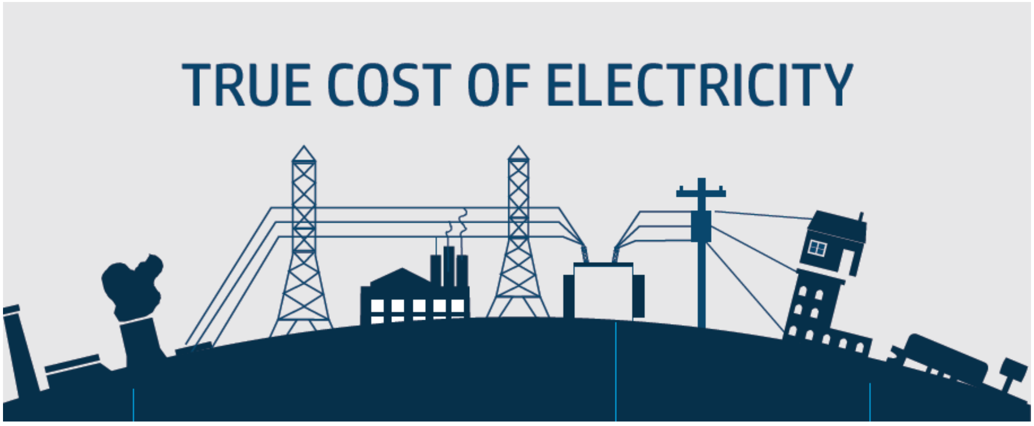

Comparison of Costs of Electricity Generation in Nigeria

Abuja, June 2017

HEINRICH BÖLL STIFTUNG NIGERIA

The Nigerian Economic Summit Group
RC:303317

This Report was produced by the Nigerian Economic Summit Group and Heinrich Böll Stiftung Nigeria. The Lead Author is Maria Yetano Roche supported by Nnanna Ude and Ikenna Donald-Ofoegbu, with inputs from stakeholders in the Nigerian power sector. The Report was reviewed by Dr. Felix Matthes (Oeko Institute, Berlin) and Hans Verolme (Climate Advisers Network, Berlin).

Contents

Table of Figures

List of abbreviations

CAPEX	Capital Expenditure
CCGT	Combined Cycle Gas Turbine
CO_{2e}	Carbon Dioxide equivalent
CRF	Capital Recovery Factor
DEA	Danish Energy Agency
ERGP	Economic Recovery & Growth Plan
FOM	Fixed Operating & Maintenance Cost
GHG	Greenhouse Gases
GIZ	German International Cooperation
HBS	Heinrich Böll Foundation
IEA	International Energy Agency
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency
kWh	Kilowatt Hour
LCOE	Levelised Cost of Electricity
MW	Megawatt
MWh	Megawatt Hour
NDC	Nationally Determined Contributions (under the Paris Climate Agreement)
NERC	Nigerian Electricity Regulatory Commission
NESG	Nigerian Economic Summit Group
NESP	Nigerian Energy Support Programme
NPV	Net Present Value
NREAP	National Renewable Energy Action Plan
OCGT	Single Cycle Gas Turbine
OPEX	Operating Expenditure
PV	Photo Voltaic
RE	Renewable Energy
RESIP	Rural Electrification Strategy Implementation Plan
SCOE	Society Cost of Electricity
SE4ALL	Sustainable Energy For All Programme
Solar PV	Solar Photovoltaic
TWh	Terrawatt Hour
U.S. DoE	United States Department of Energy
VOM	Variable Operating & Maintenance Cost
WACC	Weighted Average Cost of Capital

Executive Summary

One hundred million Nigerians, representing 60% of the country's population, have no access to grid electricity. Those who do have grid access experience extremely unreliable supply. Efforts are underway to accelerate the transition to an adequate electricity generation capacity that can meet the current and future demand of Nigerian citizens and their businesses. However, there is as yet no clear vision of what Nigeria's future electricity generation mix can and should be, nor is there a concept of how to align such a vision with the country's sustainable development, industrialisation and climate protection goals.

This report summarises the results of an exploratory study into the costs of different electricity generation technologies in Nigeria. This study uses the concepts of levelised cost of electricity (LCOE) and society's cost of electricity (SCOE) as tools to expose two different standpoints in the evaluation of the costs of power generation: that of the private investor, and that of society as a whole. One of the key strengths of the study is its reliance on Nigerian-based data wherever possible, complemented where necessary with international data from renowned sources.

The findings show that, from an investor's perspective, onshore wind, biomass, and hydropower are currently competitive with coal and gas-fired power stations, despite investment risks being higher in Nigeria than the global average (both for renewables and conventional power). The lower range of costs for utility-scale solar PV in Nigeria (US 10-11cents/kWh) is also within the range of coal power generation costs. When forecasting costs up to 2025 based on widely agreed cost reduction assumptions, on-grid solar PV will be fully competitive with coal generation in Nigeria in the next 5 years. The competitiveness of natural gas-powered electricity remains strong, however the availability of fuel in the long term is in doubt, be it due to deficient distribution or to resource depletion in the midterm. The cost structures of renewable energy sources and natural gas differ widely. Natural gas-based power generation has lower upfront costs but is vulnerable to volatile fuel prices, whereas electricity generation from renewables has higher upfront costs but provides electricity at costs that are highly predictable.

At present the costs to society as a whole (encompassing the health-related costs of air pollution and damages of climate change) drive the costs of fossil-fuel based technologies up and make solar PV fully competitive with coal and with natural gas under a cost of carbon of 40 and 100 USD/tCO2e, respectively. If society's costs are projected ten years into the future, solar PV and wind undercut the costs of even the cheapest fossil-fuel based generation.

In off-grid generation, off-grid solar PV systems are already cost competitive in Nigeria on a lifetime basis, costing an average of USD 20 cents/kWh as opposed to diesel generators USD 30 cents/kWh and gasoline over USD 60 cents/kWh. The lower upfront costs of diesel and petrol generators make them more attractive to investors (who are frequently the consumers of the power as well). Global innovations in financing and business models that overcome this barrier remain underexploited in Nigeria.

While the significance of renewable energy in Nigeria's future mix is now routinely acknowledged, it is still perceived as a high-risk investment despite recent technological and policy innovations. This study gives evidence that renewable energy is competitive today and in the mid-term in Nigeria, and more so when the costs to society are considered.

There are a number of limitations to this exploratory study. Merely comparing electricity generation costs between different plant types can be misleading, as other metrics such as total system costs are relevant in national scale investment decisions. LCOE does not elucidate which generation technology is the most viable at specific locations in Nigeria.

Resource availability, distance to grid and other location-specific considerations are needed to give the full picture. Moreover, the comparison of costs across offgrid systems of different size and load type must be approached with caution.

The comparison of LCOE provides one element of the information needed for designing robust strategies and cost recovery arrangements for Nigeria's energy sector. Any future assessment of different options or pathways towards Nigeria's future electricity vision should reflect the dynamics of cost trajectories. Global developments over the last two decades as well as recent trends clearly indicate that the costs of solar and wind energy as well as of storage technologies are set to decrease in Nigeria whereas the investment costs for conventional generation (in particular for coal and nuclear power) will at best remain constant.

1. Background

One of Nigeria's most demanding challenges today is to deliver access to electricity to millions. This means, among other things, a dramatic increase in electricity generation capacity. Various important targets were put forward in 2016 (see Box 1) and many parties are vigorously working on improving the regulatory framework and triggering the necessary investments. But, apart from the 30-30-30 targets (which assume a 30% share[1] of renewable energy in the energy mix by 2030, given a total of 30,000 MW electricity generation), what is Nigeria's vision for its future electricity generation *mix*? How much coal, gas, hydro and renewables-based generation is feasible and desirable? How does the vision align with the country's sustainable development, industrialisation and climate protection goals?

Today's on-grid power generation capacity in Nigeria is dominated by natural gas power stations (86% of capacity) and three large hydropower plants (14% of capacity). On the other hand, off-grid generation occurs almost exclusively via expensive and polluting diesel and petrol generators, of which there are an estimated 60 million in the country (NDC, 2016). Less than half of the Nigerian population has access to electricity, and it is estimated that per capita electricity consumption in Nigeria– currently at 151kWh per year- should be four to five times higher than the current level, when considering latent and suppressed demand. For comparison, the per capita electricity consumption of Ghana and South Africa are 3 and 30 times higher than Nigeria's, respectively.

Box 1. Nigeria's 30:30:30 vision for its electricity mix

The targets in Nigeria's "30:30:30 electricity vision" (by 2030, 30 GW of installed on-grid capacity and 30% of generation from grid-connected renewable energy technologies) are laid out in different policy documents:

Sustainable Energy for All (SE4ALL) Action Agenda, approved July 2016:

- Increase in grid supply from about 5 GW in 2015 to at least 32 GW by 2030.

National Renewable Energy Action Plan (NREAP), approved June 2016:

- On-grid RE of 5.3 GW installed capacity by 2020 and 13.8 GW installed capacity by 2030. This would generate about 50 TWh/year of grid electricity by 2030, representing a 30% share of generation and 45% share of installed capacity.
- Excluding medium and large hydro, the renewable energy targets are 2.7GW by 2020 and 9.1GW of installed capacity by 2020. This would generate 25 TWh/year, representing a 15% share of generation and 30% of the installed capacity.
- Targets for the proportion of the rural population served with off-grid RE electricity of 25% by 2020 and 40% by 2030.

Rural Electrification Strategy and Implementation Plan (RESIP), July 2016

- Increase access to electricity to 75% and 90% by 2020 and 2030 respectively.

The challenge for Nigeria to generate sufficient electricity can only be understood in the context of the current crisis in the power sector. Overcoming this crisis is one of the main

[1] Or 15% share if one excludes medium and large-scale hydropower.

areas of focus of the 2017 Economic Recovery and Growth Plan (ERGP). In its short-term outlook, the ERGP reiterates the support for inclusion of renewable energies in the energy mix. These ambitions are, however, detached from any mid-term plan for the future energy mix that takes into account the relative costs and benefits of different options for economic recovery of the power sector.

The full costs and benefits of different electricity generation sources are yet to be sufficiently explored for Nigeria. Different electricity generation sources seldom receive a fair comparison, and the costs and benefits to society as a whole i.e. including externalities such as the costs of air pollution, climate change, water over extraction, etc, are rarely considered. It is in this context that the Nigerian Economic Summit Group (NESG) and the Heinrich Böll Foundation (HBS) are aiming to develop a fact-based political narrative that will trigger a conversation on the Nigerian energy mix. This requires developing a solid cost comparison that encompasses the full costs of different generation technologies today and in the future, from which one can draw meaningful conclusions as to the implications for future decisions.

