More for Less:
How Decentralised Energy Can Deliver Cleaner, Cheaper and More Efficient Energy in Nigeria

A report by World Alliance for Decentralized Energy (WADE), Christian Aid and the International Centre for Environment and Energy Development (ICEED)

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Abbreviations

CCGT	Combined Cycle Gas Turbine
CG	Centralised Generation
CHP	Combined Heat and Power, or cogeneration
CO_2	Carbon dioxide
DE	Decentralised Energy
DSM	Demand Side Management
Env	Environmental Concern
IPPs	Independent Power Producers
NEPA	National Electric Power Authority
NERC	Nigerian Electricity Regulatory Commission
NELMCO	National Electricity Liability Management Company
NESCO	Nigerian Electricity Supply Corp Ltd
NGC	Nigeria Gas Company
NIPP	National Integrated Power Project
NO_x	Nitrogen oxide
O&M	Operation and Maintenance
PHCN	Power Holding Company for Nigeria
PM_{10}	Particulate Matter
PV	Photovoltaic
RETs	Renewable Energy Technologies
RES	Renewable Energy System
SoS	Security of Supply
SO_2	Sulphur dioxide
SoS	Security of Supply
SSM	Supply Side Management
T&D	Transmission & Distribution
UNDP	United Nations Development Programme
US$	United States Dollar
WADE	World Alliance for Decentralised Energy

Glossary

Biomass
Biomass is defined as any plant matter used directly as fuel or converted into other forms before combustion. This includes wood, vegetal waste (including wood waste and crops used for energy production), animal material/waste, sulphite lye — also known as 'black liquor' (an alkaline-spent liquor from the digesters in the production of sulphate or soda pulp during paper manufacturing, where the energy content derives from the lignin obtained from the wood pulp), and other solid biomass.

Biogas
Biogas is derived principally from the anaerobic fermentation of biomass and solid wastes. It is combusted to produce heat and/or power. Included in this category are landfill gas and sludge gas (sewage gas and gas from animal slurries) and other biogas. Liquid biomass, which includes bio-additives such as ethanol, is also included in this category.

Centralised generation
Electricity is generated in large remote plants. Power must then be transported over long distances at high voltage before it can be used.

Combined Cycle Gas Turbine (CCGT)
An electric generating technology in which electricity is produced from otherwise lost waste heat exiting from one or more gas (combustion) turbines. The exiting heat is routed to a conventional boiler or to a heat recovery steam generator. A steam turbine is then used to produce electricity. Such designs increase the efficiency of electric generating units.

Cogeneration
Cogeneration, or Combined Heat and Power (CHP), is defined as the simultaneous generation of heat and power in a single process. The power output is usually electricity, but may include mechanical power. Heat outputs can include steam, hot water or hot air for process heating, space heating or absorption chilling.

Decentralised generation
Electricity production at or near the point of use, irrespective of size, technology or fuel used — both off-grid and on-grid.

Emission factor
The emission factor is the ratio between the amount of pollution generated and the amount of a given raw material processed. The term may also refer to the ratio between the emissions generated and the outputs of production processes.

Fossil fuel
Carbon-based fuels from fossil carbon deposits, including coal, oil, and natural gas.

Feed in tariff
This is an incentive structure to encourage the adoption of renewable energy through government legislation. The regional or national electricity utilities are obligated to buy electricity generated from renewable sources such as solar photovoltaics wind power, biomass, hydropower and geothermal power) at specific-market rates set by the government.

Gas turbine
A turbine that expands hot gases to produce mechanical energy.

Geothermal energy
Hot water or steam extracted from geothermal reservoirs in the earth's crust that is supplied to steam turbines at electric power plants that drive generators to produce electricity.

Grid
A high voltage electricity transmission network

Heat rate
An expression of the conversion efficiency of a thermal power plant or engine, as heat input per unit of work output — for example, Btu/kWh.

Hydroelectric plant or hydro power plant
A plant in which all power is produced from natural stream flow, as regulated by the available storage

Load Growth
The annual incremental electricity demand.

Nuclear energy
Energy derived from the nuclear transformation (fission or fusion) of atoms.

Nuclear power plant
A facility that converts atomic energy into usable power. In a nuclear electric power plant, heat produced by a reactor is generally used to drive a turbine, which in turn drives an electric generator.

Photovoltaics (PV)
A photovoltaic solar cell converts light directly into electricity. Light striking the front of a solar cell produces a voltage and current – it has no moving parts. A group of interconnected cells creates a solar panel. In turn, these can be connected in a series or parallels to create a solar array and any voltage-current combination required.

Renewable energy
Energy sources that are sustainable within a short time frame relative to the Earth's natural cycles. They include non-carbon technologies such as solar energy, hydropower, and wind, as well as carbon-neutral technologies such as biomass.

Solar energy
This includes:
solar radiation exploited for hot water production and electricity generation by flat plate collectors (mainly of the thermosyphon type) for domestic hot water or for the seasonal heating of swimming pools;
photovoltaic cells;
solar thermal-electric plants.

Simple cycle gas turbine or open cycle gas turbine
A gas turbine system where the gases are exhausted into the atmosphere.

Steam turbine
A steam turbine uses steam to drive a generator, which then produces electricity.

Thermal efficiency
The ratio of heat absorbed by the boiler to heat available in the fuel.

Thermal plant
A power generating plant which uses heat to produce energy. Such plants may burn fossil fuels or use nuclear energy to produce thermal energy.

Wind energy
Energy present in wind motion that can be converted to mechanical energy for driving pumps, mills, and electric power generators. Wind pushes against sails, vanes, or blades radiating from a central rotating shaft.

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Executive summary

Energy demand in Nigeria is growing fast and, being a developing country, this trend is likely to continue. Nigeria's plentiful and varied energy resources are mainly conventional or non-renewable, such as crude petroleum oil, natural gas, coal, tar sand and uranium. However, the country's current power sector planning process mainly favours conventional centralised gas fired generation. By 2020, this is set to comprise 74 per cent of the country's total electricity output.

The Government faces many challenges in providing clean and efficient electricity throughout the country. These include low technical maintenance of power plants and the electrical grid, and inefficient conventional power plants. In addition, one third of Nigeria's primary energy is currently lost by the time it reaches the end costumer. A limited natural gas supply and Government unwillingness to implement renewable energy technologies are also issues that need to be addressed in order to reform the power sector.

This report outlines the background to these issues. It also assesses the potential benefits of increased use of decentralised energy (DE) in Nigeria's future electricity mix, both in terms of cost and carbon emissions. It explores ways of improving Nigeria's future electric energy supply in secure and environmentally friendly ways, and provides detailed outlines of three alternative energy scenarios for Nigeria's future electricity scheme over a 20-year period (2009-2028). These scenarios were developed using the World Alliance for Decentralised Energy (WADE) Economic Model. Current barriers, drivers, and the regulatory framework necessary for implementing decentralised technologies in Nigeria are also discussed in this report.

The power sector was evaluated as part of the country's wider economic and environmental circumstances. The total cost of investment, operations and delivery all form part of this report's economic assessment. The level of pollutants, including sulphur dioxide (SO2), nitrogen oxide (NOx), particulate matter (PM10) and carbon dioxide (CO2), were considered as part of the environmental analysis. Fuel consumption was also analysed.

Conclusions

This report concludes that increasing the use of decentralised energy in Nigeria can help improve the environment, because it will generate lower emissions. DE will also have positive outcomes for the economy, as the cost of delivering power will decrease. We calculate that using decentralised energy can achieve a saving of US$80 billion for Nigeria, or a 20 per cent reduction in capital costs by 2028, compared to using centralised generation. These savings mainly result from reduced investment in transmission lines.

In order for DE to reach its full potential, a more comprehensive and systematic power sector planning process needs to be implemented. The Government must also establish policies and strategies to create a competitive market framework for DE. In particular, the following strategies should be considered:

- improving the gas supply from the Niger Delta and allowing for more decentralised gas-fired power generation;
- accelerating electricity access in Nigeria's rural areas by incorporating the rural electrification program into the Nigeria Power Development Plan;
- reviewing the power sector's current policy framework, to remove obstacles and provide incentives for private sector entities that are interested in generating on-site energy:
- implementing the Renewable Electricity Action Programme

Chapter 1 Introduction

This chapter sets out the problems involved in reforming Nigeria's energy sector. Although Nigeria is one of the largest oil producing countries in the world, it has rampant energy poverty. The country's energy industry is inefficient and unable to meet its customers' needs. This has had a negative impact on people's living standard throughout the country. There are several major problems with Nigeria's current electricity framework, including energy poverty, low maintenance of plants, high network losses, a limited availability of natural gas fired power plants, and social barriers.

Energy poverty

In 2005, just 40 per cent of Nigerian households had access to electricity. Access varies widely between regions. For example, fewer than 10 per cent of households in the rural northern states of Ligawa, Katsina, Kebbi, Sokoto and Taraba currently have access to grid electricity. In comparison, almost everyone living in the southern Lagos state has access to electricity. About 60 per cent of residents in the southern states of Edo, Ondo, and Osun can access the national grid.

