual Energy Outlook.

Us Department Of Energy/Energy Information Administration (Usdoe/Eia),2006. Electric Power Annual.

Van Wyk, L., Kolev, M., Osburn, L., De Villiers, A. & Kimmie, Z. 2011. The Employment Aspects Of Energy-Related Improvements In Construction In South Africa. 1 Ed. Geneva: International Labour Organization.

Virdis, M.R., 2002. Energy Policy And Externalities: The Life Cycle Approach. Workshop Proceedings, 15–16 November2001,Oecd,Paris.

Vorster, S., Winkler, H. & Jooste, M. 2011. Mitigating Climate Change Through Carbon Pricing: An Emerging Policy Debate In South Africa. *Climate And Development,* 3**,** 242-258.

Wang, Y. & Sun, T. 2012. Life Cycle Assessment Of Co2 Emissions From Wind Power Plants: Methodology And Case Studies. *Renewable Energy,* 43**,** 30-36.

Wang, L.,Chu,J.,Wu,J.,2007. Selection Of Optimum Maintenance Strategies Based On A Fuzzy Analytic Hierarchy Process. International Journal Of Production Economics 107,151–163.

Wijayatunga, P.D.C., Siriwardena, K., Fernando, W.J.L.S., Shrestha,R.M.,Attalage, R.A., 2006. Strategies To Overcome Barriers For Cleaner Generation Technologies In Small Developing Power Systems: Srilanka Case Study. Energy Conversion And Management 47,1179–1191.

Winkler, H. 2012. South Africa To Introduce Rising Price On Carbon Pollution From Major Sources In 2013. *National Resources Defense Council Staff Blog* [Online]. Available

From:Http://Switchboard.Nrdc.Org/Blogs/Jschmidt/Guest_Blog_By_Harald_Winkler_S.Html.

Winkler, H., Hughes, A. & Haw, M. 2009. Technology Learning For Renewable Energy: Implications For South Africa's Long-Term Mitigation Scenarios. *Energy Policy,* 37**,** 4987-4996.

World Bank, T. 2013. Global Economic Monitor (Gem).

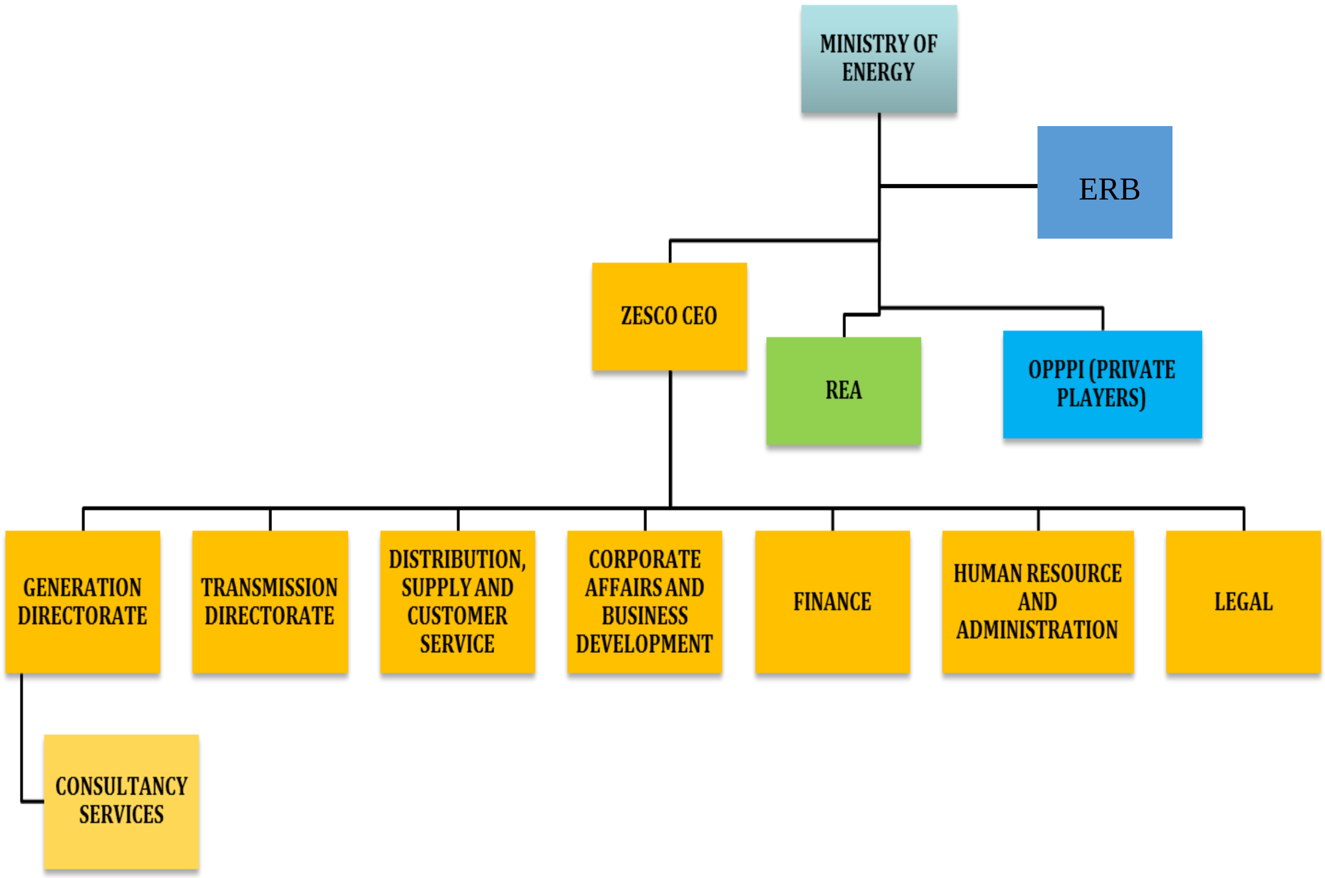
World Nuclear Association (Wna),2006. Supply Of Uranium.