The present document presents the findings of a cost comparison carried out on the basis of Nigerian and international cost data and refined via stakeholder consultations.

The document is organised as follows: first, the goals and approach to the cost comparison are presented, followed by the sources of data and preliminary results. The analysis then draws from the results and complements them with other relevant literature. Finally, limitations and caveats are presented and some conclusions are put forward.

2. Goals and objectives of the cost comparison

This study aims to contribute a key building block to the political narrative on the choices for electricity generation in Nigeria, by providing an exploratory but solid comparison of the costs of generating electricity from different sources in Nigeria and abroad.

The specific objectives are to:

1. Calculate the costs of electricity generation in Nigeria and in comparable international contexts from an **investor's perspective**, via the levelised cost of electricity (LCOE) approach.
2. Calculate a range of **societal costs, i.e. investor costs + external costs** for the different generation technologies.
3. For both objectives 1 and 2, forecast the **evolution of costs up to 2025**, based on assumptions in fuel cost projections and cost reductions via technological learning.

3. Approach

3.1. Costs of generation from the investor's perspective

There are a number of approaches to calculating the cost of a power asset over its lifetime: e.g. levelised cost, marginal cost, avoided cost. The levelised cost approach was considered an adequate starting point for an exploratory comparison such as this one. The **levelised cost of electricity (LCOE)** metric is widely used to compare different ways of generating electricity on an equal footing. LCOE's limitations include the inability to incorporate costs of transmission and distribution as well as timing/market factors associated with matching production to demand (dispatchability, availability profile). Despite these limitations, levelised costs are a necessary prerequisite for making comparisons before demand profiles and grid implications are considered. LCOE is moreover mainstream (used by public and private sectors, international bodies) and there is a wealth of international data available publicly

(IEA, DoE, IPCC, IRENA, investment banks, etc.). Importantly, it has been calculated before for Nigeria by the World Bank (Cervigni et al., 2013)[2].

LCOE can be defined as the ratio of lifetime costs to lifetime electricity generation, both discounted back to a common year using a discount rate that captures the cost of finance (in our case, the Weighted Average Cost of Capital or WACC). The lifetime costs elements include total installed cost, fixed and variable operating and maintenance costs (O&M), fuel costs (if any) and financing costs. No taxes or subsidies are considered. The analysis of costs can be very detailed, but for comparison purposes and transparency, the approach used here is a simplified one. The formula used is that of the U.S. NREL's Simple Levelized Cost of Energy (LCOE) Calculator, as shown in Equation 1.

Equation 1. Simplified Levelised Cost of Energy (NREL)[3]

sLCOE = { (overnight capital cost * CRF + FOM/ (8760 * capacity factor) } + (specific fuel cost * heat rate) + VOM

CRF (capital recovery factor) = $\frac{r^{*}(1+r)^{i}}{((1+r)^{i}-1)}$

where **r** is the WACC and ***i*** is the investment life (in the case of this study this is 11% as defined by NERC).

FOM: annual fixed operation and maintenance costs
VOM: variable operation and maintenance costs

This simplified LCOE equation allows greater scrutiny of the underlying assumptions, improves confidence in the analysis, and also facilitates the comparison of costs by source for the same technologies in order to identify the key drivers in any differences. More complex equations follow the same principle but allow for consideration of elements such as construction times, depreciation, auxiliary power, etc.

It is important to note that the present LCOE calculation encompasses Nigeria as a whole and does not capture differences among specific geographical locations: e.g. resource availability, distance to the grid, land ownership, population density etc. As such it does not allow us to compare which generation technology is the most viable at specific locations in Nigeria.

The LCOE calculation is moreover not making assertions on the technical feasibility of meeting future demand with the available resources, nor hence on security of supply. Exhaustive work on technical potential and resource mapping has been carried out recently for West Africa (IRENA, 2016a) and for Nigeria by the Nigerian Energy Support Programme (NESP)[4].

2 The World Bank carried out a comprehensive comparison of two electricity mix scenarios for Nigeria, based on projections of levelised costs of fuel and technologies (Cervigni, Dvorak, und Rogers 2013). Their findings pointed to significant impacts on GDP growth and relative savings.

3 http://www.nrel.gov/analysis/tech_lcoe.html

4 The Nigerian Energy Support Programme (NESP), has been cooperating with the Nigerian Government to promote and improve investments in renewable energy, energy efficiency and rural electrification. NESP is co-funded by the European Union (EU) and the German Federal Ministry for

3.2. Costs of electricity generation borne by society

To arrive at a more realistic estimate of which electricity generation technologies would most benefit Nigerian society today as well as in the future, a truer and more accurate representation is provided by the **Society's Cost of Electricity (SCOE).**

The SCOE perspective is based on costs and benefits to society as a whole, i.e. including environmental and social externalities. Examples of possible externalities are the costs of air pollution damage, climate change damage, system integration costs, subsidies, employment effects, cost of water pollution and water over extraction, geopolitical risks, etc. In contrast to LCOE, SCOE is not a well defined metric, and different practitioners may define it in rather different ways. SCOE builds on LCOE, adding quantitative estimates of the costs of the externalities. The more data is available for a particular energy system, the more detailed the SCOE calculation can be. In the case of this exercise, SCOE values for Nigeria are calculated as follows:

Equation 2. Society's cost of Electricity (SCOE) as calculated within this study.

SCOE = LCOE + cost of climate change damage + cost of air pollution damage + system integration costs

Over the last decade, monetary values have increasingly been used to express external costs and benefits of electricity generation (even though they do not capture every loss and gain to society). This has however never been done in Nigeria.

This study relies on European data for cost of air pollution, as compiled by the Danish Energy Agency (DEA, 2016), as well as for system costs. The costs related to climate change are based on widely accepted EPA-defined greenhouse gas (GHG) direct emission profiles of different generation sources. To reach a value for the climate change related cost of generation, assumptions need to be made on the cost of GHG emissions to society as a whole, which would manifest in form of emission / pollution / environmental charges and other government levies meant to recover the cost of fixing the impacts of climate change exacerbated by carbon / GHG emissions, such as desertification, gulley erosion and flooding.

The economic consequences of **climate change** are a major topic of research that is beyond the scope of this study. One method to determine the costs is to try to assess the damages, also known as 'cost of carbon to society'. Society's costs of carbon are associated with considerable uncertainty. The range of possible societal costs of carbon chosen for this study (40, 60 and 100 USD/tCO2e) offer a representative sample of the possible costs to Nigeria, a country particularly vulnerable to climatic shocks and trends, in particular to floods and droughts.

According to the World Climate Change Vulnerability Index, as quoted in the NDC (2016), Nigeria is one of the ten most climate-vulnerable countries, and Lagos is the tenth most vulnerable city in the world. Estimates of Nigerian GDP loss from climate change of between 2-11%, a figure that is brought into focus by ongoing processes such as the shrinking of Lake Chad or the crises such as the 2012 floods.

The lower-bound values chosen for this exercise (40-60 USD/tCO2e) represent the cost that most companies are now already assuming in their long-range and project planning, whereas

Economic Cooperation and Development (BMZ). The programme is jointly implemented by the Federal Ministry of Power, Works and Housing and GIZ.

the 100 USD/tCO_2e value is proposed as a reflection of costs of climate change damage that are already being observed, based on international literature (e.g. see Stiglitz and Stern (2017)).

The other possible way of determining the costs of climate change would be to consider the costs of limiting GHG emissions to safe levels, otherwise known as climate abatement costs. These are however estimated to be much higher than 100 USD/tCO_2e.

The health effects of **air pollution** from electricity generation are mainly local and regional. The most important emissions are SO_2, NOx and small particles (PM). Health impacts can be measured as statistically increased mortality and morbidity. Besides health effects, air pollution can also cause lake acidification and corrosion of buildings and infrastructure.

System costs include the costs of handling deviations from planned production and are dependent on the penetration level of renewable energy sources, and the flexibility of the electricity system. Nigeria's electricity system is relatively slow to adjust, which would penalise intermittent sources like renewables.

It is important to note that the valuation of environmental and system integration costs is highly context-specific. The present exercise cannot claim to represent external costs with accuracy for the Nigerian context, but is a reasonable basis on which to build on in the future.

3.3. Forecast

This study offers a mid-term perspective by providing an estimate of what today's costs to investor and society would translate into in the mid-term. The forecast is carried out by applying:

- DEA's fuel cost projections to the fuel cost component of natural gas and coal generation;
- U.S. DoE's predicted cost reduction rates for fossil fuel generation technologies; and,
- IRENA's predicted cost reduction rates for renewables.

It is important to stress that this study uses cost reduction rates, not learning curves, as the latter would require a forecast of the evolution of installed capacity of each technology in Nigeria, which is beyond the scope of this exercise. The following section presents the data sources in detail.

4. Data collection

This cost comparison undertook to rely on Nigerian-based data wherever possible, and relied heavily on publicly available data from NERC. These were validated by the stakeholders consulted. The datasets were complemented with international data from renowned institutional sources, most of which are publicly available. A balance was sought between traditionally moderate international sources (e.g. U.S. DoE, IEA) and more optimistic cost estimates, such as that of Lazard.

Technologies for which data was deemed insufficient were either left out of the scope or, if relevant, evaluated via modifications to data of related technologies. Any such adjustment, extrapolation or approximation was recorded and adequately justified. The full set of assumptions used is available in Annex 1.

The data sources for the quantitative evaluation of private and society costs can be summed up as follows:

- The **Nigerian OCGT** (single cycle gas turbines)**, coal and large hydro cost data** are based on the assumptions behind the electricity tariffs calculated by the Nigerian regulator in 2012 (NERC, 2012, p. 21). Assumptions for Nigerian CCGT (combined cycle gas turbines) are extrapolations of these based on stakeholder consultations.
- Assumptions for **Nigerian on-grid renewables** (excluding large hydro) are based on those used for the calculation of the feed-in tariffs in 2015 (NERC, 2015, p. 20). It is important to note that stakeholder consultations revealed that plans are in place to revise these assumptions downwards to reflect recent and foreseeable cost reductions.
- Most of the Nigerian off-grid technology cost data and a number of on-grid gas, coal and PV data points were derived from **private communications with Nigeria-based** Independent Power Producers (IPPs), off-grid solar entrepreneurs and academic papers. In the case of on-grid sources, the IPP data did not depart significantly from NERC assumptions. The data collection process revealed severe limitations in the amount of project-based data accessible in Nigeria, be it on-grid or off-grid.
- The sources for the **international cost data** are based on the International Energy Agency's World Energy Outlook 2016 (IEA, 2016a), the U.S. DoE Energy Information Administration Annual Energy Outlooks 2015 to 2017 (EIA, 2017) and the latest report of the investment bank Lazard (Lazard, 2016).
- Projected **LCOE reduction rates for renewables** are based on IRENA (2016b), including 5,9% decrease for utility-scale PV LCOE up to 2025, 2,6% for onshore wind, and 3.7% for CSP.
- **LCOE reduction rates for fossil fuels** are based on the historical LCOE reductions in past Annual Energy Outlook reports of the U.S. DoE from 2010 to 2016.
- Projections for **fuel cost variations (gas and coal), system costs and air pollution costs** are based on data by the Danish Energy Agency (DEA, 2016). Stakeholder consultations revealed that no reliable fuel cost variation projections were available for Nigeria.
- **GHG emission factors** were derived from U.S. EPA.