There are many major constraints in terms of providing Nigeria's rural areas with universal electricity access. These include:

- low and isolated loads in rural areas where population density is sparse;
- dispersed and inaccessible locations;
- rural consumers' limited ability and willingness to pay;
- high cost of extending the grid.

A large increase in electricity supply and infrastructure will be necessary in order to improve people's access to electricity across Nigeria.

Low technical maintenance and high network losses

The Nigerian power sector is characterised by comparatively large technical losses of between 20 and 50 per cent from 1980 to 2000. According to Power Holding Company for Nigeria (PHCN) data, 25.1 per cent of the energy sent out by power stations is lost in transmission and distribution. Some of these losses are due to unmetered and unbilled energy consumption; others are due to technical problems encountered as a result of the long distances between consumers and power stations. Ultimately, Nigeria loses on average at least one third of its energy by the time it reaches the end consumer. Another persistent problem is the low technical maintenance of many of Nigeria's power plants, resulting in sometimes heavily reduced efficiency.

Limited availability of natural gas fired power plants

Social and political instability in the Niger Delta has substantially reduced Nigeria's natural gas supply. This, in turn, has negatively impacted on power supply, given that gas power plants comprise 75% of total installed energy capacity in Nigeria. Many hydro and thermal power plants in Nigeria have been, or remain, unavailable for service because they have been literally run aground. Some of these plants have never undergone full maintenance in around three decades of continuous service. This problem is often attributed to a lack of funds allocated to this crucial aspect of Nigeria's utility operations in government budgets.

Social barriers

Corruption, persistent mismanagement, and high manufacturing costs make Nigerian firms some of the most uncompetitive on the continent. Another obstacle to reform is the inability or unwillingness at all levels of Nigeria's Government to move forward forcefully on large-scale deployment of Renewable Energy Technologies (RETs) and Renewable Energy Systems (RES) across the economy. Nigeria's energy profile is still dominated by fossil fuel, even though the country has considerable renewable energy resources. However, these have not been used to their full potential yet, as renewable energy sources are not economically competitive compared to conventional fuels.

Chapter 2
The Nigerian energy sector and current policy challenges

This chapter describes Nigeria's current electricity sector and addresses the main energy policy challenges involved. While the government's comprehensive Power Sector Reform Programme, outlined in the National Electric Power Policy, aims to solve the country's current problems and achieve sustainable and affordable electric power supplies, many of the challenges involved have yet to be tackled.

The Nigerian Energy Sector

Nigeria's current grid power system has a mix of thermal and hydroelectric power plants. In 2008, its three hydro stations had a total installed capacity of 1,938.4 MW, while the 15 thermal power plants had a total installed capacity of 6,199.6 MW. The thermal power plants are generally dual fuelled by oil and natural gas, but are mostly fired by natural gas.

By the end of 2008, under the National Integrated Power Project (NIPP), several new thermal power plants capable of producing a total of 3,000 MW were at various stages of construction. These include a large Steam Turbine Plant with a total installed capacity 1,320 MW, a 300 MW Steam Turbine Plant, 11 Gas Turbine Plants, and a 480 MW Combined Cycle Gas Turbine (CCGT). CCGT power plants generally have a thermal efficiency of 50-60 per cent while Simple Cycle (Combustion) Gas Turbines have an efficiency of only about 35-40 per cent, depending on the age of the plant. Steam Turbine plants have much lower efficiencies of just 25-30 per cent.

Nigeria has a mothballed Coal-fired Steam Turbine plant with a potential capacity of 30 MW. The country also has a number of isolated grid power plants that are Independent Power Producers (IPPs), some of which are private and others that are run by the State Government. The private IPPs have an installed capacity of about 30 MW, while the State Government IPPs have a 100 MW installed capacity. These facilities all have infrastructures that are old and beset by water flow and gas supply problems.

Nigerian Energy Policy

In short, Nigeria's electric power sector is in dire need of development. Introduced in 2005, Nigeria's Power Sector Reform Act hinges on the premise that the Government cannot fully finance the development of this sector. The private sector needs to be involved, but it can only participate in projects that are commercially viable and secure. It is therefore imperative to establish commercial viability and security before involving the private sector. It will also be key to strengthen the national grid, both in terms of wheeling the power to the various load centres, and by allowing private investors into the sector. Finally, the power sector needs proper investment in order to function. Well-run power utilities always have an excess capacity to call on during peak demand or in emergencies.

The Power Sector Reform Act, which was enacted in March 2005, repealed the statute establishing the National Electric Power Authority (NEPA), and gave legal backing to restructuring and eventually privatising its successor companies. It also outlined specific structures for reforming the sector, for example:

- transforming NEPA, a statutory authority, into a limited liability company called Power Holding Company of Nigeria (PHCN);
- unbundling PHCN and establishing successor companies;
- creating an independent regulator — the Nigerian Electricity Regulatory Commission (NERC);
- establishing the Consumer Assistance Fund;
- establishing the National Electricity Liability Management Company (NELMCO);
- developing a competitive electricity market;
- establishing a Rural Electrification Agency and Fund;
- creating a new, competitive electricity industry.

The Reform Act was introduced to achieve the following objectives:

Short to Medium Term Objectives:

- to ensure a system of generation, transmission, distribution and marketing that is efficient, safe, affordable and cost-effective throughout the country;
- to develop a transparent and effective regulatory framework for the power sector;
- to develop and enhance indigenous capacity in electric power sector technology;
- to promote competition to meet growing demand through the full liberalization of the electricity market.

Long Term Objectives:

- to provide a new regulatory environment that is sufficiently flexible to take into account new technological developments and the international trends in the power sector;
- to ensure that electricity supply is made more reliable, economically efficient and equitable so as to effectively support the socio-economic development of the country;
- to provide universal access to electricity, although not necessarily through the grid;
- to encourage domestic production of electrical equipment in Nigeria, and the development of related software and services;
- to encourage Nigerian electric power sector operating companies to become global leaders in the industry;
- to ensure minimum adverse environmental impact;

On paper, the power sector reform program seems ideal. However, commitment and cooperation from the various stakeholders, such as government and the private sector, are needed in order to implement the program successfully.

Developing Nigeria's power sector is also one the main objectives of President Umaru Yar'Adua's 'Eight Point Agenda' launched in Abuja, May 29, 2007. However, his administration's plans for energy development revolve around increasing energy generation by expanding the national grid. The expected 15-fold increase in conventional centralised power generation would have a significant negative impact on Nigeria's greenhouse gas emissions. It is also questionable whether a conventional, centralised energy system, managed by one or several very large entities, will actually generate energy efficiently. Recent history has shown that this isn't necessarily the case.

Funded by the United Nations Development Programme (UNDP), Nigeria's Renewable Energy Master Plan was launched in 2006. It identifies considerable potential for generating solar, small and large hydro, biomass, biogas and wind energy across the country. But very little progress has been made in implementing the Master Plan, and decentralised or renewable energy sources are not part of Nigeria's national energy strategy.

Chapter 3
The case for decentralised energy

Introduction

The World Alliance for Decentralized Energy (WADE) defines decentralised energy (DE) as 'electricity production at, or near, the point of use, irrespective of size, technology or fuel used — both off-grid and on-grid'. This includes:

1) on-site renewable energy

2) high efficiency cogeneration

3) industrial energy recycling and on-site power.

The fundamental element of a DE system is where power is generated. DE technologies generate electricity where it is needed. Central generation, on the other hand, generates electricity in large remote plants, requiring power to then be transported over long distances at high voltage before it can be used. It does not matter which technology being used to generate power, if it is connected to an existing grid or in a remote village, or whether the power comes from a clean renewable source or from burning fossil fuel: if the generator is 'on-site', it produces decentralised energy.

Strictly speaking, this means DE could involve technologies that are not necessarily environmentally friendly, such as diesel generators without heat recovery. More often than not, however, DE is synonymous with cleaner electricity — indeed that is one of DE's main benefits.

The various renewable DE technologies include:

- solar photovoltaic panels such as crystalline-silicon technologies and thin-film technologies;
- roof-top/local wind turbines;
- small-scale local hydro power, such as small-scale tidal or run-of the river;
- geothermal energy;
- renewable energy-powered fuel cells;
- thermal based technologies, including biomass-fired engines, biomass-fired steam turbines, gas turbines and micro turbines;
- plug-in electric hybrid vehicles.

Nigeria currently has only two power generators that can be categorised as DE. These are a Nigerian Electricity Supply Corp Ltd. (NESCO) small hydro plant and a diesel engine at Calabar in Cross River State. Most of the industrial and commercial companies in Nigeria and some households rely on self-generation, but they are excluded from this analysis due to insufficient data.

Centralised generation vs. decentralised energy

Renewable DE, fossil-fired DE and energy recycling offer many advantages over conventional power generation. This is true in terms of the environment, the economy, efficiency, as well as security and reliability. This is not just because of how DE technologies generate electricity, but also because of where they generate power. All three types of DE are beneficial because they provide electricity where it is required. Specifically, the advantages of using DE include the following:

Optimum use of existing energy infrastructure

Building decentralised energy ensures optimum use of existing energy infrastructure, such as gas pipelines and electricity distribution and transmission wires. Pipelines are a much more efficient and environmentally friendly way of moving energy than high voltage wires. There may therefore be a future shift from building more power wires to more fuel pipelines.

