Diesel Power Generation

Inventories and Black Carbon Emissions in Nigeria

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LIST OF ACRONYMS AND ABBREVIATIONS

BC: Black Carbon

CDMA: Code Division Multiple Access

CO_2: Carbon Dioxide

EFs: Emissions Factors

FCT: Federal Capital Territory

GSM: Global System for Mobile Communications

GWh: Gigawatt-hour

HNLSS: Harmonized Nigeria Living Standards Survey

HP: Horsepower

IIASA: International Institute for Applied System Analysis

IPP: Independent Power Producer

JV: Joint Venture

kt: Thousand tons (Kilo tons)

KVA: Kilovolts- Ampere

MAN: Manufacturers Association of Nigeria

MMt: Million metric tons

MNOs: Mobile Network Operators

MW: Megawatt (10^6 Watts)

MWh: Megawatt-hour

NOx: Nitric Oxides

OC: Organic Carbon

PF: Power Factor

PSC: Production Sharing Contracts

TCN: Transmission Company of Nigeria

UNFPA: United Nations Fund for Population Activities

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EXECUTIVE SUMMARY

Diesel gensets contribute to emissions of fine particulate matter (PM), including black carbon, which derives from the incomplete combustion of diesel (as occurs in many diesel generating sets or gensets). Particulate matter is a predisposing factor for respiratory and cardiopulmonary disease leading to increased hospital visits and risk of premature death. Local health costs can have a greater impact in the short-run in densely populated urban centers such as Abuja and Lagos. Black carbon (BC) is the most strongly light-absorbing component of particulate matter and is the second largest warming agent after carbon dioxide. The emerging role of BC as a significant driver of global climate change is increasing attention on its mitigation efforts. In addition to the negative health and the climate effects of emissions, most gensets contribute significantly to noise pollution which further reduces the quality of life of users and non-users alike.

Current demand for electricity in Nigeria is estimated to be between 8,000-10,000 MW and a significant part of this demand is met by onsite generating sets which are primarily fueled by petrol and diesel. At the current pump price of about $1 per liter of diesel, it costs about twice as much to run a diesel genset compared with the power from the grid. These factors are increasing attention on the use of diesel gensets for self-generation. With the removal of subsidies on gasoline, the share of diesel gensets could rise.

This study is a first attempt to develop an inventory of emissions of various types of pollutants (including black carbon) from diesel gensets in Nigeria. Due to inadequate resources to conduct new surveys or gather additional primary data, the study draws on available literature and data to estimate Nigeria's diesel genset inventory and emissions from the generation of electricity with such gensets. In doing so, it illustrates an approach to estimate emissions within the constraints of available data. For example, given that data on local emission factors was unavailable, an approximation had to be made based on international emission factors including the US EPA standards. Such an approach could be used to initiate a dialogue with interested stakeholders like the Federal Ministry of Environment as well as analysts and researchers, but would not be robust for arriving at policy recommendations.

The availability and quality of data varies across the various sectors and the inventory numbers presented should be regarded as preliminary. Data of relatively better quality was available for the oil and gas, manufacturing and telecommunication sectors; however, the residential and commercial sector inventory of diesel genets was much harder to assess. For example, the Nigeria Harmonized Living Standards Survey was used to estimate the residential sector usage of diesel gensets. This survey does not indicate the sizes of gensets which has an impact on emission levels and it was assumed that all gensets are under 1.5MVA thus leading to a lower level of confidence in the resulting estimates of BC emissions from the residential sector. A similar assumption was made for the commercial sector. The number of diesel gensets in these sectors were assumed to be small (about 600,000 or 3.5% of the total number of gensets) but due to the large number of (up to 17.5 million generators in the two sectors), a more rigorous assessment is necessary because as fuel subsidies on gasoline are revised, the number of diesel gensets could increase.

Improving data collection of diesel genset use and emissions are first steps toward setting priorities for action. For example, it could help track changes in emissions over time. This might necessitate sector specific surveys or follow-up surveys. There are indications that data exists with various agencies in Nigeria which could be used in estimating self-generation, and sector specialists such as those who participated in a stakeholders workshop organized for this study in Abuja, could help scope and source relevant data and information on diesel genset use across the economy. While data may be routinely collected in some instances, it is not collated or stored in a format that allows for easy collation and this calls for better data management practices. By strengthening the analysis and evidence base, the results could help inform policy and further bolster the case for improving the reliability of power supplies to customers.