The assumptions and findings of the cost comparison were discussed with a range of Nigerian stakeholders (civil society organisations, governmental bodies, private energy developers, international cooperation agencies) in a series of meetings which led to modifications and additions of assumptions in a small number of cases. Most meetings provided an opportunity to focus on a particular set of technologies (e.g. PV or natural gas). The discussions also resulted in many valuable non-quantitative insights which enrich the analysis.

5. Findings and discussion

5.1. Costs of generation from the investor's perspective

<u>On-grid</u>

The results of the LCOE calculation for on-grid electricity generation are shown in Figure 1 below. The lower panel in Figure 1 displays the values in a bandwidth format to give a better understanding of the spread of costs. The term on-grid is used here to refer to grid-connected utility-scale generation in the order of megawatts. Annex 1 provides details on the assumptions of average capacity for each technology.

As expected, the picture emerging from the calculation is that, in terms of LCOE, the most competitive technologies for generating electricity at the moment in Nigeria are large scale hydropower and natural gas, in particular combined cycle turbines, all presenting costs of USD 0.05 to 0.07kWh on average. In practice **hydropower** projects in Nigeria generally lead to higher costs than expected and as a result the investment pipeline (including those into renovation of existing dams) is rather slow. With regards to **gas-powered electricity**, combined cycle gas turbines are gradually taking over the inefficient single cycle turbines, and it is expected that this will be a major source of Nigeria's future electricity mix.

The comparison of LCOE for power generation from natural gas highlights the comparatively low share of capital costs for this option on the one hand but also the vulnerability of generation costs to changing or volatile natural gas prices during the lifetime of the plant. The cost is very dependent on the price of the fuel as it represents 60% of the LCOE. As such, there is considerable difference between the LCOE when comparing the government regulated price for gas to power of 3.80 USD/mbtu price with the market reflective price of 7 USD/mbtu that is paid by IPPs in the southwest of the country. The success of current policy drives, like those on the regulatory framework and investment incentives for the gas distribution infrastructure, will determine the success of the technology. Currently gas generation plans are severely limited by availability of fuel, with more than 2GW of the average daily capacity shortfall being reported due to lack of gas supply to power stations (NDC, 2016). Moreover, stakeholder consultations revealed high uncertainty regarding the extent of gas reserves in Nigeria, with some estimates indicating that reserves could be depleted in three decades (Sambo, 2017).

The next most competitive generation technology, costing an average of USD 0.09/kWh, is onshore **wind** energy, although the higher bound of the cost values (USD 0.014/kWh) is out of the area of competition with fossil fuels. There is currently only one wind power project in Nigeria and there is a widespread perception among stakeholders that the technology does not hold high potential in the country. However, a number of experts consulted did point out that the existing survey of the resource (LAMEA map) has insufficient data points and that the study of specific sites merits more attention, in particular given the high prospects of cost reductions in wind technology. The potential of offshore wind for Nigeria is yet to be researched.

There is currently no **coal**-powered electricity generation in Nigeria, although at least one coal-powered plant has been awarded planning permission. It intends to use the less innovative FGD – flue gas desulphurisation – technology and does not include carbon capture and sequestration (CCS). In LCOE terms, and based on Nigerian and IEA assumptions for cost of coal generation in Africa, it costs an average of USD 0.10/kWh to generate electricity with coal. Stakeholder discussions revealed a number of significant costs that are not always included in the investment plans, such as the capital expenditures required to build roads for transporting coal to the plant, the cost of the infrastructure needed for transporting the coal plant from the port arrival. These costs can lead to considerable increases in the agreed tariff during power purchase negotiations. Moreover, international experience shows that the scale of coal power plant capacities and the high capital intensity can lead to comparatively high cluster risks in case of cost or overruns or delays during the construction period. In this sense the investment risk profile of solar PV and wind utilities differs from that of conventional power: investments in renewables are shared by a wide number of investors in different geographical locations, and the failure of one project has limited repercussions on the rest. Fuel availability is a further challenge for coal power plants in Nigeria. In a recent study (Sambo, 2017), coal reserves were expected to be exhausted over the next 40 years.

There are plans underway for commissioning a **nuclear** energy plant in Nigeria, but the cost data was not obtainable for this study. Based on international data, the LCOE appears attractive, however stakeholder consultations revealed that these data are usually of theoretical nature and rarely backed by recent empirical evidence . It is, moreover, important to note that our exploratory analysis did not consider decommissioning costs, which are particularly high for nuclear plants, nor other parts of the nuclear waste management and fuel supply chain.

The Cost of On-Grid Electricity Generation, based on LCOE

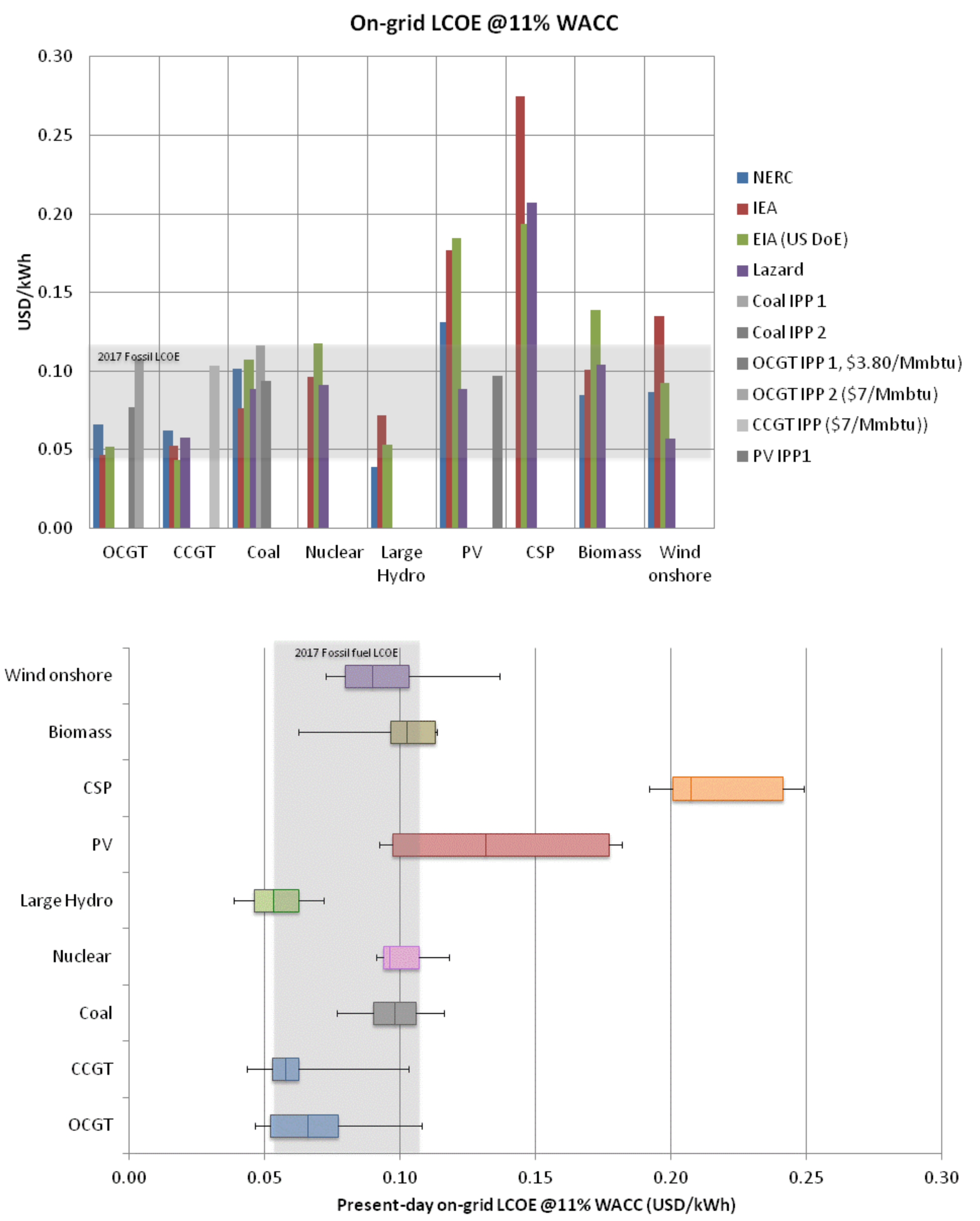

Figure 1. Unsubsidised LCOE for electricity generation via on-grid sources in Nigeria, at 11% WACC. In stack chart (above), coloured stacks correspond to the values derived from publicly available data whereas grey stacks correspond to values derived from data obtained in stakeholder discussions. In bandwidth chart (below), width of box denotes range from first quartile to third quartile of values, whereas whiskers denote minimum and maximum values. Shaded areas delimit the low and high bounds of LCOE for fossil-fuel based generation technologies (CCGT, OCGT and coal).

Both NERC and international data show that **biomass** generation offers a good prospect in

Nigeria. However the market in Nigeria is particularly immature and would require a more detailed analysis of the various types of feedstock and conversion technologies (e.g. gasification, liquid fuels). Related options such as waste-to-energy remain understudied.

The renewable energy resource which is currently of most interest in Nigeria for utility-scale electricity generation is **solar PV**. Theoretically, Nigeria has a potential for electricity production from solar PV technology in the range of 207,000 GWh per year (ten times the production in Nigeria in 2011) if only 1% of the land area were covered with PV modules (NESP, 2015). At present, there is no significant utility scale power generation in Nigeria, but this analysis shows that it can compete at the lower cost range with coal generation (before external costs are considered) at US 10-11cents/kWh[5]. Fourteen solar PV companies signed power purchase agreements (PPAs) at USD 0.11/kWh with NBET in 2016, with a combined capacity of 1 GW. Some controversy exists as to the feasibility of the project at this price, but our analysis shows that it is a plausible reflection of the lower-bound costs in 2017.