Quick start-up

One of the most important benefits of DE is that it takes very little time to install a new system. The time needed to identify, develop, negotiate, build and start a DE project is significantly shorter than for large centralised power plants. On average, 5 to 7 years are needed to start up a conventional power plant, and between 6 and 18 months for any type of DE application. DE systems have the potential to generate significant power quickly and efficiently. This makes them particularly useful in developing countries coping with rapid population growth.

Higher overall efficiency

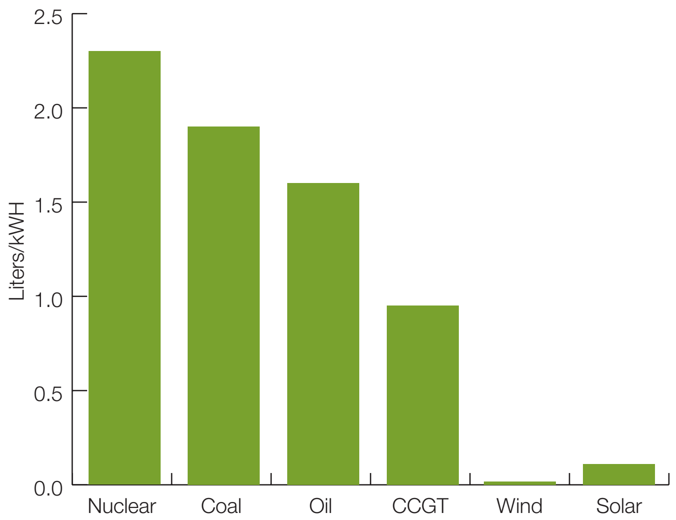
DE reduces the need for transmission and distribution (T&D) and has a higher overall efficiency than centralised power generation. Any DE application provides higher efficiency through low T&D losses. Fossil fuel DE, particularly cogeneration technology, also offers high efficiency in producing electricity and heating or cooling. Meanwhile, renewable energy technologies offer zero emission power generation, and reduce the level dependence on imported energy by using local, domestic resources.

Low water requirement and environmental benefits

Large centralised power plants, especially fossil fuel and nuclear power plants, require huge quantities of water to operate (see figure below). As a result of climate change, the lack of a sufficient water supply for power generation is quickly becoming a critical issue.

In principle, environmental protection and energy security can be drivers for developing DE in Nigeria.

Figure 3.1 Water Consumption of Different Types of Power Plants



Source: Zahedi, 2008

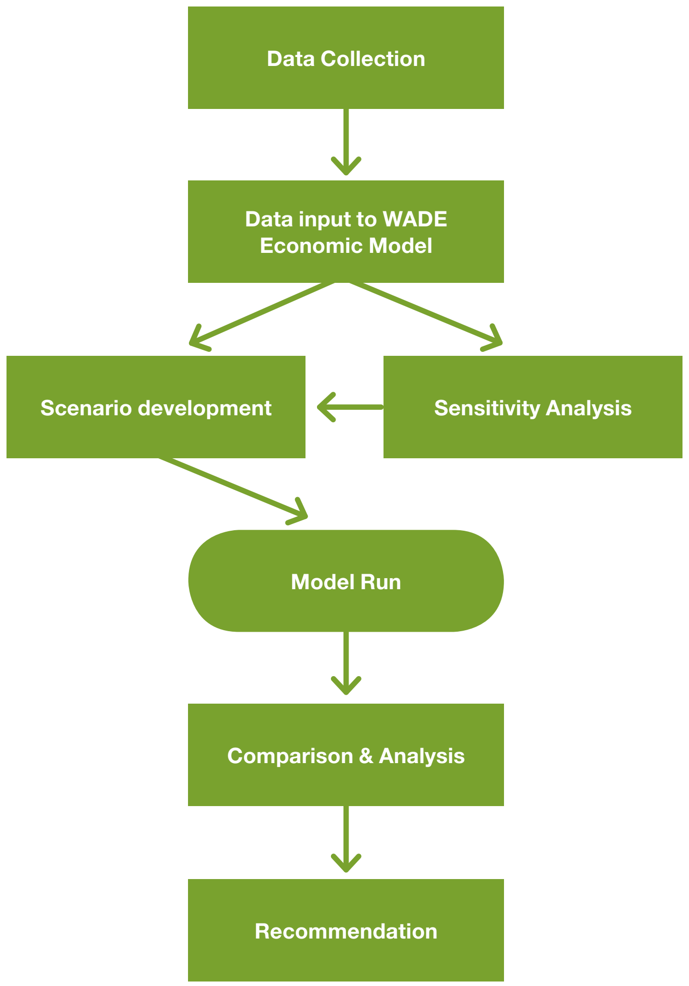
Chapter 4
Report Methodology and the WADE Economic Model

Methodology

Energy planning generally aims to design a future energy framework in a local, national, regional or even global energy system. An energy sector assessment model basically reflects complex systems in an understandable form, helps to organise large amount of data, and provides a consistent framework for testing hypotheses.

The complexity of such a model depends on variables, the parameters involved, and the extensiveness of available data to capture a reliable picture of future conditions. In many cases an energy planner has to deal with uncertainties because no scientific methods can foresee the future precisely.

Figure 4.1 shows a flow chart of the Methodology Structure used in this report:



How the WADE model works

The WADE Economic Model is designed to calculate the economic and environmental impacts of supplying and incrementally increasing electric load by using different mixes of decentralised (DE) and central power generation (CG). By changing the input assumptions, this model can be adapted to any country, region or city in the world. It has been widely used in many countries, including Canada, China, the European Union–15, the Group of 8 (G8)+5 nations (the G8 nations are Canada, France, Germany, Italy, Japan, Russia, the United Kingdom and the USA, and the five leading emerging economies are Brazil, China, India, Mexico and South Africa), Iran, Sri Lanka, Scotland, the United Kingdom, and the USA.

The model starts by establishing the generating capacity for year 0 and estimates of retirement of existing power plants and the annual incremental electricity demand (load growth). It goes on to build a picture of the capacity necessary to meet future growth and retirement over a 20-year period. The model determines the need for new capacity in each of the 20 years of the modelling period, depending on the assumptions input by the user. These include demand growth, retirement of existing plants, extent of Transmission and Distribution (T&D) losses, and load factors of new and existing plants. It assumes a constant capacity margin over the 20-year period. The model's data input requirements are detailed and extensive, requiring comprehensive information on a range of factors, including:

- existing capacity and generation by technology type;
- current and future pollutant emissions by technology type;
- future and current heat rates and fuel consumption by technology type;
- future and current capital and investment costs by technology type and for transmission and distribution (T&D);
- future and current average operation and maintenance (O&M) costs and fuel expenses by technology type;
- system growth properties for the chosen system;
- estimates of existing yearly capacity retirement by technology type;
- estimates of future growth in capacity by technology type.

The WADE model consists of four major input variables, shown in Table 4.1 below.

Input	Type of data
Capacity and Generation	• Technology selection to be included in the generation mix of CG and DE • Existing capacity and generation by technology • Current and future load factor by technology
Pollution	• Emission factor for NO_x, SO_2, PM_{10} and CO_2 by technology • Heat rate by technology
Costs	• Current and future capital cost, Operation and Maintenance (O&M) cost by technology • Current and future fuel cost • Transmission and Distribution (T&D) costs, financing term, return on capital by technology • CO_2 emission costs
Growth properties	• Annualized demand growth and peak growth • System losses - Average T&D losses - Peak T&D losses • DE peak deliverability penalty • Back up capacity: CG, DE, and T&D safety margin • Coincident peak • DE random outage • Existing capacity yearly retirement determination • New capacity: future growth determination

The model outputs are:

- total capital costs for investment (generation capacity, plus transmission and distribution) over 20 years;
- retail costs in year 20 (T&D amortisation, plus generation plant amortisation, plus O&M, plus fuel costs) for the new generation capacity;
- fossil fuel use by the new capacity in year 20, both in total and by type;
- CO_2 and other pollutant (SO_2, NO_x, PM_{10}) emissions from new generation mix and capacity in year 20;
- generation by source in year 20.

The model builds cases for new capacity to meet incremental demand over 20 years, ranging from scenarios with 0 per cent DE/100 per cent CG, to 100 per cent DE/0 per cent CG. The model also builds cases between these extremes. The WADE Economic Model enables users to run any number of scenarios that, for example, favour certain technologies, involve changed fuel prices or are required to meet specific environmental goals.

The model then determines how this new-build capacity is spread across the range of generation technologies using the 'scenario' defined by the user. This scenario specifies the percentages of energy production from each generation technology in total new build. For example, a centralised scenario could incorporate 50 per cent CCGT (gas) plant, 30 per cent coal plant and 20 per cent large-scale wind. The process of determining exactly how much capacity of each type is required is iterative, as different types of capacity have different load factors. The type of capacity built and the total amount of new capacity required to meet demand are therefore interdependent.

By taking into account the full range of cost information and input assumptions put forward by the user, the model then calculates the full costs of developing new capacity according to the chosen scenario. This calculation includes costs such as plant capital costs, fuel and operation costs, T&D costs and total carbon emissions.