1 INTRODUCTION

Demand for electricity in Nigeria is currently estimated to range between 8,000-10,000 MW[1] while available capacity on the national grid averages around 3,500 MW (World Bank 2014). A significant proportion of this shortfall is met with onsite generating sets (gensets) at consumer locations; some of these gensets operating between 15-18 hours a day (NBS, SMEDAN 2010).

Diesel gensets contribute emissions of fine particulate matter (PM), including black carbon, which derives from the incomplete combustion of diesel (as occurs in many diesel gensets). Particulate matter is a predisposing factor for respiratory and cardiopulmonary disease leading to increased hospital visits and risk of premature death. Local health costs can have a greater impact in the short-run in densely populated urban centers such as Abuja and Lagos. (World Bank, 2011, 2013)

Black carbon also affects the climate. It absorbs sunlight and generates heat in the atmosphere, which warms the air and can affect regional cloud formation and precipitation patterns. When deposited on bright surfaces, such as snow and ice, it reduces the reflectivity of the surface and absorbs sunlight, generating heat. This warms the air above and the surface below, thus accelerating melting (the albedo effect). Since BC remains in the atmosphere for only a short period (typically 1-2 weeks) its climate effects would dissipate quickly if emissions were reduced.

Black carbon is often emitted with organic carbon and sulfates which are lighter in color. While black smoke has a high proportion of BC and exerts a strong warming influence, white smoke, which usually contains mostly organic carbon, exerts a cooling influence. Although the combustion of diesel in diesel gensets is dominated by black smoke, it is important to take account of co-pollutants, which reflect sunlight and thus have a cooling effect on the climate.

In addition to the negative health and the climate effects of emissions, most gensets contribute significantly to noise pollution which further reduces the quality of life of users and non-users alike. The financial burden of operating a diesel genset in Nigeria is also significant. At the current pump price of nearly $1 per liter of diesel[2], it costs about twice as much to run a diesel genset compared with the currently subsidized power from the grid.

The health impacts and emerging role of BC as a significant contributor to global climate change, possibly second only to CO_2, is increasing the focus on the potential climate impacts of diesel genset use (USEPA 2005). This study attempts to estimate the order of magnitude of black carbon and other pollutants from the use of diesel gensets in Nigeria.

[1] The low carbon study for Nigeria estimates available grid and off-grid capacity for electricity usage at 7,940MW. Babatunde and Shuaibu estimate total demand at 10,000MW (http://www.africametrics.org/documents/conference09/papers/Babatunde_Shuaibi.pdf)
[2] Diesel price from http://www.globalpetrolprices.com/Nigeria/diesel_prices/

2 BACKGROUND

Nigeria is the largest country in Africa with its population of 158 million people and accounts for 47% of West Africa's population (World Bank 2013). Despite the general increase in per capita electric power consumption from year 2000, the national average has been significantly below the average for the sub region as seen from figure 1. Nearly half of the entire population had no access to electricity according to 2010 statistics (World Bank a).

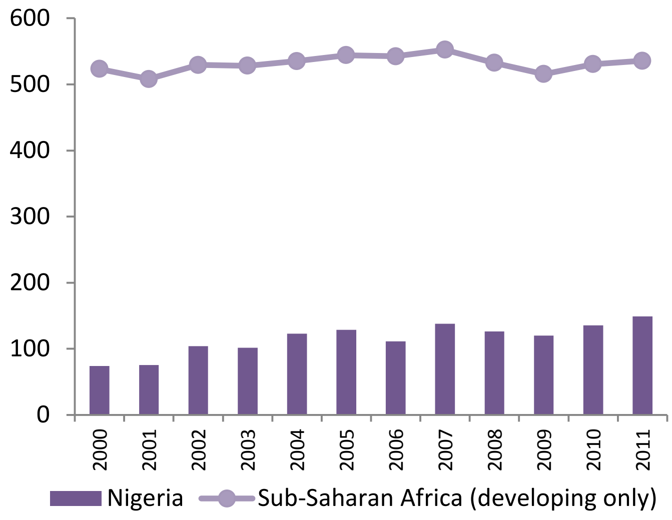

Figure 1: Electric power consumption (kWh per capita)
SOURCE: WB World Development Indicators

For the other half with access, the quality of supply is poor and availability of electricity is reduced due to load curtailment necessitated by inadequate capacity, lack of natural gas, transmission constraints and equipment outages at various points in the power grid. A load demand study in 2009 estimated that plant utilization factor for industries dropped to almost 35% forcing a sizeable number of industries, including those of labour intensive ones such as the textile mills in Kaduna, Kano and Lagos to shut down. Many industries and individuals therefore run gensets to augment power supply from the grid (Tractebel Engineering Suez, Omega Systems 2009).