Globally, the average LCOE of utility-scale PV fell by around 60% between 2010 and 2015, making utility-scale projects competitive with new fossil fuel- based generation (IEA, 2016b). The global average LCOE for newly installed utility-scale solar PV in 2015 was USD 0.13/kWh, compared to USD 0.05-0.10/kWh from coal and natural gas. In fact, utility-scale PV broke even with coal-based generation in 2016 (Bloomberg New Energy Finance, 2017). The most competitive utility-scale projects in 2015 delivered electricity for USD 0.08/kWh, and auctions in 2017 have seen winning bids around USD 0.03/kWh (BNEF, 2017). Solar PV is competing without financial support even in regions with abundant fossil fuels and in high-cost regions with comparatively poor solar radiation conditions such as Germany. Germany auctions for utility scale PV projects cleared in February 2017 at average costs of USD 0,07/kWh and, probably more important, at costs that are 30% lower than those of 2015 (Bundesnetzagentur, 2017).

Nigerian PV investments share the same risks as other power generations investments (high costs of capital, local currency risks, limitations in the foreign exchange market). These risks are at times exacerbated in PV due to the smaller scale of the projects, in particular as perceived by traditional investors used to larger investments. Other PV-specific risks include the poor wheeling capacity of the grid in high potential locations. Solar PV counters some of its higher investment risks with lower cluster risks: investments in renewables are shared by a broader range of investors facing different local circumstances, and therefore the failure of one project has limited repercussions on the rest. Moreover as mentioned above solar PV is not vulnerable to fuel price volatility or resource depletion.

Finally, **Concentrated Solar Power (CSP)** is currently not cost-competitive as it can be 50 to 100% more expensive than PV depending on location and irradiation.

Off-grid

The result of the LCOE calculation for off-grid electricity generation is shown in Figure 2 below. Annex 1 provides details on the detailed assumptions for each of the off grid values collected. The data available for this comparison are primarily sourced from Nigerian literature and private communications.

[5] The top panel of Figure 1 shows higher variability among the solar PV LCOE values than in other technologies. This is to do with the rapidly changing costs and large influence of key assumptions such as the capacity factor. A balance has been sought between traditionally moderate international sources (e.g. U.S. DoE, IEA) and more optimistic cost estimates such as that of Lazard.

The Cost of Off-Grid Electricity Generation, based on LCOE

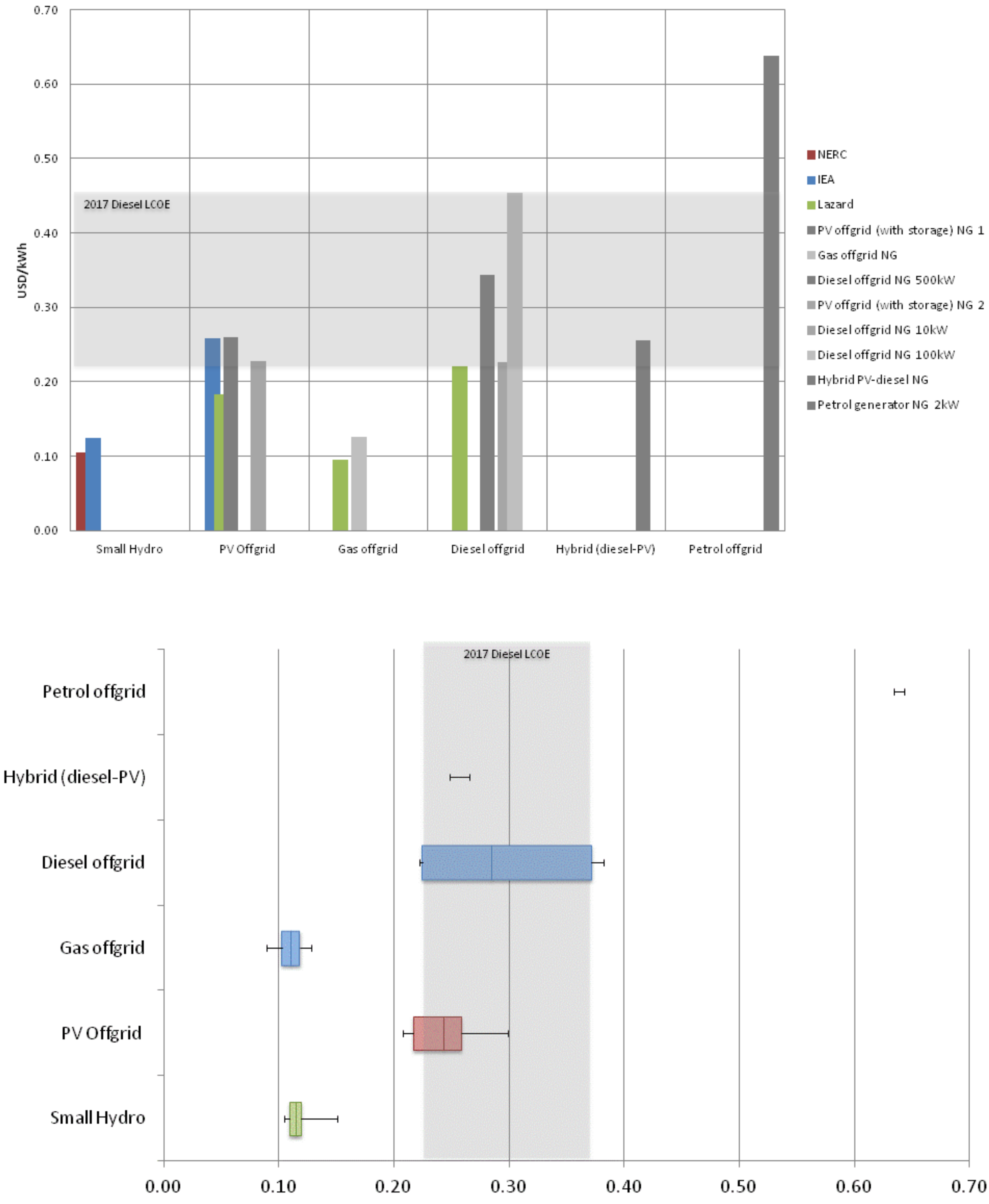

Figure 2. Unsubsidised LCOE for electricity generation via off-grid sources in Nigeria, at 11% WACC. In stack chart (above), coloured stacks correspond to the values derived from publicly available data whereas grey stacks correspond to values derived from data obtained in stakeholder discussions. In bandwidth chart (below), width of box denotes range from first quartile to third quartile of values, whereas whiskers denote minimum and maximum values. Shaded areas delimit the low and high bounds of LCOE of diesel generator- based electricity.

NB: PV solar system costs include storage costs.

There are three important considerations to bear in mind with regards to the scope of this section of the cost comparison:

- The present LCOE calculation focuses on generation only and **does not capture cost of distribution or connection to the grid.** As such, no distinction is made between the costs of stand-alone off grid power systems and that of mini-grids. The different roles that stand-alone systems and mini-grids have and will have in incremental electrification in Nigeria is the subject of recent studies (Bertheau et al., 2016; Mentis et al., 2015; World Bank, 2016) and deserves further consideration. However, it is important to note that the cost of mini-grids encompasses the generation system, the distribution system, and the connections.

- Off-grid systems are **more diverse than on-grid systems in terms of design and hence cost.** The design of an off-grid systems is usually tailored to the appliance or load that is powered by it, whether it is a phone charging rack or an industrial cluster. There is a broad array of possible appliances with very different load profiles and requiring different storage configurations. Even within the same size range, an off-grid system designed to power home appliances will not have the same design and, therefore, cost as that of one powering a small motor, a barbing kit or an irrigation pump. This "case-by-case" nature of off-grid systems makes it less conducive to comprehensive comparisons such as this one. There is a marked increase in installed costs with decreasing system size.

- The investor in off-grid power systems is often also the consumer of the electricity. The absence of on-grid energy or unreliable power supply from the grid has led consumers from all segments (manufacturers, agricultural enterprises, SMEs, households) to invest in and maintain their own generation systems. Depending on their socio-economic context and power consumption needs, the **discount rates and investment timeframes** of these consumers may differ significantly from those of investors in on-grid generation.

The analysis shows that off-grid generation by **small hydro** (10 to 30 MW) is highly competitive, and indeed rural dams are often quoted as a priority electrification policy and as a viable option for small isolated communities. The potential is however under-researched and cost data are lacking for mini hydro (under 1 MW), micro hydro (under 100 kW) and pico-hydro systems.

Many Nigerian industrial facilities or small industrial clusters use **off-grid natural gas generators**, as they are less costly than diesel generators, assuming stable supply of fuel (the recent scarcity of natural gas has resulted in many of these investments becoming uncompetitive). The actual extent of gas-powered captive systems in terms of capacity installed and electricity generated is not known.

Off-grid solar PV systems are already cost competitive in Nigeria on a lifetime basis, costing an average of USD 0.20/kWh (including storage costs) as opposed to diesel generators USD 0.30/kWh and gasoline over USD 0.60/kWh. However, they have significant upfront costs and, without affordable financing, diesel generators are more accessible to households and small businesses. It is important to note that costs of batteries, a major component of the PV system costs, are rapidly decreasing, driven mainly by the global take-off of electric vehicles (BNEF, 2017).

Cost comparisons between solar and diesel often take place on a case-by-case basis. Stakeholders consulted in this study provided a number of case studies and business plans based on Nigerian data, using net present value (NPV) rather than the LCOE metric, and providing detailed system designs for meeting different demands, from irrigation to household appliances. Not all these studies rendered themselves usable for the LCOE calculation, but they revealed that **diesel and petrol**-based off-grid systems are consistently more expensive and can have as much as three times higher NPV than solar PV. As an example of the use of another alternative metric, IRENA (2016c) shows that the annualised cost of a solar home system below 1kW is 55-210 USD per year, which is significant lower than the annual expenditure on lighting (including candles and kerosene lamps) and mobile phone charging in Nigerian households (156-228 USD per year).

It is important to note that cost of diesel, capacity factors and depth-of-discharge considerations are key technical assumptions affecting the competitiveness of solar PV vs. diesel and petrol generation systems. In particular, during stakeholder discussions the costs assumed in this study for diesel and gasoline were deemed to be on the low side (but were kept nevertheless to ensure coherence in the use of the data sources).

5.2. Costs of electricity generation borne by society

The result of the SCOE calculation for on-grid electricity generation is shown in Figure 3 below for the lower and higher bound scenarios of 40 and 100 USD/tCO_2e, respectively. The three panels in Figure 4 show the relative weight of the various components of SCOE in the 40, 60 and 100 USD/tCO_2e scenarios. As outlined in section 3, SCOE values are calculated by adding LCOE, costs of damage from climate change and air pollution (mainly health costs), costs of system integration (which slightly penalise renewables, in particular wind) and cost of the risk of nuclear accidents.