The WADE Economic Model is an electricity generation sector model. However, Combined Heat and Power (CHP) co-generates heat and electricity. To determine the value of these efficiency benefits it is necessary to compare the CHP's electrical and heat output. This is the electricity generated by an alternative source and heat generated from a boiler. In the context of a full model of the energy sector, this would occur automatically within the model. But the WADE model only explicitly models the electricity generation sector. In order to bring in the full benefits of CHP for fuel efficiency, it is therefore necessary to scale up the CHP's electrical efficiency to proxy for the heat output that is also produced when electricity is generated in a CHP plant.

Key inputs

The WADE model is an input-output model, rather than an optimisation model. It simply takes the input data provided by the user and calculates the total cost accordingly. The values of the inputs are therefore crucial in determining the relative costs of different scenarios. The following are likely to be the most critical aspects in terms of determining the costs of alternative scenarios:

- Demand growth: The higher the assumed demand growth over time is, the greater the quantity of new generation will be. This in turn impacts on the quantity of capacity required to meet this demand.
- Scenario: The mix of technologies specified to meet any requirement for new generation, and therefore new capacity, drives the total costs of the scenario. This reflects the cost and emissions differences between alternative technologies.
- T&D infrastructure costs: The need to maintain and upgrade T&D networks is a key aspect of the costs incurred in any scenario.
- Efficiencies: These determine the amount of fuel required to generate electricity using a given technology, as well as the resulting carbon emissions (given the emissions factors associated with burning the relevant fuel).
- Load factors: The WADE model calculates total quantities of generation to be delivered by each technology to meet electricity demand. The translation of this total generation into a capacity figure depends upon the load factor that the plant is assumed to achieve. A higher load factor means fewer plants need to be built, and hence lower costs.
- T&D losses: The higher the losses that electrical output from a given plant is assumed to incur in transmission and distribution to the customer, the greater the total quantity of plants that must be built to meet a given level of demand.

The completed input sheet and sources for the inputs for the Nigeria reference scenarios can be found in Appendix A of this report.

Future developments

WADE is constantly working to build in additional generation technologies and more graphical representations of inputs and outputs to satisfy user requirements and improve user-friendliness. We would welcome any suggestions and recommendations from users for how to improve our model, and are happy to forward revised copies to users when any changes have been made to the model.

For further information on the WADE Economic Model, please visit www.localpower.org

Chapter 5
Developing Scenarios for Nigeria's Future Energy Sector

Developing Alternative Energy Scenarios

There are large uncertainties involved in planning a country's future energy framework. The availability of resources, global fuel prices, and new economic, technical and political situations can all affect a given energy situation. In this report we deal with these uncertainties by using different scenarios. The energy-related discussion about fighting climate change also needs to be balanced out by considering the security of the energy supply and what consumers can afford.

The WADE model builds cases for new capacity to meet incremental demand over 20 years, covering scenarios of decentralised energy's (DE) proportion of a future electricity mix. The scenarios range from 0 per cent DE and 100 per cent centralised generation (CG) to 100 per cent DE and 0 per cent CG. It is highly unlikely that the extreme cases will arise in reality, i.e. where 100 per cent of incremental generating capacity between years 1 and 20 is allocated to either new CG or DE. The variation mix of 90 per cent CG/10 per cent DE, and 60 per cent CG/40 per cent DE, was therefore applied in all the different scenarios. Later on in this report, *90 per cent CG/10 per cent DE* is referred to as CG case; and *60 per cent CG/ 40per cent DE* is referred to as DE case.

It should be kept in mind that the model compares scenarios that consider the impacts of how new generation capacity is developed, based on either a centralised or a decentralised model. In all scenarios, some existing generating plants remain in operation in 20 years' time (2009-2028), emphasising the long timeframe of infrastructure change.

Additional energy generation, as well as remaining generation from centralised and decentralised energy systems, will tend to fulfil the incremental demand in Nigeria over 20 years. Numerical assumptions for future growth determination are the parameters used to define the final share of each technology. Appendix A of this report shows the detail input of reference scenario and Appendix B shows the future shares generation in other scenarios.

Three alternative energy scenarios for Nigeria's future electricity scheme over a 20-year period (2009-2028) were developed using the World Alliance for Decentralised Energy (WADE) Economic Model:

Scenario 1: Reference Scenario

The future electricity scheme was based on the Power Development Plan in Nigeria, as quoted from the Nigeria Power Sector Reform Report for the period 2009–2020.

Scenario 2: Environmental Concern (Env) Scenario

The driver of this second scenario is environmental sustainability. Developing and deploying cleaner energy should be part of Nigeria's future investment strategy. The focus should be on progressively adopting cleaner fossil fuels based on renewable energy sources to meet electricity demand. The environmental scenario focuses on renewable energy technologies, particularly from small hydro plants, biomass and Photovoltaics (PV) in DE generation, while decreasing the share from fossil fuel plants. Clean coal technology is expected to enter the Nigerian market in this scenario.

Scenario 3: Security of Supply (SoS) Scenario

The focus of this scenario is to ensure a secure fuel supply. According to the Nigeria Power Sector Reform Report, coal and nuclear energy also feature on the list of investment options. A nuclear generating capacity of 2,000 MW is expected by 2020 and the share of clean coal technology in the electricity mix is also increased.

Input of future share generation in the Env and SoS scenarios can be seen in Appendix B of this report.

Developing sensitivity analysis scenarios

A sensitivity analysis is *'used to determine how sensitive a model is to change in the value of the parameters of the model and to change in the structure of the model'* (Breirova, 2001). Various departures from the above reference scenarios were considered to take into account the uncertainty of future projections. This helped to explore the impact on the outputs of varying several key starting assumptions. In particular, the sensitivity of the results to fuel price trends was analysed, as well as overall fuel efficiency to electricity improvement and changes in electricity demand growth. This led to the following three sensitivity scenarios, as follows:

Case A: Low electricity demand growth scenario

This scenario aims to examine the effect of changing the demand growth on the generation portfolio. Nigeria requires considerably increased demand (18.42 per cent annual growth) to reach a total capacity generation of

57,078 MW by 2020. While there is currently no coordinated Government program focusing on energy conservation and energy efficiency, various energy sector agencies sporadically speak out on this issue. There is therefore a great need for a national program on Demand Side Management (DSM). To observe the impact on the framework by assuming that the DSM program will come on board in future, the lower demand growth of 9 per cent was applied in Case A.

Case B: High natural gas price scenario

The Government fixed price for natural gas purchased by PHCN is 0.52 US$/mscf[1], according to the latest 2008 agreed pricings with Nigeria Gas Company (NGC). This is considerably lower than the price on the international market of about four US$/mscf. This scenario examines the sensitivity involved if the natural gas price in Nigeria were equal to the international gas price. This would mean a substantial reduction in the subsidy currently provided by the Government.

Case C: Low heat rate of fossil fuel-fired DE

Case B presented the future electricity framework in Nigeria in a high gas price era. The Government currently subsidises almost about 87 per cent of the retail gas price in the international market price. Besides examining the model in a high gas price era, it is also instructive to examine the impact of technology improvements in DE systems, in terms of overall efficiency, and capital and retail cost.

In the DE case it was assumed that fossil fuel fired plants were applied in on-site cogeneration systems. Cogeneration technology is predominantly applied where heat and power are consumed. In Nigeria, cogeneration technologies are mostly installed in industry. However, due to insufficient data, the onsite cogenerations in industry were excluded from this report. This scenario examines the heat rate of fossil fuel fired DE applications and evaluates the impact on the output by assuming that a DE-fired plant could achieve high overall efficiency, translating to a heat rate of 6,000 kJ/kWh or a technical efficiency above 75 per cent.

Chapter 6
Applying the WADE Economic Model to Nigeria: Main Findings

Future scenarios

The Reference, Environmental Concern (Env) and Security of Supply (SoS) scenarios outlined in Chapter 5 were developed by varying the future growth of the Nigerian generation portfolio.

- The Reference scenario was based on Nigeria's power development plan, as outlined in the Electric Power Sector Reform Act, 2005
- The Env scenario involved an increased share of renewable energy from small hydro plants, photovoltaics and biomass in DE.
- The SoS scenario included nuclear technology in CG, and coal-fired power in CG and DE.

Only the inputs of future shares of generation were altered for these scenarios; all other inputs in the model remain the same as in the Reference scenario. Appendix A shows the complete input. Table 6.1 below summarises the model outputs in year 20 by scenario.