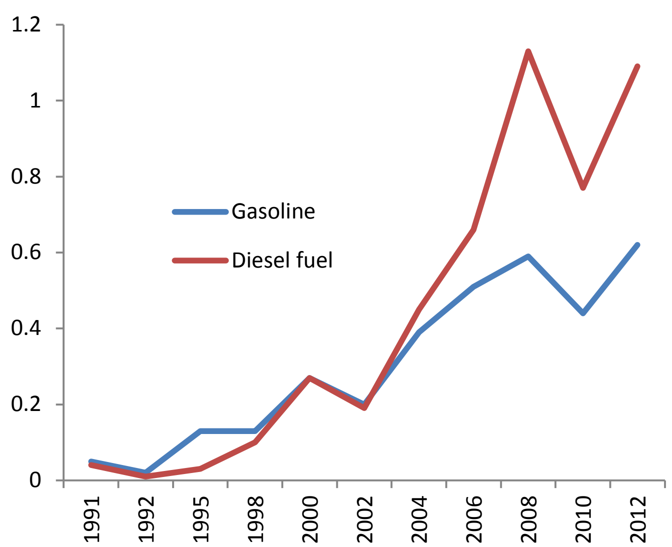

Figure 2: Pump price per liter of fuel in Nigeria (US$)

The gensets are imported from North America, Europe and Asia with the Perkins brand holding approximately 70% of the total market of the international original equipment manufacturers (OEMs). It is estimated that the total gensets market is the largest in Africa in terms of revenue and is seen as a highly lucrative and competitive industry. Repairs and overhauling services account for an average of 40 to 60 percent of the total market revenues. It is also estimated that Nigeria spends approximately $250 million annually to import gensets and their spare parts. (Frost & Sullivan 2011) The types of gensets used are also affected by fuel prices. Gasoline is subsidized in Nigeria and therefore cheaper than diesel as shown in figure 2. This has influenced consumption patterns. For example, most private vehicles run on gasoline due to the lower price. Subsidies are expected to gradually reduce and narrow the price difference between gasoline and diesel which will affect consumption patterns and the composition of generators. (IISD 2012) (Cervigni, Rogers and Dvorak 2013)

There are no quality control regulations so the market consists of gensets of varying quality and prices (Frost & Sullivan 2011). While there are regulations to control vehicular emissions from petrol and diesel engines, there are no regulations to control emissions from gensets (NESREA 2013a). The National Environmental Standards and Regulations Enforcement Agency (NESREA), a parastatal agency of the Federal Ministry of Environment, has responsibility for the protection and development of the environment, biodiversity conservation amongst others and are also responsible for enforcement of regulations (NESREA 2013b).

A draft National Policy on the Environment proposed in 1998 sought to control amongst others: air pollution by establishing ambient air quality standards and monitoring stations at designated zone; and noise pollution by setting up noise standards including acoustic guarantees and prescribing guidelines for the control of noise (FEPA 1998). These are yet to be established.

Despite the challenges, the government is working to improve supply. The ongoing National Integrated Power Projects (NIPP) will add 3,700 MW capacity in the coming three years (World Bank, 2014) with the vision of expanding available capacity to 40,000MW by 2020 (PTFP, 2013).

2.1 Scope and Methodology

This study draws on available literature and data to estimate Nigeria's diesel genset inventory and emissions from the generation of electricity with such gensets. In doing so, it illustrates an approach to estimate emissions within the constraints of available data.

The sectors of the Nigerian economy with significant utilization of diesel genset for electricity generation include manufacturing; residential; telecommunications; oil and gas; and the commercial and construction sectors. The commercial sector is a broad categorization that includes banks, other offices, schools, hospitals, hotels, restaurants, markets, and shops amongst others.