SCOE was not calculated for off-grid sources, due to the lack of data on the costs of air pollution from diesel and petrol generators. Costs of climate change alone – based only on the calculation of generators' carbon emissions – would nevertheless already increase the cost of diesel generation by USD 0.04-0.10/kWh.

Figure 3 shows that the inclusion of environmental costs makes on-grid solar PV fully competitive with coal generation at relatively low cost of carbon (40 USD t/CO2e), and at a higher cost of carbon (100 USD/tCO2e) solar PV becomes competitive with natural-gas power generation as well. In all cases wind energy remains the most competitive renewable energy resource, despite its slight increase in cost due to its higher system integration costs. Figure 4 shows that the cost of climate change damage plays a particularly strong role in SCOE. Gas-based generation has lower climate change costs relative to coal but they still have a significant effect on the overall cost to society.

Studies such as the European ExternE project[6] have established that the most important environmental impacts of electricity production are:

- Climate change due to emissions of greenhouse gasses
- Health impacts due to air pollution, including gasses and particles
- For nuclear power: risks associated with waste storage and decommissioning (not for major nuclear accidents, which have very low probability of occurrence but very high levels of damage, which would result in much higher costs).

There are many other relevant environmental impacts associated with power generation, for example emissions of toxic metals (such as in coal generation), dioxins, water use, degradation of land etc. These have been excluded in the SCOE calculation for reasons of simplicity. Also, upstream environmental impacts (for example due to mining and transportation of fuels and manufacturing of equipment) are not considered. Land use changes, deforestation or displacement of communities are further costs to society, but this study cannot put a quantitative figure on these occurrences.

[6] www.externe.info

The Cost to Society of On-Grid Electricity Generation, based on SCOE

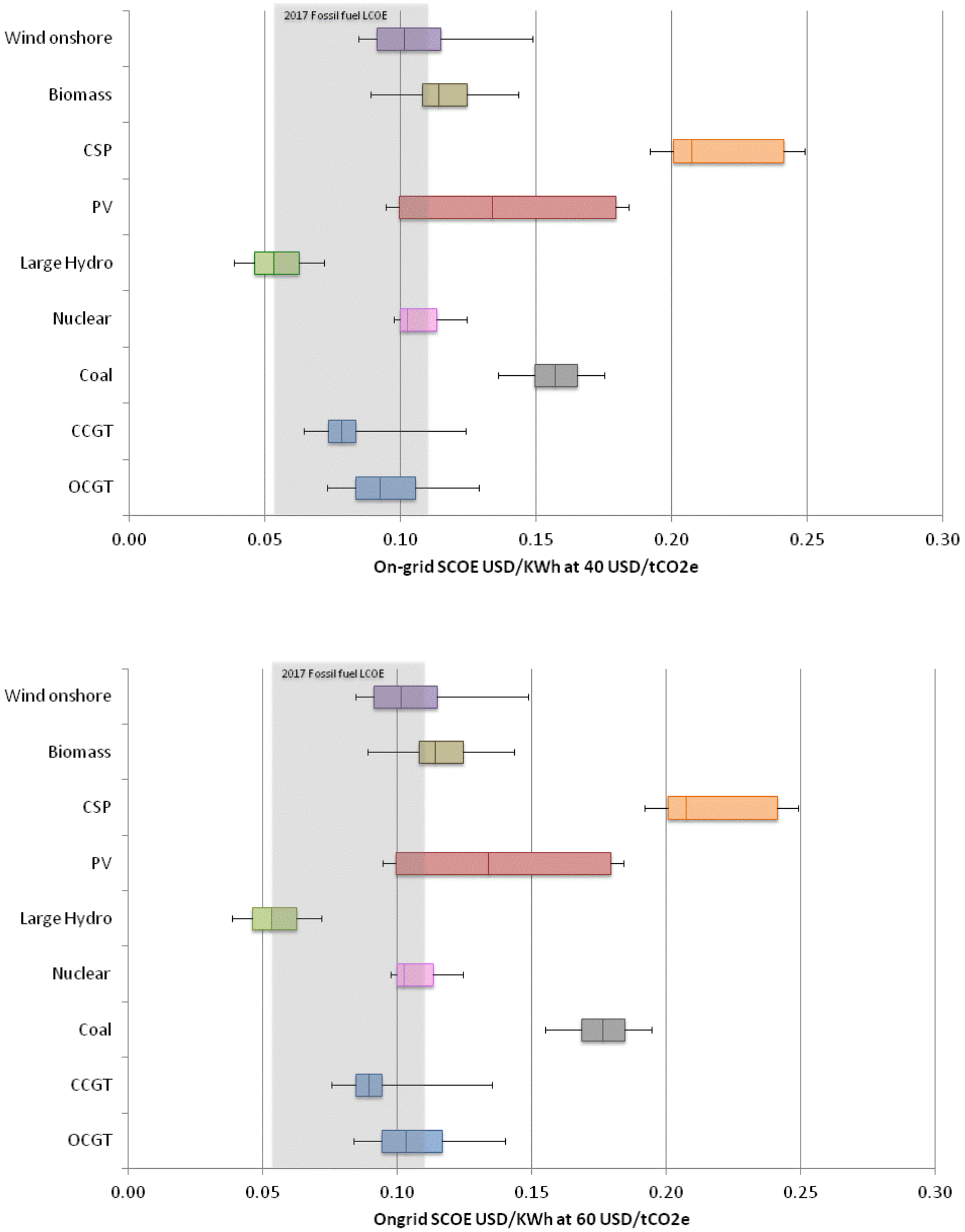

Figure 3. SCOE (in USD/kWh) of on-grid generation in Nigeria assuming cost of climate damage of 40 USD/tCO2e (top panel), 60 USD/tCO2e (lower panel) and 100 USD/tCO2e (overleaf) and including costs of air pollution, minor nuclear accident risks and system integration. Width of box denotes range from first quartile to third quartile of values, whereas whiskers denote minimum and maximum values. Shaded area delimits the low and high bounds of LCOE for fossil-fuel based generation technologies (CCGT, OCGT and coal).

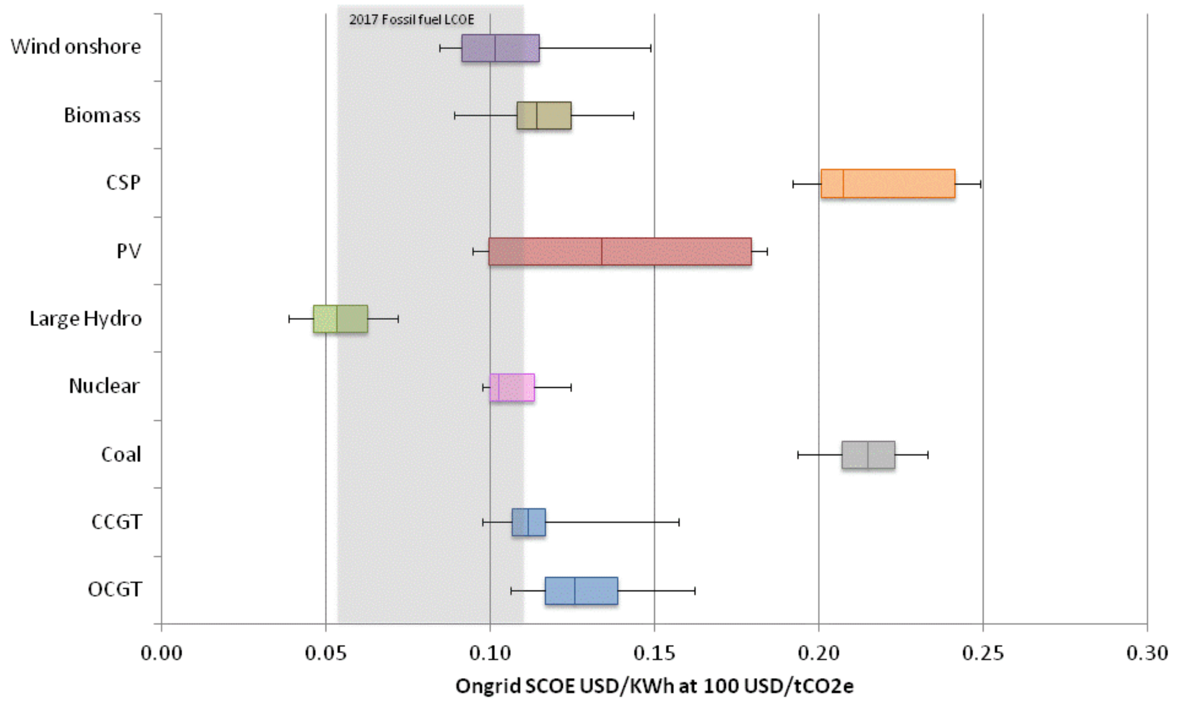

Figure 3 cont'd (see caption on previous page).

5.3. Forecast

Figures 5 and 6 below extend our analysis into the future by applying projections on fuel prices for natural gas and coal, cost reduction rates for fossil fuel generation technologies and cost reduction rates for renewables to the average values of LCOE and SCOE.

The LCOE forecast (Figure 5) indicates that in the time that it takes to build a coal power plant in Nigeria (4 years) the average LCOE of utility-scale PV would have dropped low enough to undercut the price of coal generation. Wind would become even more competitive than it currently is. When external costs are considered (Figure 6), solar PV will be competitive with gas-based generation in 2025, and even CSP would be able to compete with coal.

The costs of renewables has plunged in recent years, with some technologies now being at par with fossil-based generation in certain countries and regions, and with projections of expansions in installed capacity being constantly reviewed upwards. Nevertheless, further reductions are expected. IRENA (2016b) estimates that by 2025 the global average LCOE of solar PV could fall by more than half, CSP could see a decline of up to 43% from present levels and onshore wind could drop by 26%. For solar PV, the greatest potential for future LCOE reductions lie in the cost of storage and finance costs. It is expected that NERC will revise its Nigerian cost data to acknowledge these latest cost trends. Further investigation of the possible cost trajectory of biomass and hydropower is warranted.