Zambia Development Agency, "Zambia Energy Sector Profile", June 2013

Zambia Development Agency: "Zambia Energy Sector Profile", September 2014

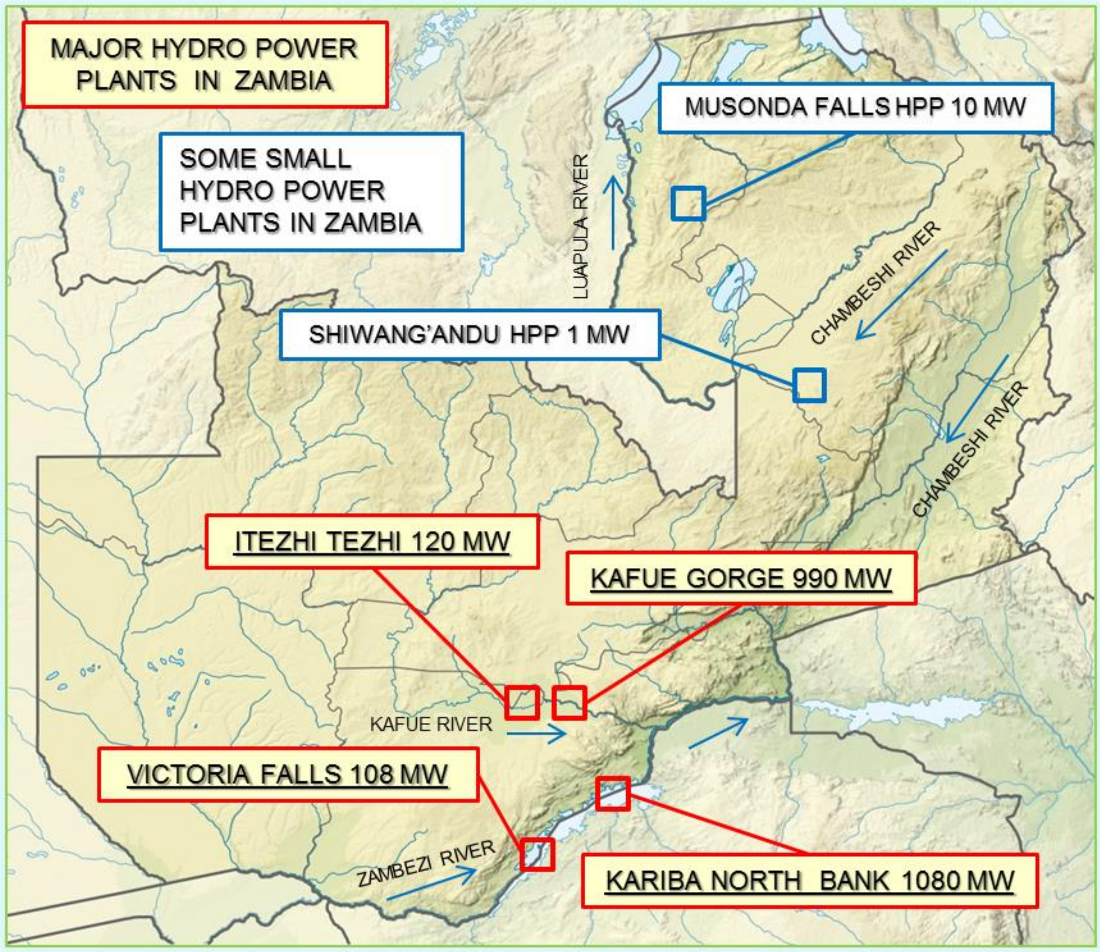
APPENDICES

Appendix A: Overview of energy framework in Zambia



Source: Own illustration

Appendix B: Overview of major hydro power stations in Zambia



Source: Energy Regulation Board of Zambia, 2015

Appendix C: Input parameters for dry-cooled coal power plant, super-critical technology with FGD

Capital costs	**Value(s)**			**Conversion to ZMW_{2017}**	**Source**
cp	2300 USD_{2012}/kW			18860	(Eskom, 2012b)
H	8760				given
f	85%				(EPRI, 2010)
CRF	5.47%				calculated
r	5%				given
T	50				(Eskom, 2013e)
O&M costs	**Value(s)**				**Source**
Fixed O&M	455 ZAR_{2010}/kW-yr			523.80	(EPRI, 2010)
Variable O&M	44.4 ZAR_{2010}/MWh			51.11	(EPRI, 2010)
e	3.5%				(StatsSA, 2012b)
Fuel costs	**Value(s)**				**Source**
LHV	17.9 GJ/t				(IEA/NEA/OECD, 2010)
Thermal efficiency	40%				(AfDB, 2009)
Coal price in 2015	349 ZMW_{2012}/t				(McKay, 2012)
Coal prices in 2065	848.06 ZMW_{2012}/t (low) 1930.48 ZMW_{2012}/t (medium) 6080.26 ZMW_{2012}/t (high)				Projections from author
e (low increase)	1.79%				Calculation from author
e (moderate increase)	3.48%				Calculation from author
e (high increase)	5.88%				Calculation from author
Economic parameters					
2008 exchange rate ZMW/USD	8.30				(World Bank, 2013)
2012 exchange rate ZMW/USD	8.20				(World Bank, 2013)
2008 PPI	14.2%				(StatsSA, 2012b)
2009 PPI	-0.1%				(StatsSA, 2012b)
2010 PPI	6.0%				(StatsSA, 2012b)
2011 PPI	8.4%				(StatsSA, 2012b)