The availability and quality of data varies across the various sectors and in the analysis, sectors with relatively better data are discussed first before other sectors where data quality is poorer. Data of relatively better quality was available for the oil and gas, manufacturing and telecommunication sectors. It is difficult to estimate the level of genset usage in the residential and commercial sectors due to the nature and distribution of users. The residential sector was analyzed using the Nigeria Harmonized Living Standards Survey (HLSS) as a basis.

An estimate of the potential contribution of the commercial sector is included based on: (i) a load demand study published in 2009 by Tractebel Engineering Suez and Omega Systems; and (ii) a survey by the Small and Medium Enterprises Development Agency of Nigeria (SMEDAN) and the National Bureau of Statistics (NBS). These two sources yield varied results and is used to present a range for the extent to which gensets are used.

To estimate energy generation from diesel gensets, the following parameters are required for each of the relevant sectors of the economy:

- Number of gensets.
- The capacity of the gensets.
- The rate of diesel consumption for electricity generation by these facilities.
- Average hours of running these facilities per day.
- Information on the fuel efficiency, the capacity factor, and the availability of the facilities.

Given the data limitations, multiple assumptions are used in estimating some of these parameters. A weakness with this approach is the need to extrapolate data across the culturally and economically diverse population of Nigeria. An alternative to this approach would be to use data on diesel consumption or sales to estimate energy generation from diesel gensets. The weakness of this alternative approach is that the distinction between the sectors is lost and with that the potential to use relatively better data from sectors like the manufacturing and telecommunication sectors.

There are indications that data exists with various agencies in Nigeria which could be used in estimating self-generation. This was apparent during stakeholder consultations held in Abuja. In some instances, it was confirmed that while the data is routinely collected, it is not collated or stored in a format that allows for easy collation. In other instances, obtained data included several missing points. This further heightens the need for better data management.

After building the inventory, emissions were estimated using emission factors available. In the absence of local factors, international factors, including U.S. EPA emissions standards, were used for the estimates. The EPA standards stipulate different emission factors for engines under 600 horsepower and engines above 600 horsepower. Per the EPA standards, the inventories for the sectors analyzed were split into two groups according to the generator rating. To capture the age and maintenance practices in Nigeria, the U.S. EPA emissions factors were modified by drawing on the expertise of the International Institute for Applied Systems Analysis (IIASA). IIASA conducts policy-oriented research into problems that are too large or too complex to be solved by a single country or academic discipline and has been involved in developing emission factors in various countries.

2.2 Structure of the Report

This report is organized as follows:

- Chapter 3 presents the inventories developed for the relevant sectors of the Nigerian economy where data/information is available.
- Chapter 4 includes a discussion of the emissions factors used in the estimation of the emissions from diesel gensets in Nigeria and the results for emissions of BC and co-pollutants. This chapter also looks at data gaps and suggested sources of data to bridge the gaps.
- Chapter 5 presents conclusions and offers recommendations for further work.

In Chapters 3 and 4, the telecommunication, oil and gas and manufacturing sectors, where relatively better data exists, are presented first followed by the residential and commercial sectors. Finally, the annexes present key data, results, and the equations used in this study.

3 THE NIGERIAN DIESEL GENSET INVENTORY

This section presents the inventory of diesel gensets for the manufacturing, residential, telecommunications, and oil and gas sectors. These sectors, along with construction and commercial, are significant users of gensets. Due to the paucity of data, the construction and commercial sectors were not analyzed.

3.1 Diesel Genset Inventory for the Manufacturing Industry

3.1.1 Data Sources

The main data source used for the inventory work for the manufacturing sector was a 2007 report by the Manufacturing Association of Nigeria (MAN),[3] Power and Energy Audit Exercise for Member Factories Nationwide (MAN 2007). The survey was commissioned by MAN to estimate the capacity that would be required for a power plant to service members of the association. This was necessitated by the erratic supply of power from the national grid.

The data from the survey is summarized in Table 1.