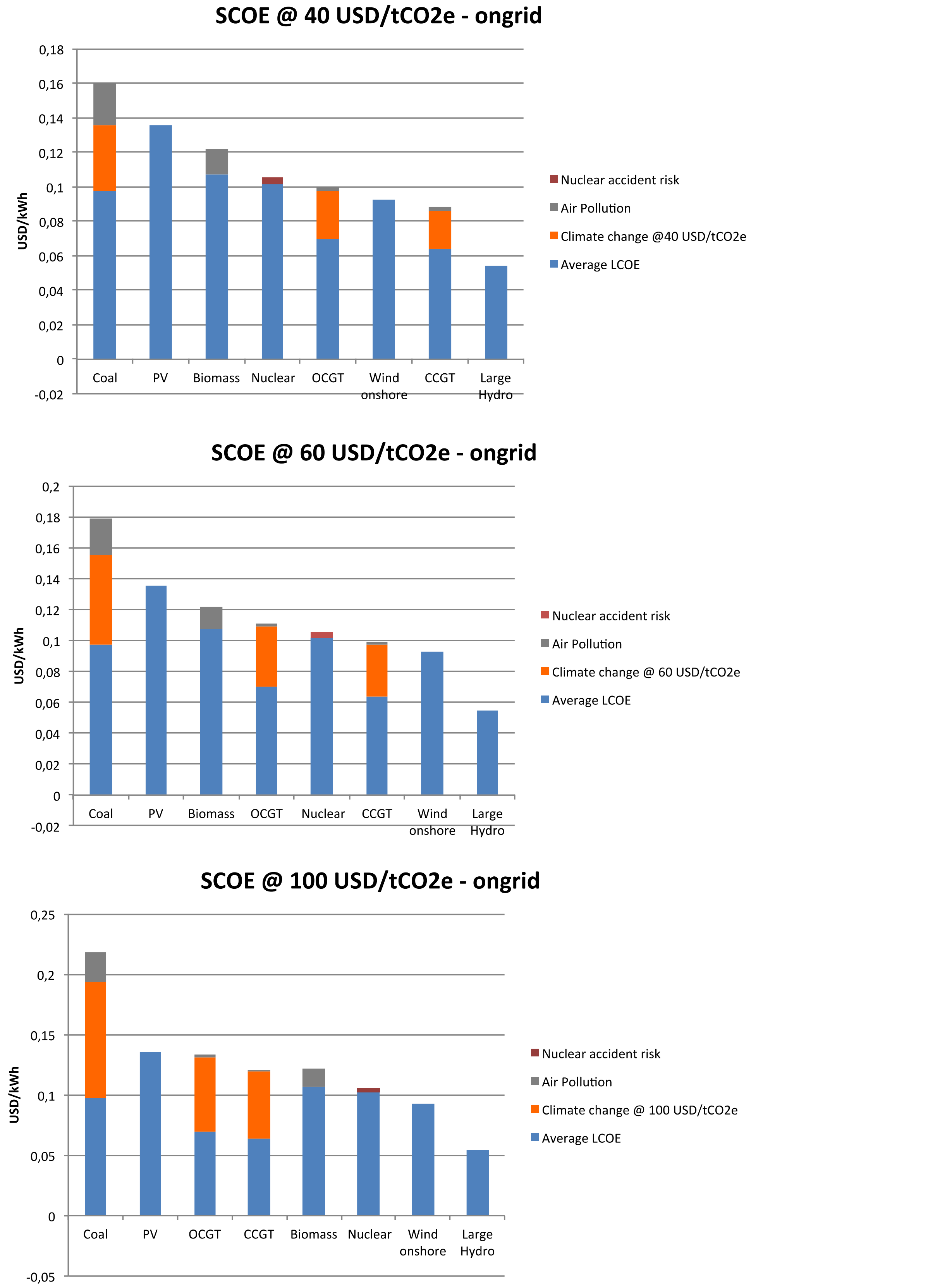

Figure 4. Components of SCOE (in USD/kWh) of on-grid electricity generation in Nigeria assuming 40, 60 and 100 USDtCO2e and including costs of air pollution, nuclear accident risks and system integration. Generation technologies placed in order of overall SCOE (descending).

Future Cost of On-grid Electricity Generation until 2025, based on LCOE

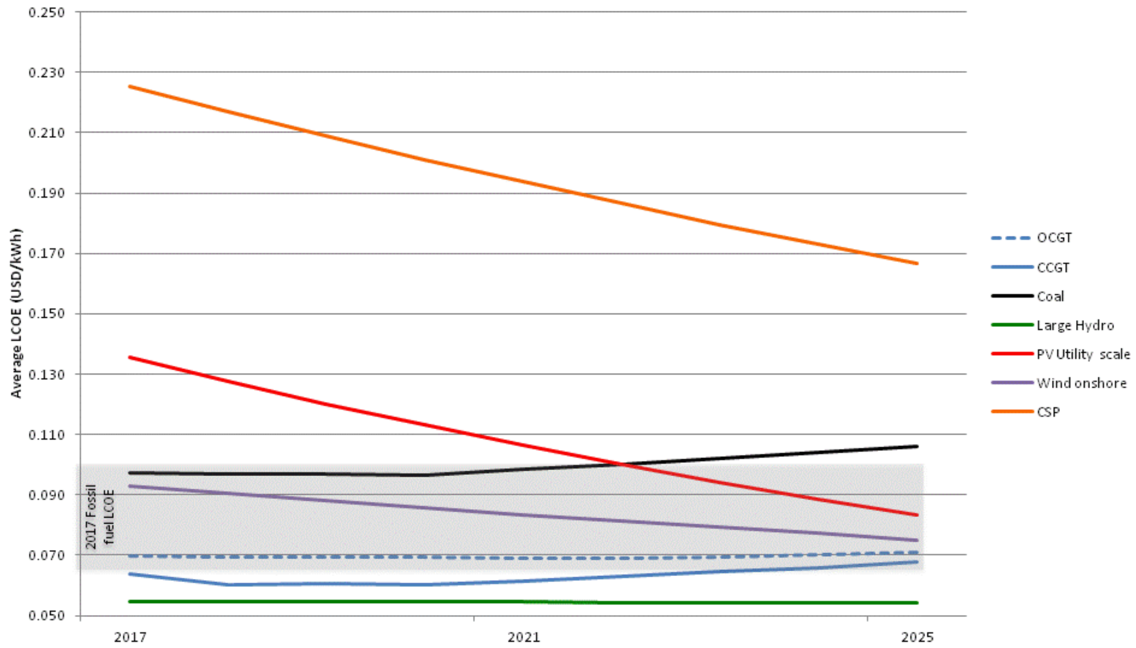

Figure 5. Forecast of average LCOE (in USD/kWh) for on-grid electricity generation up to 2025, based on cost reduction rates and fuel cost projections. Shaded area delimits the low and high bounds of 2017 LCOE for fossil-fuel based generation.

Future Cost of On-grid Electricity Generation until 2025, based on SCOE

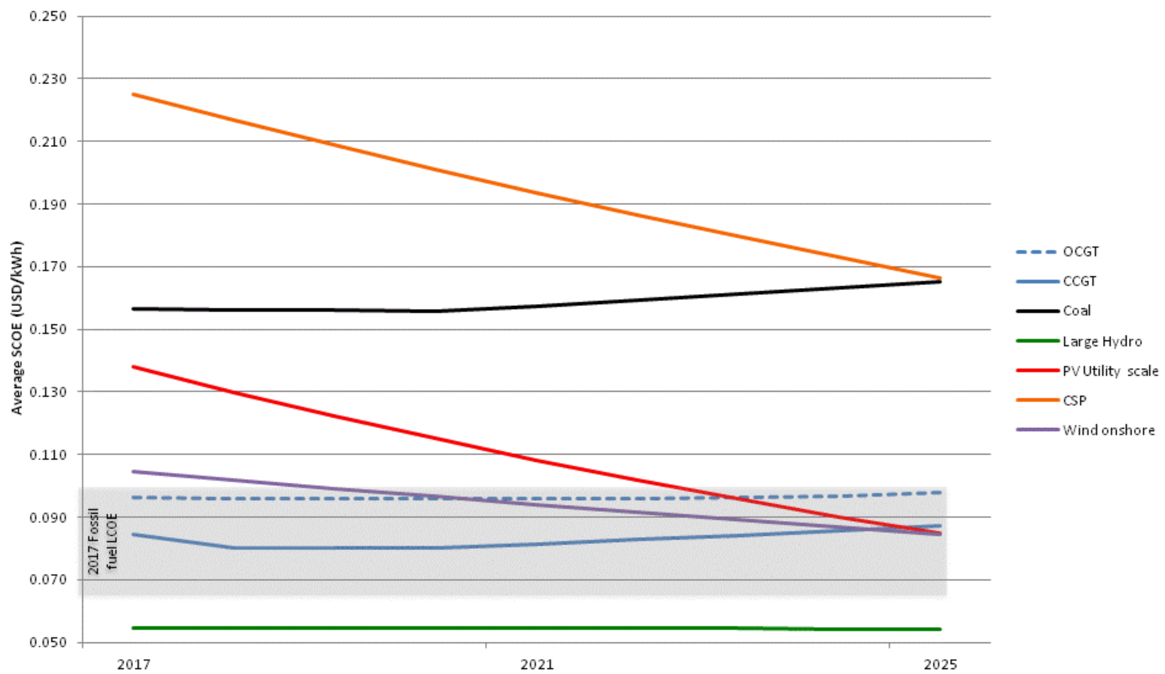

Figure 6. Forecast of average SCOE (in USD/kWh) for on-grid electricity generation up to 2025, based on cost reduction rates and fuel cost projections. Shaded area delimits the low and high bounds of 2017 LCOE for fossil-fuel based generation technologies.

6. Conclusions

The full costs and benefits of different electricity generation sources are yet to be sufficiently explored for Nigeria. This exploratory study uses the concepts of levelised cost of electricity (LCOE) and society's cost of electricity (SCOE) as tools to uncover the different perspectives to evaluating the costs of power generation: that of the private investor, and that of society as a whole. One of the key strengths of this comparison is its reliance on Nigerian-based data wherever possible.

The cost comparison reveals that renewables are one of the strongest options for Nigeria to deliver the needed power in the most cost competitive way. Globally, wind and solar power are now competitive with conventional sources of electricity as their costs have plunged in recent years. In Nigeria, onshore wind, biomass, and hydropower are currently competitive with coal and gas-fired power stations, despite there being higher investment risks (both for renewables and conventional power). When including costs to society, i.e. costs of climate change damage and health costs from air pollution, renewable energies are at present fully competitive with conventional generation. In off-grid generation, off-grid solar PV systems are already cost competitive in Nigeria on a lifetime basis, but are hindered by the lower upfront costs of diesel and petrol generators. Global innovations in financing and business models that overcome this barrier remain underexploited in Nigeria.