2012 PPI	6.2%				(StatsSA, 2012b)
Externalities Scenarios	**low**	**median**	**high**		
Health externalities in ZMW_{2010}/KWh	0.006	-	0.007		(Blignaut et al., 2011)
Conversion to ZMW_{2012}/MWh	6.91		8.06		calculated

Climate change externalities in ZMW_{2010}/KWh	0.097	-	0.165	(Blignaut et al., 2011)
Conversion to ZMW_{2012}/MWh	111.67		189.95	calculated
Opportunity cost of water use in ZMW_{2010}/KWh	0.66	-	1.311	(Blignaut et al., 2011)
Conversion to ZMW_{2012}/MWh	759.80		1509.23	calculated
Coal mining externalities in ZMW_{2010}/MWh	202,40	-	393,00	(Nkambule and Blignaut, 2011)
Conversion to ZMW_{2017}				
Total externalities ZMW_{2017}/MWh	1111.38	1635.53*	2159.67	calculated

**) Computed average value, given lack of median values.*

Appendix D: Input parameters for nuclear power plant, generation III type

Capital costs	**Value(s)**	**Conversion to ZMW_{2017}**	**Source**
cp	7000 USD_{2012}/kW	57400	(ERC, 2013)
H	8760		given
f	90%		(Lazard, 2012)
CRF	5.28%		calculated
r	5%		given
T	60		(Tidball et al., 2010)
Plant capacity	1600 MW		Assumption
O&M costs	**Value(s)**		**Source**
Fixed O&M	0 ZAR_{2010}/kW-y	0	(DoE, 2010)
Variable O&M	95.2 ZAR_{2010}/MWh	110.67	(DoE, 2010)
e	0.5%		Assumption
Fuel costs	**Value(s)**		**Source**
Energy content uranium	3900 GJ/kg		(Lazard, 2012)
Thermal efficiency	37%		(WNA, 2013)
Price natural uranium	81.00 USD_{2012}/kg	664.20	(TradeTech, 2013)
Calculated variable fuel cost	1.66 ZAR_{2012}/MWh		Calculation from author
Total fuel cost	135.50 ZAR_{2012}/MWh		(Kotzé, 2012)
e	1 %		Assumption
Economic parameters			