Table 6.1 Impact of Meeting Demand Growth by 2028 with CG or DE Generation by Scenario

PARAMETERS		Reference		Environment		SoS		40%DE Env Scenario Compared to 90% CG of Reference scenario	40%DE SoS Scenario Compared to 90% CG of Reference scenario
		CG case (90% CG)	DE case (40% DE)	CG case (90% CG)	DE case (40% DE)	CG case (90% CG)	DE case (40% DE)		
		Reference		Environment		SoS			
CAPITAL COSTS (Billions of USD)	RESULTS	433	346	487	389	490	392	-10% less capital costs	-10% less capital costs
	CG-DE DIFFERENCE	-20%		-20%		-20%			
		Reference		Environment		SoS			
RETAIL COSTS (USD/kwh)	RESULTS	12.14	10.17	10.92	9.21	12.16	10.38	-24% less retail costs	-15% less retail costs
	CG-DE DIFFERENCE	-16%		-16%		-15%			
		Reference		Environment		SoS			
CO_2 EMISSIONS (Mt)	RESULTS	714	657	611	577	705	657	-19% less CO2 emissions	-8% less CO2 emissions
	CG-DE DIFFERENCE	-8%		-6%		-7%			
		Reference		Environment		SoS			
NO_x EMISSIONS (Mt)	RESULTS	2,903	2,803	2,585	2,535	2,689	2,679	-13% less NOx emissions	-8% less NOx emissions
	CG-DE DIFFERENCE	-3%		-2%		-0.39%			
		Reference		Environment		SoS			
SO_2 EMISSIONS (Mt)	RESULTS	621	467	507	386	532	401	-38% less SO2 emissions	-35% less SO2 emissions
	CG-DE DIFFERENCE	-25%		-24%		-25%			

high moderate low

continued overleaf

Table 6.1 continued

PARAMETERS		Reference		Environment		SoS		40%DE Env Scenario Compared to 90% CG of Reference scenario	40%DE SoS Scenario Compared to 90% CG of Reference scenario
		CG case (90% CG)	DE case (40% DE)	CG case (90% CG)	DE case (40% DE)	CG case (90% CG)	DE case (40% DE)		
		Reference		**Environment**		**SoS**			
PM_{10} EMISSIONS (Mt)	RESULTS	427	382	385	347	393	361	**-19% less PM_{10} emissions**	**-15% less PM_{10} emissions**
	CG-DE DIFFERENCE	-11%		-10%		-8%			
		Reference		**Environment**		**SoS**			
FUEL USE (TWh fuel/year)	RESULTS	3,251	3,071	2.883	2,875	3,119	2,980	**-12% less fuel use**	**-8% less fuel use**
	CG-DE DIFFERENCE	-6%		-0.27%		-4%			

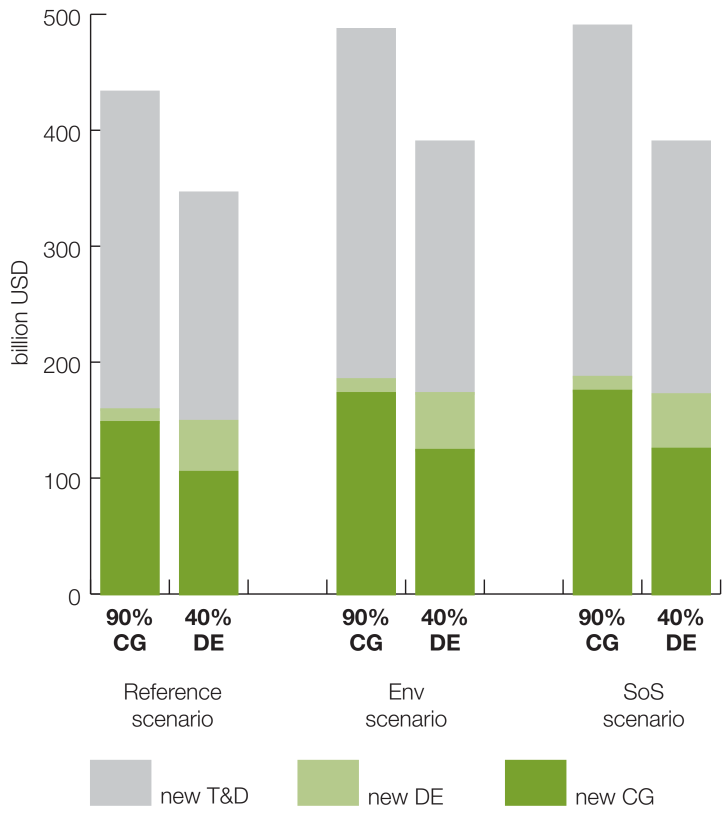
high moderate low

Source: WADE, 2009

Impact on capital costs

The total investment cost required for each scenario was calculated based on the capital cost of new power plants built during simulation periods, including CG, DE and T&D costs. Figure 6.1 shows detailed impact on capital costs for year 20 by scenario.

Figure 6.1 Impact on Capital Costs in 2028 by Scenario



Source: WADE, 2009

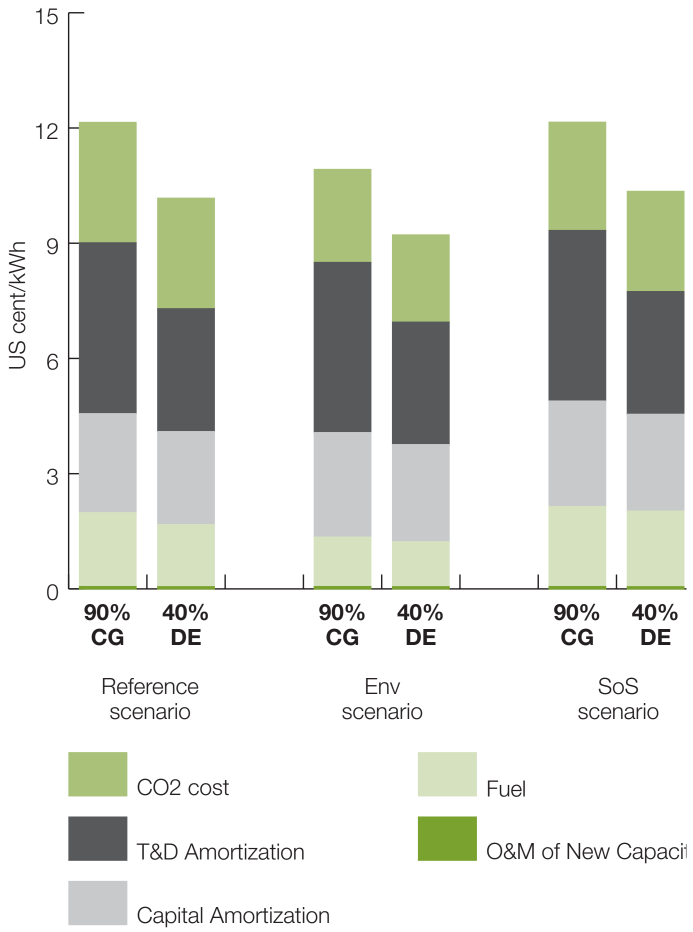
Main findings

- Huge investment of around US$400 billion will be required for all scenarios to achieve their total capacity of generating up to 57,000 MW by 2020, according to the Nigeria Power Development Plan.
- The DE case (see Chapter 5 paragraph 2 for the definition of the DE case) reduced capital costs by 20 per cent, saving more than US$80 billion in all scenarios compared to the CG case. This reduction results from fewer T&D networks being required to transmit and distribute electricity to the end consumer.
- A reduction in CG capital costs requires investment in new DE systems to meet incremental demand over 20 years. Since 2006, Nigeria's Government has involved the private sector in developing the power sector. However, until now, the Government does not have an incentive investment mechanism in place to make the system attractive. A feed-in tariff mechanism (see glossary) has been implemented successfully in several countries, and could be applied in Nigeria to promote DE development and to attract investors.
- Significant savings occur from reduced investment in the transmission network (around 86 per cent of total savings). DE technologies supply electricity at the point of use or at the distribution level. DE systems do not require high voltage transmission lines. Therefore, T&D investment is reduced as DE market share increases.
- The reference scenario provides the lowest capital costs. The SoS scenario presents the highest capital costs as a result of commissioning a new nuclear plant.
- Compared to the CG case in the Reference scenario, a four-fold increase in DE capacity in the Env and SoS scenarios yields 10 per cent fewer capital costs respectively.

Impact on retail cost

WADE estimates the retail cost of the three scenarios based on summing up five parameters: operation and maintenance (O&M) cost, CO2 cost, T&D amortisation, capital amortisation and fuel cost. The following table compares the delivered electricity price in 2028 by scenario.