Any assessment of different pathways towards adequate power generation should reflect the dynamics of cost trajectories. The developments over the last two decades and the recent trends show clearly that the costs of solar and wind energy as well as for batteries have decreased steadily, whereas the investment costs for conventional generation have either increased (at least for coal and nuclear power plants) or at best remained constant. When forecasting costs up to 2025 based on widely accepted cost reduction assumptions, our study shows that on-grid solar PV will be fully competitive with coal generation in Nigeria in the next five years. If society's costs are included in this projection, solar PV and wind undercut the costs of even the cheapest fossil-fuel based generation.

In Nigeria, renewables are still perceived as a high-risk investment despite recent technological and policy innovations. This study counters this prevailing view by providing evidence that renewable energy is competitive today and in the mid-term in Nigeria, and more so when the costs to society are considered. Moreover it puts into perspective the issue of risks, by distinguishing those risks that are common to all power investments (high costs of capital, local currency risks, limitations in the foreign exchange market) and those that are specific to some technologies (e.g. cluster risks, fuel price volatility and resource availability for conventional sources; higher capital costs, lower investment size and innovation risks in renewable sources).

Finally, this study points toward the effect of different cost structures on their short and long term viability. Natural gas-based power generation has lower upfront costs but is vulnerable to volatile fuel prices, whereas electricity generation from renewables has higher upfront costs but provides electricity at costs that are highly predictable.

There are a number of limitations to the study:

- Merely comparing electricity generation costs between different plant types can be misleading. LCOE does not elucidate which generation technology is the most viable at specific locations in Nigeria. Resource availability, distance to grid and other location-specific considerations are needed to give the full picture.
- The comparison of costs across offgrid systems must be approached with caution as offgrid systems are tailored to the loads and because levelised costs increase markedly with decreasing system size.

Investments in new power generation are important long-term decisions, locking public spending and environmental impacts for decades. The comparison of LCOE and SCOE across power generation options provides one of the relevant elements for designing robust strategies and cost recovery arrangements for the energy sector. However are a more in-depth and dynamic study of the full costs and benefits of the transition to an adequate energy mix is now needed.

Some further research topics that would complement the present study include:

- Perform sensitivity analysis for key parameters (capacity factor, fuel costs, projected cost reductions), e.g. LCOE of natural gas-fired power plants is particularly sensitive to the price of fuel.
- Elaborate SCOE and forecasts for off-grid generation, based on existing literature on health costs from exposure to diesel generator exhausts.
- Quantify other cost elements that play an important role in Nigeria electricity generation, such as the impacts on land use of different generation sources, or water requirements.
- Understand the socio-economic impacts of offgrid electrification with different generation sources. There is a growing body of literature on such socio-economic costs and benefits, which together with anecdotal evidence and case-studies for Nigeria would allow the assessment of these less well known impacts.

Finally, a number of integrated research efforts would be warranted:

- Explore costs and implications of longer-term high-penetration (80-100%) scenarios for renewables. Contrary to other international contexts, there is currently little to no debate on the potential for such high-penetration scenarios in Nigeria. Two studies (Oxfam America, 2017; Oyewo et al., 2017) find that this is the least-cost pathway for Nigeria to meet its energy needs rapidly and sustainably. These studies take into consideration the cost of large-scale storage of electricity, a major element in the viability of a high-penetration renewable future and currently the subject of major innovations and cost reductions.
- Model the electrification and grid expansion strategy that optimises cost and benefits from generation through to distribution.

Bibliography

Bertheau, P., Cader, C., Blechinger, P., 2016. Electrification Modelling for Nigeria. Energy Procedia, Africa-EU Symposium on Renewable Energy Research and Innovation 93, 108–112. doi:10.1016/j.egypro.2016.07.157

BNEF, 2017. BNEF Summit 2017 Keynote Presentation by Michael Liebreich [WWW Document]. URL https://data.bloomberglp.com/bnef/sites/14/2017/04/2017-04-25-Michael-Liebreich-BNEFSummit-Keynote.pdf

Bundesnetzagentur, 2017. Hintergrundpapier Ergebnisse der EEG Ausschreibung für Solaranlagen vom 01. Februar 2017 [WWW Document]. URL https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Energie/Unternehmen_Institutionen/ErneuerbareEnergien/EEG_Ausschreibungen_2017/Hintergrundpapiere/Hintergrundpapier_01_02_2017.pdf?__blob=publicationFile&v=3### (accessed 6.16.17).

Cervigni, R., Rogers, J.A., Henrion, M., 2013. Low-Carbon Development: Opportunities for Nigeria, Directions in Development - Countries and Regions. The World Bank. doi:10.1596/978-0-8213-9925-5

DEA, 2016. Levelized Cost of Energy (LCoE) Calculator [WWW Document]. Energistyrelsen. URL https://ens.dk/en/our-responsibilities/global-cooperation/levelized-cost-energy-calculator (accessed 3.9.17).

EIA, 2017. Annual Energy Outlook 2017. U.S. Energy Information Administration.

IEA, 2016a. World Energy Outlook 2016. Organisation for Economic Co-operation and Development, Paris.

IEA, 2016b. Next Generation Wind and Solar Power - From Cost to Value.

IRENA, 2016a. Investment Opportunities in West Africa (Global Atlas).

IRENA, 2016b. The Power to Change: Solar and Wind Cost Reduction Potential to 2025.

IRENA, 2016c. Solar PV in Africa: Costs and Markets.

Lazard, 2016. Lazard's Levelized Cost of Energy Analysis 10.0 [WWW Document]. URL https://www.lazard.com/perspective/levelized-cost-of-energy-analysis-100/ (accessed 4.3.17).

Mentis, D., Welsch, M., Fuso Nerini, F., Broad, O., Howells, M., Bazilian, M., Rogner, H., 2015. A GIS-based approach for electrification planning—A case study on Nigeria. Energy Sustain. Dev. 29, 142–150. doi:10.1016/j.esd.2015.09.007

NDC, 2016. Nigeria's Draft Nationally Determined Contribution (NDC). Implementation action plan for the power sector.

NERC, 2015. Draft Feed-in Tariff Regulations for Renewable Energy Sourced Electricity in

Nigeria [WWW Document]. URL https://www.iea.org/media/pams/nigeria/NIGERIA_FIT_regulation2015enteringintoforceFeb2016.pdf

NERC, 2012. The Multi Year Tariff Order for the determination of the cost of electricity generation for the period 1st of June 2012-31st May 2017 [WWW Document]. URL http://www.nercng.org/index.php/document-library/func-startdown/67/

Oxfam America, 2017. The energy challenge in sub-Saharan Africa [WWW Document]. URL https://www.oxfamamerica.org/explore/research-publications/the-energy-challenge-in-sub-saharan-africa/ (accessed 2.17.17).

Oyewo, S., Aghahosseini, A., Breyer, C., 2017. Assessment of energy storage technologies in transition to a 100% renewable energy system for Nigeria (PDF Download Available), in: 11th International Renewable Energy Storage Conference.

Stiglitz, J.E., Stern, N., 2017. Report of the High-level Commission on Carbon prices [WWW Document]. URL https://www.carbonpricingleadership.org/news/2017/5/25/leading-economists-a-strong-carbon-price-needed-to-drive-large-scale-climate-action (accessed 6.16.17).

World Bank, 2016. Achieving universal access in the Kaduna electric service area [WWW Document]. URL http://documents.worldbank.org/curated/en/782491487138851242/Achieving-universal-access-in-the-Kaduna-electric-service-area (accessed 5.24.17).

Annex 1: Cost data tables

Open Cycle Gas Turbine

Parameters	Unit	NERC 2012	IEA WEO 2016	AEO 2017	OCGT IPP 1, ($3.80/Mmbtu)	OCGT IPP 2 ($7/Mmbtu)
Currency and year		2012 USD (NGN for FOM and VOM)	2015 USD	2016 USD	Not stated	Not stated
Installed capacity	MW	250	Not stated	237	Not stated	Not stated
Capital Cost	$/kW	1200	400	672	1500	1500
Technical lifetime	yr	20	20	20	20	20
Capacity Factor	%	80%	80%	80%	80%	80%
Fixed O &M	$/kW/yr	15,50	20,0	6,76	15,50	6,90
Variable O & M	$/kWh	0,006	0	0,011	0,006	0,003
Fuel cost (HHV)	$/Mbtu	3,30	3	3,3	3,80	7,00
BTU/KWh produced	btu/kWh	11039	11039	8550	11039	11039
sLCOE (11% WACC)	**$/KWh**	**0,066**	**0,046**	**0,052**	**0,077**	**0,108**
World Bank 2013 LCOE	$/KWh	0,057				

Combined Cycle Gas Turbine

Parameters	Unit	NERC / Consult.	IEA WEO 2016	AEO 2017	Lazard 2016	CCGT IPP ($7/Mmbtu)
Currency and year		2012 USD (NGN for FOM and VOM)	2015 USD	2016 USD	not stated	Not stated
Installed capacity	MW	Not stated	not stated	429	550	Not stated
Capital Cost	$/kW	1000	700	1094	1150	1000
Technical lifetime	yr	20	20	20	20	20
Capacity Factor	%	80%	80%	80%	60%	80%
Fixed O &M	$/kW/yr	15,50	25	9,94	5,85	15,50
Variable O & M	$/kWh	0,006	0	0,002	0,006	0,006
Fuel cost (HHV)	**$/Mbtu**	**3,30**	**3,30**	**3,30**	**3,45**	**7,00**
BTU/KWh produced	btu/kWh	11,039	11,039	6,200	6,600	11,039
sLCOE (11% WACC)	**$/KWh**	**0,062**	**0,053**	**0,043**	**0,057**	**0,103**
World Bank 2013 LCOE	$/KWh	0,050				

Coal

(scrubbed coal, subcritical, FGD – flue gas desulphurisation, no CCS)

Parameters	Unit	NERC 2012	IEA WEO 2016	AEO 2015	Coal IPP 1	Coal IPP 2
Currency and year		2012 USD (NGN for FOM and VOM)	2015 USD	2013 USD	Not stated	Not stated
Installed capacity	MW	250	not stated	1300	1200	Not stated
Capital Cost	$/kW	2730	1300	2917	2730	1800
Technical lifetime	yr	40	40	40	40	40
Capacity Factor	%	70%	70%	70%	70%	70%
Fixed O &M	$/kW/yr	32,00	45,00	31,16	32,00	32,00
Variable O & M	$/kWh	0,001	0	0,004	0,016	0,010
Fuel cost (HHV)	**$/Mbtu**	**5,10**	**5,10**	**5,10**	**5,10**	**5,10**
BTU/KWh produced	btu/kWh	8937	8937	8740	8937	8937
sLCOE (11% WACC)	**$/KWh**	**0,101**	**0,077**	**0,107**	**0,016**	**0,010**
World Bank 2013 LCOE	$/KWh	0,065				