Table 1: Summary of the MAN Survey Database

	Industrial Areas	No of Industries Covered	Present Max Power Demand (MW)	Self-Installed Generating Capacity (KVA)	Average Weekly Diesel Consumption (Liters)
1.	West 1 (Lagos & Ogun State Areas)	871	484.53	311,179.00	4,653,127
2.	West 2 (Oyo, Osun & Ekiti States Areas)	175	33.58	9,775.48	196,291
3.	Edo/Delta States Areas	44	11.82	27,950.00	118,164
4.	Rivers, Abia, Akwa Ibom, Cross Rivers State Areas	90	39.10	35,140.95	216,241
5.	Anambra, Enugu and Imo State Areas	164	81.40	69,555.00	1,864,617
6.	Plateau, Gombe and Bauchi State Areas	28	30.20	47,675.00	847,984
7.	Kano State Area	106	160.73	201,998.00	731,377
8.	Kaduna, Sokoto States and FCT Areas	22	22.80	25,548.00	51,837
	TOTAL	**1,500**	**864.16**	**728,821.43**	**8,679,638**

SOURCE: Manufacturing Association of Nigeria

3.1.2 Analysis of the MAN Database and the Resulting Inventory

According to the MAN survey report, the 1,500 manufacturing sites covered by the survey is said to be about 90% of the manufacturing industries in Nigeria. Analysis of the data indicated that only 602 of the sites had complete data that can be used for this analysis. This means that the sample size that is being used to build this inventory is about 36% of the sector population of diesel gensets;

[3] MAN is an umbrella body for all the organizations and entities engaged in manufacturing activities in Nigeria.

The following steps were taken to analyze the MAN database and develop the diesel genset inventory for the manufacturing industry:

- The MAN database, which was organized in accordance with MAN's eight zonal regions, was reorganized into the 11 Transmission Company of Nigeria (TCN) power distribution zones.
- For each manufacturing entity, the HP[4] rating of the onsite generation facility was calculated, and the resulting database was graded by HP rating. The reason for grading by HP rating was to facilitate the use of the emissions factors which are available by HP rating.
- Using the weekly diesel consumption per site for generation of electricity and an assumption of fuel efficiency for each of the sector gensets, the electricity generation (MWh) at each site was estimated.
- The KVA rating of the generators and the power factor (PF) at each site were included in the survey; these were used to estimate the available power capacity (MW) at each site.

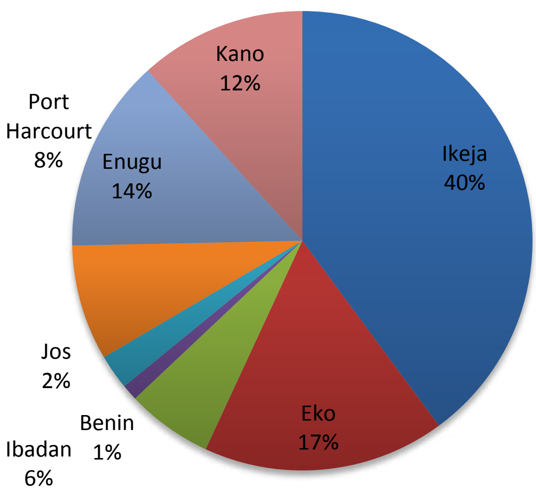

Figure 3: Number of Diesel Gensets (HP<600) in 8 Distribution Zones in the Manufacturing Sector (2007)

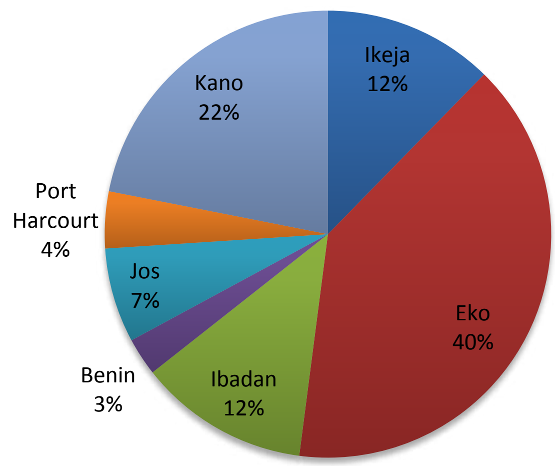

Figure 4: Number of Diesel Gensets (HP≥600) in 7 Distribution Zones in the Manufacturing Sector (2007)

As shown in Figure 3 and Figure 4, 40 percent of gensets with capacities above 600 HP are in Eko while 40 percent of gensets with capacities under 600HP are in Ikeja. Analysis of the data indicate that only 602 of the sites had complete data that could be used for analysis, which translates to a sample size that is about 36 percent of the sector's population of diesel gensets.