Figure 6.2 Retail Electricity Price in 2028 by Scenario



Source: WADE, 2009

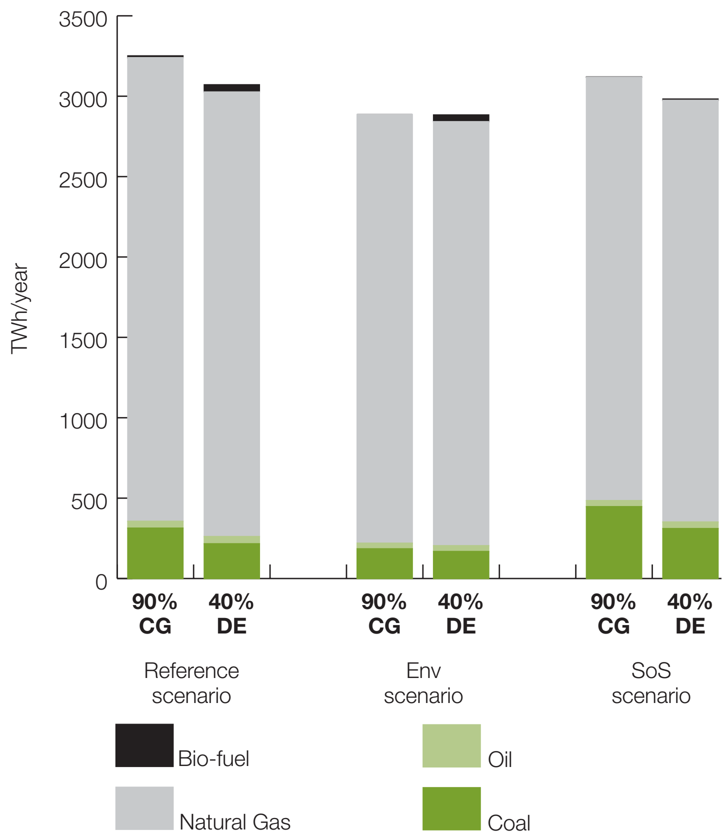
Main findings

- A higher DE share reduces the delivered cost because it requires a less extensive T&D network compared to CG. In addition, it cuts energy losses from the network and therefore requires less fuel input.
- The Env scenario has the lowest retail costs due to its high renewable energy share (hydro and solar PV). Much of the reduction comes from reduced fuel costs.
- Compared to CG in the Reference scenario, a four-fold increase in DE capacity in the Env and SoS scenarios yields 24 per cent and 15 per cent fewer retail costs respectively.

Impact on fuel use

Four different types of fuel were analysed as part of the different scenarios: coal, oil, natural gas and bio-fuel. Figure 6.3 shows in detail the impact on fuel use for year 20, by scenario.

Figure 6.3 Fuel Consumption in 2028 by Scenario



Source: WADE, 2009

Main findings

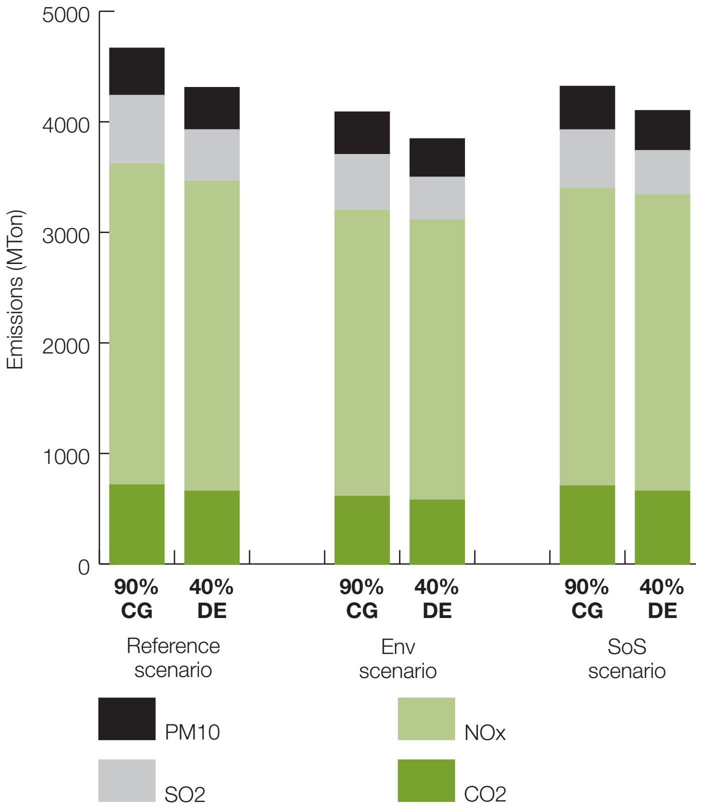
- The fuel input required to generate electricity in all scenarios by 2028 is still heavily reliant on fossil fuels, particularly natural gas, with a relative share of around 90 per cent.
- In all scenarios, the DE case consumed less fossil fuel than in the CG case. This was due to the impact of reduced network losses, ultimately reducing the fuel used to generate electricity.

Impact on pollution levels

In the case of Nigeria it was assumed that introducing decentralised energy generation aims to increase energy efficiency, reduce dependence on imports and improve the national economy. However, positive environmental effects would also result from increased DE deployment.

Four pollutant levels were analysed in this report, including NO_x, SO_2, PM_{10} and CO_2. This report calculated the amount of emissions caused by new power generation over 20 years. The emission level of different pollutants by scenario can be seen in Figure 6.4.

Figure 6.4 Pollution Levels in 2028 by Scenario



Source: WADE, 2009

Main findings

- Decentralising the electricity supply offers a more effective way of reducing emissions. Compared to CG, in all scenarios DE cuts above 6 per cent, 0.4 per cent, 24 per cent, and 8per cent for CO2, NOx, SO2, and PM10 respectively.
- The Env scenario results in the lowest pollution levels in 2028 of the three scenarios. This is due to the fact that generating renewable energy emits less pollution than conventional fossil fuels.
- Natural gas is well known as a clean fossil fuel. Although the Reference scenario has a higher natural gas share compared to the Env and SoS scenarios, it cuts fewer emissions overall than the other scenarios. This is because future gas-fired plants will mostly be built in the form of gas turbines. According to data provided by Nigerian experts, the future technical efficiency of fuel to electricity conversion (expressed as a heat rate parameter in the WADE Economic Model) has a lower heat rate than in the actual situation. Improved technology to increase the technical efficiency will cut emissions and mitigate the impact of climate change considerably.

Sensitivity analysis

Several scenarios were also run to test the sensitivity of the inputs. One of the specific objectives of this report is to examine the sensitivity of the model results and to understand the consequences of changing electricity demand growth for system capacity and economic parameters in the scenario costing. Refer to Table 6.2 for the summary of variable changes in the sensitivity test.

Table 6.2 Summary of Variable Changes in the Sensitivity Test

PARAMETERS	Reference	Case A - Low demand growth	Case B - High Gas Cost	Case C - Low heat rate of fossil fuel-fired DE
NATURAL GAS COST (USD/GJ)	0.52	0.52	4	4
DEMAND GROWTH (%)	18.42%	9%	18.42%	18.42%
HEAT RATE OF FOSSIL FUEL FIRED IN DE GENERATION (KJ/kWh)	10,000	10,000	10,000	6,000

Source: WADE, 2009

In each of these scenarios, only the named variable was changed; all other inputs remain as in the Reference scenario.

Table 6.3 Summary of Results of Sensitivity Test

PARAMETERS			BAU		Case A – Low demand growth		Case B –High Gas Cost		Case C – High DE fossil fuel efficiency	
			CG (90% CG)	DE (40% DE)	CG (90% CG)	DE (40% DE)	CG (90% CG)	DE (40% DE)	CG (90% CG)	DE (40% DE)
CAPITAL COST (Billions of USD)		RESULTS	433	346	74	57	433	346	433	346
		DIFFERENCE	-20%		-23%		-20%		-20%	
RETAIL COSTS (USD/kWh)		RESULTS	12.14	10.17	11.59	9.36	18.40	16.21	188.10	14.99
		DIFFERENCE	-16%		-19%		-12%		-17%	
EMISSIONS (Mton)	CO_2	RESULTS	714	657	128	114	714	657	709	599
		DIFFERENCE	-8%		-11%		-8%		-15%	
	NO_x	RESULTS	2,903	2,803	553	555	2,903	2,803	2,817	2,461
		DIFFERENCE	-3%		0%		-3%		-13%	
	SO_2	RESULTS	621	467	130	94	621	467	620	464
		DIFFERENCE	-25%		-28%		-25%		-25%	
	PM_{10}	RESULTS	427	382	79	67	427	382	419	346
		DIFFERENCE	-11%		-15%		-11%		-17%	
FUEL USE (TWh/year)		RESULTS	3,251	3,071	637	590	3,251	3,071	3,168	2,741
		DIFFERENCE	-6%		-7%		-6%		-13%	

Source: WADE, 2009

Main findings

- Electricity demand growth is the variable that most affects the future electricity framework. Reducing demand growth to 9 per cent from 18.42 per cent would reduce the costs, emission levels, and fuel use to meet incremental demand over a 20-year period. It cuts capital costs by more than 80 per cent, while reducing retail costs by over 5 per cent in comparison with CG and DE cases between the Reference and Case A sensitivity scenarios. It indicates that an energy efficiency program, particularly Demand Side Management (DSM), is a highly effective solution that can reduce the power demand and delay or offset the need for future power plant construction.
- Increasing natural gas price from 0.52 US$/mscf to 4 US$/mscf in Case B increased the retail cost compared to the Reference scenario. It shows that retail cost is the most sensitive variable output when fuel costs change. Moreover, the increase in the natural gas price for power generation in Nigeria obviously has a substantial impact on the overall retail cost because natural gas dominates the fuel input in the country's power sector.
- Case C assumed a low heat rate for fossil fuel-fired DE. The DE case in the Reference scenario is based heavily on gas-fired cogeneration, while the CG case is based heavily on gas-fired conventional plants. The DE savings between CG and DE in Case C increase from 1.98 US$/kWh in the reference scenario to 3.11 US$/kWh in Case C. This implies that in competitive terms, cogeneration will suffer less from an increase in the gas price than CG plants in high gas penetration markets. This is because cogeneration derives more value from the primary energy and produces both heat and electricity, in contrast to a combined cycle plant without heat recovery. This indicates that cogeneration should be in a position to compete in the electricity market. The viability of cogeneration systems in Nigeria requires further research to investigate the potential uses of waste heat output. There is huge potential for using steam to generate power for Nigeria's industrial and commercial building sectors, as well as ordinary households.