Externalities Scenarios	low	median	high	
External cost of accident, in $Eurocent_{2012}$/KWh	0.08	0.38	2.29	
Conversion to ZMW_{2012}/MWh	8.44	40.09	241.60	
External cost of current operation, in $Eurocent_{2012}$/KWh	0.07	0.21	0.63	
Conversion to ZMW_{2012}/MWh	7.39	22.16	66.47	
External cost of waste management, in $Eurocent_{2012}$/KWh	0.10	0.20	0.30	
Conversion to ZMW_{2012}/MWh	10.55	21.10	31.65	
Total external cost, in $Eurocent_{2012}$/KWh	10.70	22.35*	34.00	
Conversion to ZMW_{2012}/MWh	1128.85	2357.93	3587.00	
2007 exchange rate ZMW/USD	7.10			(World Bank, 2013)
2012 exchange rate ZMW/USD	8.20			(World Bank, 2013)
2008 PPI	14.2%			(StatsSA, 2012b)
2009 PPI	-0.1%			(StatsSA, 2012b)
2010 PPI	6.0%			(StatsSA, 2012b)
2011 PPI	8.4%			(StatsSA, 2012b)
2012 PPI	6.2%			(StatsSA, 2012b)
Externalities				
I_{SA} (GNI South Africa (2011) PPP in intl. $)	10710			(World Bank, 2012)
I_{BC} (GNI Euro area (2011) PPP in intl. $)	35250			(World Bank, 2012)
I_{BC} (GNI Germany (2011) PPP in intl. $)	40190			(World Bank, 2012)
2012 exchange rate ZMW/EUR	10.55			(World Bank, 2013)
Total externalities ZMW_{2012}/MWh (Rabl & Rabl)	26.38	83.35	339.72	calculated
Adjusted to Zambian PPP	8.02	25.33	103.26	(Nahman, 2011)
Total externalities ZMW_{2012}/MWh (Meyer)	1128.85	2357.93	3587.00	calculated
Adjusted to Zambian PPP	300.96	628.65	956.33	(Nahman, 2011)

**) Computed average value, given lack of median values.*

Appendix E: Input parameters for CCGT gas power plant

Capital costs	Value(s)	Conversion to ZMW_{2017}	Source
cp	5780 USD_{2010}/kW	6653.98	(EPRI, 2010)
H	8760		given
f	5%, 50%, 88%		(Lazard, 2012)
CRF	6.51%		calculated

r	5%		given
T	30		(EPRI, 2010)
Plant capacity	800 MW		Assumption
O&M costs	**Value(s)**		**Source**
Fixed O&M	148 ZAR_{2010}/kW-y	170.38	(EPRI, 2010)
Variable O&M	0 ZAR_{2010}/MWh		(EPRI, 2010)
e	0.5%		(Roques et al., 2006)
Fuel costs	**Value(s)**		**Source**
Price natural gas	73.56 ZAR_{2012}/GJ		(NERSA, 2013a)
Thermal efficiency CCGT plant	50%		(Godoy et al., 2010)
Conversion factor GJ/MWh	3.6		given
Total fuel cost	481.48 ZMW_{2017}/MWh		calculated
e	1 %		(Roques et al., 2006, ERC, 2013)
Economic parameters			
2010 PPI	6.0%		(StatsSA, 2012b)
2011 PPI	8.4%		(StatsSA, 2012b)
2012 PPI	6.2%		(StatsSA, 2012b)
Externalities			
Average emission intensity CCGT power plant	470 gCO_2-eq./KWh		(Nicholson et al., 2011)
Upstream emission intensity shale gas	103 gCO_2-eq./KWh		(Laurenzi and Jersey, 2013)
Health impacts from power generation	0.34 ZAR_{2009} cents /KWh	0.42	(Edkins et al., 2010c)
Health impacts from fuel production	0.14 ZAR_{2009} cents /KWh	0.17	(Edkins et al., 2010c)
Biodiversity loss	0.39 ZAR_{2009} cents /KWh	0.48	(Edkins et al., 2010c)
Loss in property values	not quantifiable, lack in research		(Muehlenbachs et al., 2012)
CCGT life cycle fresh water consumption	224 gallon/MWh		(Laurenzi and Jersey, 2013)