Reliable estimates of average hours of grid availability in each of the 11 power distribution zones in Nigeria are not available; the electricity generated at each site was estimated from the diesel fuel utilized and an assumption of average fuel efficiency of the gensets. In a recent World Bank Low Carbon

[4] Both "**Horsepower** (**HP**)" and "KiloWatt"(**kW**) are units of power. Power (**kW**) = Power (**HP**) x 0.7457. Power (**HP**) = Power (**kW**) x 1.341. Also, 1 KW = PF * KVA.

study for Nigeria, an average fuel efficiency of 25 percent was assumed for diesel generators operating in Nigeria and this assumption was adopted for the study (Cervigni, Rogers and Dvorak 2013). This efficiency accounts for the fact that many of the generators in Nigeria are old and poorly maintained. Key assumptions that were used in the development of diesel genset inventory, as well as the electricity generation estimates by diesel gensets in this sector are provided in Table 2.

Table 2: Summary of Assumptions for the Development of Diesel Genset Inventory and Electricity Generation in the Manufacturing Sector

	Parameter Name	Value	Source	Comments
1.	Percentage of Manufacturing Industries in Nigeria Covered by the MAN Survey	90	Discussions with MAN Officials	Although this was not included in the survey report, the number was obtained from MAN officials.
2.	Fuel Efficiency of an Average Generator Operated in Nigeria's Manufacturing Sector (%)	25	Low-Carbon Development – Opportunities for Nigeria	It was assumed that, on the average, the generators used for onsite electricity generation in the manufacturing sector were old.

Given these assumptions, it was estimated that in 2007 generators with capacity less than 600 HP within the MAN database generated about 312.3 GWh of electricity. Diesel generators with capacity ≥ 600 HP generated about 184.1 GWh that same year, giving a total of 496.4 GWh by the 602 gensets covered in the MAN survey data (Figure 5 and Figure 6). Details of the calculations can be found in Table A- 1 and Table A- 2 in the Annex.

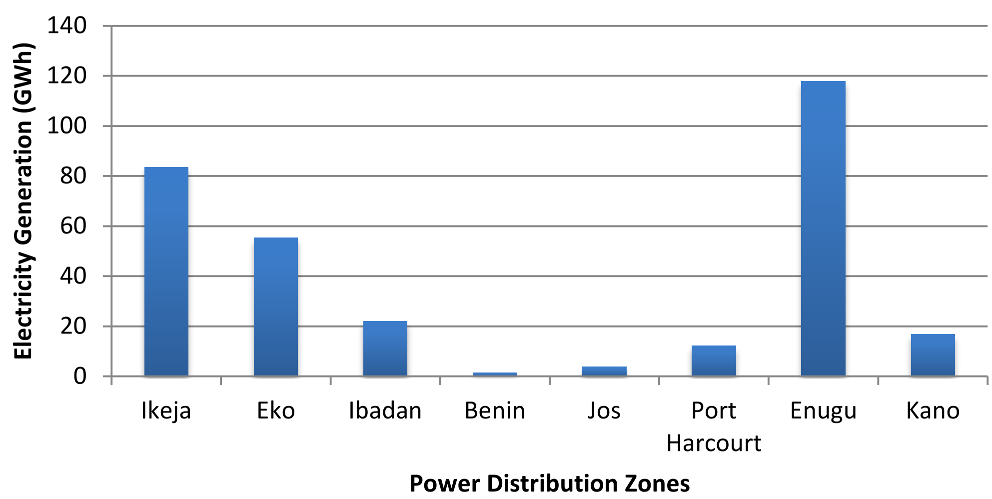

Figure 5: Electricity Generation for HP<600 in the 8 Distribution Zones in Manufacturing Sector (2007)