In conclusion, our findings show that using decentralised energy will bring significant benefits for Nigeria's economic and environmental sectors. The country can achieve a saving of US$80 billion, or a 20 per cent reduction in capital costs by 2028, compared to using centralised generation. These savings mainly result from reduced investment in transmission lines. Nevertheless, approximately US$400 billion must be invested in each DE case.

Among the three scenarios, the Reference scenario provides the lowest capital costs, while the Security of Supply scenario presents the highest capital costs as a result of commissioning a nuclear plant. Moreover, the DE case produces a lower retail cost compared to the CG case (15-16 per cent reduction). The Environmental Concern scenario yields the lowest retail cost, as a result of reduced fuel costs due to a high renewable energy share.

Chapter 7
Next Steps: Creating A Competitive Framework for Decentralised Energy in Nigeria

Decentralised energy generation has been shown to offer substantial advantages over conventional power generation in Nigeria. This remains true across a range of areas, including the environment, the economy, efficiency, security and reliability, as outlined in the previous chapters. A future DE framework can bring considerably more benefits than it has done in the past. However, many barriers still prevent DE from competing with large-scale centralised generators. This section describes these barriers and discusses possible steps to remove them.

Ending unrest in the Niger Delta

Natural gas currently plays a vital role in the Nigerian electricity sector, and this is likely to continue in the future. However, the natural gas supply to power plants is often interrupted by social and political instability in the Niger Delta. This often leaves natural gas plants unavailable for use. Higher application of DE, particularly gas-fired technology, requires natural gas pipelines to be expanded in order to supply natural gas directly to power plants. Ending the social problems in the Niger Delta would improve access to natural gas supplies and allow more gas-fired power to be generated.

Improving access to electricity in rural areas

People's access to grid power varies substantially across Nigeria's various regions, and is particularly low in rural areas. Using decentralised energy in these areas will help to reduce energy poverty because of greater reliance on local energy resources. In order to achieve improved access to grid electricity in rural areas, the rural electrification program needs to be merged with the Nigeria Power Development Plan.

Honest and open dialogue

The success of power sector reform in Nigeria depends on all parties involved being willing to discuss the process honestly and openly. Corruption and chronic mismanagement of the energy sector must end for true reform to take place.

Recommendations

The following recommendations are key to moving forward on large-scale deployment of renewable energy technologies in Nigeria:

Establishing a legal and regulatory framework
All the objectives listed in the Power Sector Reform programme, if fully implemented, will help solve the energy poverty issue in Nigeria. NERC must monitor the activities of all participants in the electricity market and ensure that all rules, regulations, and codes are enforced in a fair, transparent and equitable way. It is also crucial to institutionalise and improve the relevant legal and administrative framework, including establishing a serious commitment to developing and enforcing standards, regulations and codes for Renewable Energy Technologies and Systems (RET/RES). NERC also has to ensure that each energy sector decision will be in the public interest.

Regular evaluation
The government should plan to review, periodically assess and evaluate the existing National Energy Policy, Renewable Energy Master Plan, Solar PV Master Plan, Energy Master Plan, and Renewable Electricity Master Plan.

Increased national awareness
In order to create awareness of new energy sources, research into Renewable Energy Technologies and Systems should be promoted nationally, as should news about their development, uses, deployment and dispersal. Disseminating information about new energy sources, drawing up public awareness strategies and Consumer Consultation Services will also be important.

Investment and private sector involvement
Speeding up DE deployment in Nigeria requires huge investment that exceeds the current capability of the domestic private sector. So far, foreign investment capital and national foreign exchange earnings have funded energy sector investment. Introducing new market incentives, along with fiscal and regulatory measures at the national and local Government levels, could encourage more private investment in the power sector. In addition, feed-in tariffs (see glossary) could stimulate the private sector to invest in DE technology and make DE viable.

International cooperation

Developing international cooperation is important, especially in the areas of developing local RETs and RES manufacturing capacity and Smart Grid systems that can enable grid stability when RE electricity is injected.

Education and training

The government, together with educational institutions, should establish education and training in RETs and RES to develop the skills and knowledge of technicians, engineers, administrators, and so on.

Further research

Many of Nigeria's potential cogeneration application target sites considered in this report remain untapped. Given the huge potential for cogeneration application in Nigeria, it is important to conduct further research into the country's existing factories and buildings and into expanding the target sectors for cogeneration application. Moreover, the cogeneration application in new residential, commercial, and industrial facilities that fulfill the cogeneration criteria should also be promoted. Electricity can be generated through cogeneration if the following criteria are met:

- there is a demand for heat or cooling from particular industries,
- the industries and the infrastructure they use operate at high annual hours
- the industries and the infrastructure they use are connected to a natural gas pipeline network if they are natural gas-based.

Promoting economic activities that fulfill the above criteria would allow them to use localised energy sources near the load center. It is more economic and less polluting to install cogeneration than to reinforce the T&D network.

Chapter 8
Key conclusions

This report's main findings have led the authors to conclude the following:

- Decentralising energy to generate electricity for Nigeria will lead to cheaper power, lower fuel use, reduced energy losses and lower levels of emissions compared to CG. This is mainly because DE is installed at, or near, the point of use, avoiding extensive transmission network investment.
- WADE's projected Environmental Concern scenario is the most advantageous scenario for Nigeria in the future — in terms of retail cost, emission levels and fuel use. The reduced retail cost is due to a reduction of fossil fuels used to generate electricity. Furthermore, this scenario also reduces the cost of generating electricity and cuts emissions. Nigeria has considerable renewable energy resources that have not yet been exploited. The Government must lead the way towards clean power generation.
- The most effective way to reduce costs and emissions in Nigeria's power sector is by reducing or preventing demand growth. Demand growth trends were the most important factor analysed when determining the costs and emissions of electricity generation. Fuel prices and Transmission and Distribution investment requirements also affected the cost results of the modelling.
- More efficient use of energy by industries and households could help Nigeria to reduce or prevent future growth in the demand for energy. In addition, Supply Side Management (SSM), for example through cogeneration applications, could provide more efficient electricity generation.
- DE with cogeneration application offers higher DE savings compared to conventional technology when natural gas dominates the fuel input to generate electricity. In a high-price natural gas era, cogeneration provides a better system price than conventional plants. Cogeneration also derives higher overall efficiency by producing two products, electricity and heat, in contrast to a conventional plant without heat recovery.
- Finally, the various stakeholders' commitment and willingness to work together is the key to successfully deploying a decentralised energy system in Nigeria.

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World Alliance for Decentralised Energy www.localpower.org

Appendix A
Input data in reference scenarios

Existing Capacity and Generation in 2008, the existing and the future load factor

TECHNOLOGY	CAPACITY	LOAD FACTOR	GENERATION	FUTURE LOAD FACTOR
	[GW]	[%]	[TWh]	[%]
Centralized Generation				
Gas Turbine (Gas)	3.804	66%	21.87	78%
Gas ST	1.32	73%	8.47	78%
Gas CC (CCGT)	0.78	82%	5.57	78%
Hydro - Large	1.30	90%	10.25	80%
Diesel Engine	0.30	73%	0	78%
Coal ST	0	0	0	78%
Nuclear	0	0	0	78%
Decentralized Energy				
Diesel engine	0.004	78%	0.027	78%
Hydro-small	0	0	0	80%
Gas Turbine	0	0	0	78%
PV	0	0	0	16%
Biomass	0	0	0	78%
Coal	0	0	0	78%

Source : PHCN, IPP, Joint Venture (JV), & private sector database

Input Pollution

	POLLUTION LEVEL									HEAT RATE	
Tech-nology	Current	Future (exist. equip)	Future (New Equip)	Current	Future (exist. equip)	Future (New Equip)	Current	Future (exist. equip)	Future (New Equip)	Existing Mix	Future Plants
	[Kg/GJ]	[Kg/GJ]	[Kg/GJ]	[Kg/GJ]	[Kg/GJ]	[Kg/GJ]	[Kg/GJ]	[Kg/GJ]	[Kg/GJ]	[kJ/kWh]	[kJ/kWh]
	NOX			SOX			PM 10				
Centralized Generation											
Gas Turbine (Gas)	0.27	0.27	0.27	0.00	0.00	0.00	0.03	0.03	0.04	10,576	11,629
Gas ST	0.27	0.27	0.27	0.00	0.00	0.00	0.03	0.03	0.03	10,526	11,575
Gas CC (CCGT)	0.05	0.05	0.05	0.00	0.00	0.00	0.02	0.02	0.02	6375.00	7003.63
Hydro - Large											
Diesel Engine	2.31	2.31	2.31	5.262	5.262	5.262	0.1225	0.1225	0.1220	10,954	10,909
Coal ST	0.10	0.10	0.10	0.00	0.00	0.00	0.01	0.01	0.01	10,954	10,909
Nuclear											
Decentralized Energy											
Diesel engine	2.31	2.31	2.31	0.00	0.00	0.00	0.01	0.01	0.01	10,000	10,000
Hydro-small											
Gas Turbine	0.27	0.27	0.27	0.003	0.003	0.003	0.0318	0.0318	0.0320	10,000	10,000
PV											
Biomass										10,000	10,000
Coal	0.10	0.10	0.10	0.00	0.00	0.00	0.01	0.01	0.01	10,000	10,000