Nuclear

Parameters	Unit	IEA WEO 2016	AEO 2017	Lazard 2016	NG?
Currency and year		2015 USD	2016 USD	not stated	
Installed capacity	MW	not stated	2234	1100	
Capital Cost	$/kW	4000	5880	4550	
Technical lifetime	yr	60	60	40	
Capacity Factor	%	80%	80%	90%	
Fixed O &M	$/kW/yr	170	99,65	135	
Variable O & M	$/kWh	0	0,002	0,001	
Fuel cost (HHV)	**$/Mbtu**	**0,85**	**0,85**	**0,85**	
BTU/KWh produced	btu/kWh	10450	10450	10450	
sLCOE (11% WACC)	**$/KWh**	**0,096**	**0,118**	**0,091**	
World Bank 2013 LCOE	$/KWh	0,101			

Fuel cost from Lazard

Large hydro

Parameters	Unit	NERC 2012	IEA WEO 2016	AEO 2017
Currency and year		2012 USD (NGN for FOM and VOM)	2015 USD	2016 USD
Installed capacity	MW	300	not stated	500
Capital Cost	$/kW	1800	2100	2442
Technical lifetime	yr	40	40	40
Capacity Factor	%	65%	46%	65%
Fixed O &M	$/kW/yr	13,77	55,00	14,93
Variable O & M	$/kWh	0,001	0	0,003
sLCOE (11% WACC)	**$/KWh**	**0,039**	**0,072**	**0,053**
World Bank 2013 LCOE	$/KWh	0,088		

Small hydro

(<30MW, cf. mini-hydro = <1MW)

Parameters	Unit	NERC 2015	IEA WEO 2016
Currency and year		Not stated	2015 USD
Installed capacity	MW	30	not stated
Capital Cost	$/kW	3100	3300
Technical lifetime	yr	20	20
Capacity Factor	%	45%	44%
Fixed O &M	$/kW/yr	23,00	65,00
Variable O & M	$/kWh	0,0003	0
sLCOE (11% WACC)	**$/KWh**	**0,105**	**0,124**
World Bank 2013 LCOE	$/KWh	0,126	

PV Utility-scale

>5MW
Storage excluded

Parameters	Unit	NERC 2015	IEA WEO 2016	AEO 2017	Lazard 2016	PV IPP1
Currency and year		Not stated	2015 USD	2016 USD	Not stated	Not stated
Installed capacity	MW	5	Not stated	150	30	100
Capital Cost	$/kW	1500	2400	2277	1450	1150
Technical lifetime	yr	20	20	20	30	20
Capacity Factor	%	19%	21%	19%	23%	19%
Fixed O &M	$/kW/yr	30,00	24,00	21,66	12,00	17,30
Variable O & M	$/kWh	0,0001	0	0	0	0
sLCOE (11% WACC)	**$/KWh**	**0,131**	**0,177**	**0,185**	**0,089**	**0,097**
World Bank 2013 LCOE	$/KWh	0,245				

Lazard: in the case of Utility-scale PV, higher-bound values chosen (contrary to other technologies where average values were used).

PV Off-grid

Rooftop (residential, C&I) – few kW to few MW
Storage included

Parameters	Unit	IEA WEO 2016	Lazard 2016	NG PV offgrid IPP	REEEP /NESP 2016	Hybrid PV-diesel
Currency and year		2015 USD	not stated	2016 USD	Naira (=315 USD)	Not stated
Installed capacity	MW	not stated	1	0.01	0.022	Not stated
Capital Cost	$/kW	2840	2400	3260	2882	2000
Technical lifetime	yr	20	20	20	20	30
Capacity Factor	%	17%	20%	23%	16%	20%
Fixed O &M	$/kW/yr	28,00	18,00	50,00	0	50
Variable O & M	$/kWh	0,00	0,00	0,00	0,10	0,00
sLCOE (11% WACC)	**$/KWh**	**0,258**	**0,182**	**0,223**	**0,26**	**0,256**
World Bank 2013 LCOE	$/KWh	0,310				

Sources:
REEEP & NESP, 2016, Cost comparison of different fuel sources in Nigeria.
Hybrid data: Cader et al (2016) Global cost advantages of autonomous solar–battery–diesel systems compared to diesel-only systems. Price of diesel: 0,84 USD/litre (GIZ value for Nigeria 2014 diesel prices survey).

CSP

Parameters	Unit	IEA WEO 2016	AEO 2017	Lazard 2016
Currency and year		2015 USD	2016 USD	not stated
Installed capacity	MW	not stated	100	110
Capital Cost	$/kW	5050	4182	10150
Technical lifetime	yr	35	35	35
Capacity Factor	%	32%	32%	69%
Fixed O &M	$/kW/yr	200,00	70,00	97,50
Variable O & M	$/kWh	0,0000	0,0000	0,0000
sLCOE (11% WACC)	**$/KWh**	0,275	0,193	0,207
World Bank 2013 LCOE	$/KWh	0,244		

Biomass

Parameters	Unit	NERC 2015	IEA WEO 2016	AEO 2017	Lazard 2016
Currency and year		Not stated	2015 USD	2016 USD	not stated
Installed capacity	MW	10	not stated	50	35
Capital Cost	$/kW	2900	2150	3790	3250
Technical lifetime	yr	20	20	20	20
Capacity Factor	%	60%	50%	60%	85%
Fixed O &M	$/kW/yr	53,50	75,00	110,34	95,00
Variable O & M	$/kWh	0,0010	0	0,0055	0,015
Fuel cost (HHV)	**$/Mbtu**	*****	**1,5**	**1,5**	**1,5**
BTU/KWh produced	btu/kWh				
sLCOE (11% WACC)	**$/KWh**	**0,084**	**0,101**	**0,139**	**0,104**
World Bank 2013 LCOE	$/KWh	0,310			

*Fuel cost NERC = 0,004 USD/kWh cf. Lazard's 0,022 USD/kWh

Wind onshore

Parameters	Unit	NERC 2015	IEA WEO 2016	AEO 2017	Lazard 2016
Currency and year		Not stated	2015 USD	2016 USD	not stated
Installed capacity	MW	10	not stated	100	100
Capital Cost	$/kW	1760	1880	1686	1475
Technical lifetime	yr	20	20	20	30
Capacity Factor	%	32%	24%	32%	47%
Fixed O &M	$/kW/yr	18,50	48,00	46,71	46,71
Variable O & M	$/kWh	0,0015	0	0	0
sLCOE (11% WACC)	**$/KWh**	**0,087**	**0,135**	**0,092**	**0,057**
World Bank 2013 LCOE	$/KWh	0,186			

Gas off-grid

Parameters	Unit	Lazard 2016	Lazard 2016 + NG gas cost
Currency and year		not stated	Not stated
Installed capacity	MW	0,63	0,63
Capital Cost	$/kW	2600	2600
Technical lifetime	yr	20	20
Capacity Factor	%	80%	95%
Fixed O &M	$/kW/yr	7,99	7,99
Variable O & M	$/kWh	0,0085	0,0085
Fuel cost (HHV)	**$/Mbtu**	**3,45**	**7,00**
BTU/KWh produced	btu/kWh	11150	11039
sLCOE (11% WACC)	**$/KWh**	**0,095**	**0,126**
World Bank 2013 LCOE	$/KWh	0,96	

Diesel off-grid

Parameters	Unit	Lazard 2016	REEEP/NESP 2016	Oladokun and Asemota 2015	Oladokun and Asemota 2015
Currency and year		USD, year not stated	Naira (=315 USD)	USD, year not stated	USD, year not stated
Installed capacity	MW	0,25	0,01	0,50	0,1
Capital Cost	$/kW	6500	2981	300	1250
Technical lifetime	yr	20	10	10	10
Capacity Factor	%	60%	80%	60%	60%
Fixed O &M	$/kW/yr	15,00	0	0	0
Variable O & M	$/kWh	0,015	0,03	0,25	0,33
Fuel cost (HHV)	**$/Mbtu**	**18,23**	*	**	**
BTU/KWh produced	btu/kWh	10000	n/a	n/a	n/a
sLCOE (11% WACC)	**$/KWh**	**0,216**	**0,226**	**0,344**	**0,454**
World Bank 2013 LCOE	$/KWh	0,251			

Sources:
REEEP & NESP, 2016, Cost comparison of different fuel sources in Nigeria.
Oladokun and Asemota (2015) Unit cost of electricity in Nigeria: A cost model for captive diesel powered generating system.

* Price of diesel: 40 Naira/kWh = 0,13 USD/kWh (using USD= 315 Naira exchange)
**Price of diesel: 0,08 USD/KWh (GIZ value for Nigeria 2014 diesel prices survey).

Petrol off-grid

Parameters	Unit	REEEP/NESP 2016
Currency and year		Naira (=315 USD)
Installed capacity	kW	0,25
Capital Cost	$/kW	139,68
Technical lifetime	yr	5
Capacity Factor	%	30%
Fixed O &M	$/kW/yr	0
Variable O & M	$/kWh	0,4
Fuel cost (HHV)	**$/Mbtu**	*
BTU/KWh produced	btu/kWh	n/a
sLCOE (11% WACC)	**$/KWh**	**0,639**
World Bank 2013 LCOE	$/KWh	0,324

*Price of gasoline: 69,8 Naira/Litre (value at time of NESP study) = 0,22 USD/kWH
Source: REEEP & NESP, 2016, Cost comparison of different fuel sources in Nigeria.

GHG EMISSIONS	Emissions profile (kgCO2e/kWh)	Additional cost (cents/kWh)	
		USD 40-60/tCO2e	USD 100/tCO2e
Gas	0.55	2.2-3.3	5.5
Coal	0.94-0.98	3.7-5.9	9.3-9.8
Diesel	0.101	4.0-6.1	10.1

AIR POLLUTION	Additional cost (cents/kWh)	
	SOx + NOx + PM 2,5	Nuclear risks
Gas	0.21	
Coal	2.42	
Biomass	1.47	
Nuclear		0.4

SYSTEM COSTS	Additional cost (cents/kWh)		
	Profile	Balancing	Total
OCGT	-0,34		-0,34
CCGT	-0,34		-0,34
Coal	-0,34		-0,34
Nuclear		0,21	0,21
PV Utility scale	0,12	0,11	0,23
Biomass	-0,34		-0,34
Wind onshore	0,96	0,21	1,17

SYSTEM COSTS	Additional cost (cents/kWh)		
	Profile	Balancing	Total
OCGT	-0,34		-0,34
CCGT	-0,34		-0,34
Coal	-0,34		-0,34
Nuclear		0,21	0,21
PV Utility scale	0,12	0,11	0,23
Biomass	-0,34		-0,34
Wind onshore	0,96	0,21	1,17