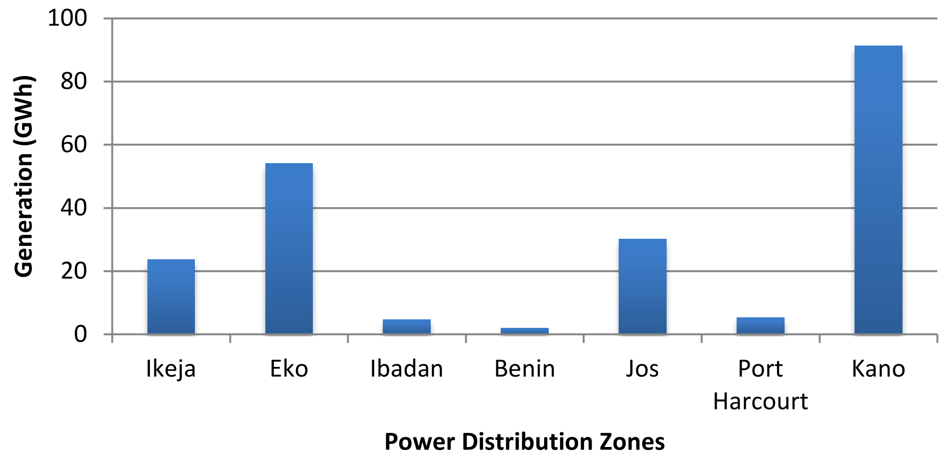

Figure 6: Electricity Generation for HP≥600 in 7 Distribution Zones in Manufacturing Sector (2007)

Given the fact that this represents about 36% of the total inventory of gensets in the sector, and assuming that the MAN survey data is a good representative of the inventory in the sector, it is estimated that electricity generation by diesel gensets in the Nigerian manufacturing sector in 2007 may be as high as 1,378.6 GWh. Using the same assumption, this is equivalent to an installed capacity of 2,400 MW.

3.2 The Telecommunications Sector's Diesel Genset Inventory

3.2.1 Data Sources

The Nigerian telecommunications sector witnessed strong growth and expansion in the last decade, expanding 15.3 percent in network size between 2011 and 2012. Nigeria, as the leading African mobile telecom market, reached a subscriber base of 107 million as of September 2012, with a current network size of 24,252 tower sites. (IFC, GSMA 2012)

A total of about 12,560 sites are deployed in off-grid locations, representing about 52 percent of the total; the remaining 48 percent represent about 11,692 sites that are purely on-grid. Off-grid sites rely on diesel generators as their primary source of power. Mobile network operators (MNOs) and tower companies, however, have pursued alternative solutions (notably battery hybrid power stations) to reduce their dependence on diesel generators.(Ibid)

Almost every on-grid site is equipped with a diesel generator as a backup power source due to unreliable grid power supplies in the country. None of the on-grid sites runs completely on grid power supply or grid-battery hybrid power. The majority of on-grid sites (75 percent) have adopted a grid/genset solution.

3.2.2 Analysis of Data and Development of the Inventory

Key information obtained from the market survey (IFC, GSMA 2012) and used for the diesel genset inventory included the following:

- Nigeria's on-grid sites consume an average of 1,500 liters per month.
- Off-grid sites consume over 1,700 liters per month.
- Given the fact that most of gensets in this sector are new, the fuel efficiency was assumed to be 35 percent.

The total number of gensets is estimated at 24,252 (see Table 3). The telecommunications sector is one of the largest end users of diesel gensets in Nigeria. Gensets in the capacity range 10-30 KVA accounts for about 80 percent of the purchases in this end-user sector. Stakeholder consultations indicated that gensets in the capacity range greater than 30 and up to 60 KVA make up about 15 percent of the inventory in the sector and those in the range 300-500 KVA, which are used to supply onsite electricity at MNO offices and switching centers, constitute 5 percent. Gensets with capacities higher than 500 KVA and whose capacities can be classified as having > 600 HP are only one percent of the sector's diesel genset inventory (see Figure 7).

Table 3: Diesel Genset Inventory for the Nigerian Telecommunications Sector in 2012

Location of Tower/Base Station	Number of Gensets	Average Diesel Consumed per Month (Liters/Month)	Average Fuel Efficiency of Gensets (%)
On-Grid Site	12,560	1,500	35
Off-Grid Site	11,692	1,700	35