Externalities Scenarios	low	median	high
Global damage cost in ZAR_{2010}/t CO_2-eq. (Blignaut et al., 2011)	5.83	109.80	177.79
Conversion to ZMW_{2017}/MWh	6.71	126.40	204.67
External cost from GHG emissions, in ZAR_{2012}/MWh (Blignaut et al., 2011)	3.75	70.72	114.51
Opportunity cost of water use in ZAR_{2010}/KWh	1.14	1.31	1.49
Conversion to ZMW_{2017}/MWh	1312.38	1508.08	1715.30
Total externalities ZMW_{2017}/MWh calculated	1326.75	1589.42	1840.43

Appendix F: Input parameters for CSP power plant, solar tower technology with 3 hour storage

Capital costs	Value(s)	Conversion to ZMW_{2017}	Source
cp	7300 USD_{2012}/kW	59860	(Lazard, 2012)
H	8760		given
f	40%		(Lazard, 2012)
CRF	5.83%		calculated
r	5%		given
T	40		(Lazard, 2012)
Plant capacity	100 MW		Assumption
O&M costs	**Value(s)**		**Source**
Fixed O&M	80 USD_{2012}/kW-y	656	(Lazard, 2012)
Variable O&M	3.00 USD_{2012}/MWh	24.60	(Lazard, 2012)
e	2.5%		(Timilsina et al., 2012)
Economic parameters			
2007 exchange rate ZMW/USD	7.10		(World Bank, 2013)
2012 exchange rate ZMW/USD	8.20		(World Bank, 2013)
2008 PPI	14.2%		(StatsSA, 2012b)
2009 PPI	-0.1%		(StatsSA, 2012b)
2010 PPI	6.0%		(StatsSA, 2012b)
2011 PPI	8.4%		(StatsSA, 2012b)
2012 PPI	6.2%		(StatsSA, 2012b)
Externalities			
Emission intensity in g CO_2-eq./KWh	38.00		(Burkhardt et al., 2012)
Health externalities in $ZARcent_{2009}$/KWh	0.09	1.10	(Edkins et al., 2010c)

Externalities Scenarios	low	median	high	
Global damage cost in ZAR_{2010}/t CO_2-eq.	5.83	109.80	177.79	(Blignaut et al., 2011)
Conversion to ZMW_{2017}/MWh	6.71	126.40	204.67	
External cost from GHG emissions in ZMW_{2017}/MWh	0.26	4.80	7.78	calculated
Total externalities ZMW_{2017}/MWh	11.26	15.80	18.78	calculated

Appendix G: Input parameters for PV plants, rural utility scale (RUS) and residential roof-top (RRT)

Capital costs	Value(s)	Conversion to ZMW_{2017}	Source
cp_{RUS}	2375 USD_{2012}/kW;	19475	(Lazard, 2012)
cp_{RRT}	3250 USD_{2012}/kW	26650	(Lazard, 2012)
H	8760		given
f_{RUS}	27%		calculated
f_{RRT}	22%		(Lazard, 2012)
CRF	8.02%		calculated
r	5%		given
T	20		(Lazard, 2012)
Plant capacity	10 MW		Assumption
Average annual solar irradiation in Zambia	3000 KWh/m²		(ZDA, 2013)
Dimensions Solaire SDT1000 - 100W	1190 x 670 x 35 mm		(Sustainable.co.za, 2013)
Area needed for 1 KWp	7.79m²		calculated
Performance ratio solar panel	0.75		(Hult et al., 2005)
Module efficiency	16%		(Darling et al., 2011)
Degradation rate module per year	0.6%		(Darling et al., 2011)
Average electricity production per KWp	2570 KWh		calculated
Plant capacity	10 MW		Assumption
O&M costs	**Value(s)**		**Source**
Fixed O&M	500 ZAR_{2011} /kWp-y	531	(SAPVIA, 2011)
e	2.5%		(Timilsina et al., 2012)
Economic parameters			
2012 exchange rate ZMW/USD	8.20		(World Bank, 2013)
2010 PPI	6.0%		(StatsSA, 2012b)
2011 PPI	8.4%		(StatsSA, 2012b)
2012 PPI	6.2%		(StatsSA, 2012b)

Externalities Scenarios	low	median	high	
Emission intensity in g CO_2-eq./KWh	23.00	33.50	44.00	
Global damage cost in ZAR_{2010}/t CO_2-eq.	5.83	109.80	177.79	
Conversion to ZMW_{2017}/MWh	6.71	126.40	204.67	
External cost from GHG emissions in ZMW_{2017}/MWh	0.15	4.23	9.01	
Externalities				
Health externalities in $ZARcent_{2009}$/KWh	0.19			(Edkins et al., 2010c)
Conversion to ZMW_{2017}/MWh	2.32			calculated
Total externalities ZMW_{2017}/MWh	1.13			calculated