Source : Emission Rates for Distributed Generation (DG) Technologies, May 2001 - RAP, Eff 5/21/01

Input Cost

	INSTALLED COST				T&D COST				O&M COST	
Tech-nology	Installed Cost	% change	Return on Capital	Financing Term	Trans-mission	Distri-bution	Return on Capital	Financing Terms	O&M (Current Plants)	O&M (Future Plants)
	[USD/kW]	[%]	[%]	[years]	[USD/kW]	[USD/kW]	[%]	[years]	[USD/MWh]	[USD/MWh]
Centralized Generation										
Gas Turbine (Gas)	622	1%								
Gas ST	622	1%								
Gas CC (CCGT)	456	1%								
Hydro - Large	1,621	-3%	10%	10	1062	1062	10%	10	0.4	0.4
Diesel Engine	778	0%								
Coal ST	778	0%								
Nuclear	1,700	0%								
Decentralized Energy										
Diesel engine	778	0%								
Hydro-small	876	0%								
Gas Turbine	778	0%	10%	10	1062		10%	10	0.4	0.4
PV	5,280	-1%								
Biomass	778	0%								
Coal	778	0%								

Source : Power Sector Reform Committee Report, 2008; and World Bank (2007)

	FUEL COST		CO2 COST							
Tech-nology	Fuel Cost	Fuel Cost – Annual-ized Increase (Reduction)	Period 1 finalyear : CO2 emissions target : 100%		Period 2 finalyear : CO2 emissions target : 95%		Period 3 finalyear : CO2 emissions target : 92%		Period 4 finalyear : CO2 emissions target : 90%	
	[USD/GJ]	[%]	2009	2010	2011	2019	2020	2025	2026	2028
			Price [USD/t]							
			100%		95%		92%		90%	
Centralized Generation										
Gas Turbine (Gas)	0.52	4%	12	12	15	30	40	42	42	45
Gas ST	0.52	4%								
Gas CC (CCGT)	0.52	4%								
Hydro - Large										
Diesel Engine	3.78	5%								
Coal ST	8.0	0%								
Nuclear	4.4	0%								
Decentralized Energy										
Diesel engine	3.779	5%	12	12	15	30	40	42	42	45
Hydro-small										
Gas Turbine	0.52	4%								
PV										
Biomass	1.00	0%								
Coal	8.0	0%								

Source : Power Sector Reform Committee Report, 2008; and World Bank (2007

In-growth Properties

TECHNOLOGY	RETIREMENT [MW]																			
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Centralized Generation																				
Gas Turbine (Gas)	95.10	95.10	95.10	95.10	95.10	95.10	95.10	95.10	95.10	95.10	95.10	95.10	95.10	95.10	95.10	95.10	95.10	95.10	95.10	95.10
Gas ST	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00
Gas CC (CCGT)	19.50	19.50	19.50	19.50	19.50	19.50	19.50	19.50	19.50	19.50	19.50	19.50	19.50	19.50	19.50	19.50	19.50	19.50	19.50	19.50
Hydro - Large	18.57	18.57	18.57	18.57	18.57	18.57	18.57	18.57	18.57	18.57	18.57	18.57	18.57	18.57	18.57	18.57	18.57	18.57	18.57	18.57
Diesel Engine																				

Source : Own assumption

- Thermal Plants : assumed the plant lifetime is 40 years 1/40 from total installed capacity will be retired every year
- Large hydro plant : assumed the plant lifetime is 70 years, then 1/70 from total installed capacity will be retired per year

TECHNOLOGY	FUTURE SHARES OF GENERATION (%)																			
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Centralized Generation																				
Gas Turbine (Gas)	73%	73%	73%	73%	78%	78%	78%	78%	78%	78%	78%	55%	55%	55%	55%	55%	54%	54%	54%	54%
Gas ST	9%	9%	9%	9%	5%	5%	5%	5%	5%	5%	5%	2%	2%	2%	2%	2%	2%	2%	2%	1%
Gas CC (CCGT)	6%	6%	6%	5%	7%	7%	7%	7%	7%	7%	7%	4%	4%	4%	4%	4%	4%	4%	4%	4%
Hydro – Large	9%	9%	10%	10%	6%	6%	6%	6%	6%	6%	6%	29%	29%	29%	29%	29%	29%	30%	30%	30%
Diesel Engine	2%	2%	2%	2%	1%	1%	1%	1%	1%	2%	2%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Coal ST	0%	0%	0%	0%	2%	2%	2%	2%	2%	2%	3%	9%	10%	10%	10%	10%	10%	10%	10%	10%
Decentralized Energy																				
Diesel engine	100%	100%	100%	100%	1%	1%	1%	1%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Hydro-small	0%	0%	0%	0%	39%	39%	39%	39%	39%	39%	39%	7%	7%	7%	7%	7%	7%	7%	7%	7%
Gas Turbine	0%	0%	0%	0%	29%	29%	29%	29%	29%	29%	29%	91%	91%	91%	91%	91%	91%	91%	91%	91%
PV	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Biomass	0%	0%	0%	0%	30%	30%	30%	30%	30%	30%	30%	2%	2%	2%	2%	2%	2%	2%	2%	2%

Source : Power Sector Reform Committee Report, 2008

Appendix B
Input of Future Shares Generation in Alternative Scenarios

Environmental Concern Scenario

TECHNOLOGY	FUTURE SHARES OF GENERATION (%), ENV SCENARIO																			
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Centralized Generation																				
Gas Turbine (Gas)	73%	70%	66%	64%	61%	59%	57%	55%	54%	52%	51%	52%	50%	49%	48%	47%	47%	46%	45%	44%
Gas ST	9%	9%	8%	8%	4%	4%	4%	4%	4%	3%	3%	2%	2%	2%	2%	1%	1%	1%	1%	1%
Gas CC (CCGT)	6%	5%	5%	5%	6%	6%	5%	5%	5%	5%	5%	4%	4%	4%	4%	3%	3%	3%	3%	3%
Hydro - Large	9%	14%	18%	22%	24%	27%	29%	31%	33%	35%	37%	38%	39%	41%	42%	43%	44%	45%	46%	46%
Diesel Engine	2%	2%	2%	2%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	0%	0%	0%	0%
Coal ST	0%	0%	0%	0%	3%	3%	3%	3%	3%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
Decentralized Energy																				
Diesel engine	100%	100%	100%	100%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Hydro-small	0%	0%	0%	0%	39%	13%	12%	12%	11%	11%	11%	11%	11%	11%	11%	11%	11%	11%	11%	11%
Gas Turbine	0%	0%	0%	0%	30%	70%	72%	72%	73%	73%	73%	73%	73%	73%	73%	73%	73%	73%	73%	73%
PV	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%
Biomass	0%	0%	0%	0%	30%	17%	16%	16%	16%	16%	16%	16%	16%	16%	16%	16%	16%	16%	16%	16%
Coal	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Security of Supply Scenario

TECHNOLOGY	FUTURE SHARES OF GENERATION (%), SoS SCENARIO																			
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Centralized Generation																				
Gas Turbine (Gas)	73%	69%	66%	63%	61%	59%	56%	54%	53%	52%	50%	49%	48%	48%	47%	46%	46%	46%	45%	45%
Gas ST	9%	9%	8%	8%	4%	4%	4%	4%	3%	3%	3%	2%	2%	2%	2%	1%	1%	1%	1%	1%
Gas CC (CCGT)	6%	5%	5%	5%	6%	6%	5%	5%	5%	5%	5%	4%	4%	4%	3%	3%	3%	3%	3%	3%
Hydro - Large	9%	15%	19%	23%	25%	27%	28%	29%	30%	31%	32%	31%	31%	32%	32%	33%	33%	34%	34%	34%
Diesel Engine	2%	2%	2%	2%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	0%	0%
Coal ST	0%	0%	0%	0%	2%	4%	5%	7%	8%	9%	9%	9%	10%	11%	11%	11%	12%	12%	12%	13%
Nuclear	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	4%	4%	4%	4%	4%	3%	3%	3%
Decentralized Energy																				
Diesel engine	100%	100%	100%	100%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Hydro-small	0%	0%	0%	0%	39%	11%	9%	8%	7%	7%	7%	5%	5%	5%	5%	5%	6%	6%	6%	6%
Gas Turbine	0%	0%	0%	0%	29%	83%	88%	90%	91%	92%	92%	74%	76%	77%	79%	80%	81%	82%	83%	83%
PV	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Biomass	0%	0%	0%	0%	30%	5%	3%	2%	1%	1%	1%	1%	1%	1%	1%	0%	0%	0%	0%	0%
Coal	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	20%	18%	16%	15%	14%	13%	12%	11%	11%

Front cover image: Small scale solar energy project in the village of Wawan Rafi, Jigawa State Northern Nigeria. 2006. Washing the solar panels on the roof of the business centre.

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