SOURCE: IFC, GSMA 2012

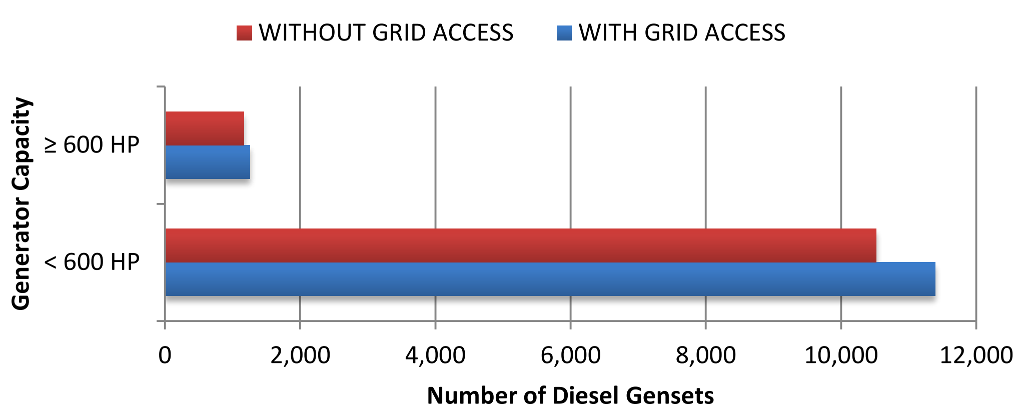

Figure 7: Distribution of Diesel Gensets in the Nigerian Telecommunications Sector by HP

Key assumptions that were used in the development of diesel genset inventory and the electricity generation estimates by diesel gensets in this sector are summarized in Table 4.

Table 4: Summary of Assumptions for Diesel Genset Inventory and Electricity Generation for the Telecommunications Sector

	Parameter Name	Value	Comments
1.	Average Quantity of Diesel Fuel Consumed by Diesel Gensets at Cell Sites With Grid Access (Liters/Month)	1,500	--
2.	Average Quantity of Diesel Fuel Consumed by Diesel Gensets at Cell Sites With No Grid Access (Liters/Month)	1,700	--
3.	Average Fuel Efficiency of Diesel Gensets in the Sector (%)	35	It was assumed that, on average, diesel gensets in this sector are of new vintage given the recent emergence of the sector in the country's economy.
4.	Percentage of Diesel Gensets with Capacity in the Range 10-30 KVA; with Capacity 30-60 KVA; and with Capacity 300-2,000 KVA	80; 15 and 5	

3.2.3 Estimation of Electricity Generation by Diesel Gensets

The estimate of electricity generation in the year 2012 by onsite diesel generators operating in the telecommunications sector in Nigeria is presented in Table 5. A total of 1,645.54 GWh was generated from diesel gensets in the telecommunications sector. This is approximately six percent of electricity production from the grid in 2011. Most of the generation was from gensets rated under 600HP (see Figure 8).

Table 5: Electricity Generation by Diesel Gensets in the Nigerian Telecommunications Sector (2012)

	Gensets with HP < 600 (GWh)	Gensets with HP ≥ 600 (GWh)	Total (GWh)
Sites With Grid Connections	767.00	85.22	852.22
Sites Not Connected to the Grid	713.99	79.33	793.32
TOTAL	**1,480.99**	**164.55**	**1,645.54**

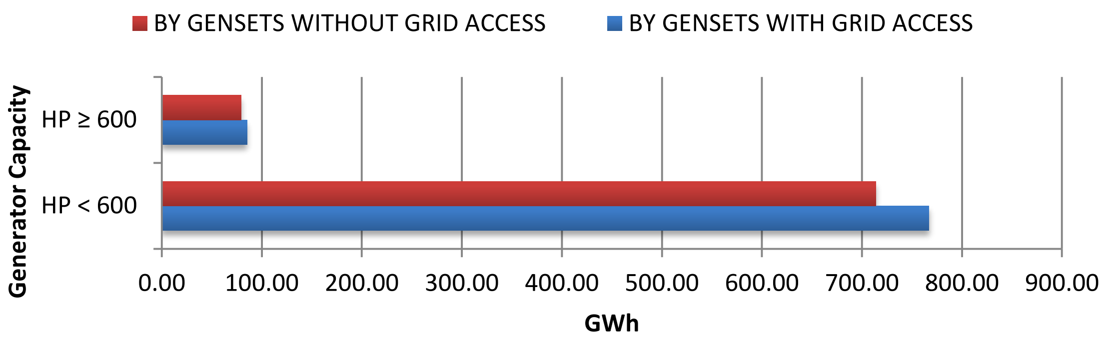

Figure 8: Electricity Generation by Diesel Gensets in the Nigerian Telecommunications Sector (2012)

3.3 The Oil and Gas Sector's Diesel Genset Inventory

3.3.1 Use of Diesel Gensets

Almost all the oil and gas fields in Nigeria are located in areas far removed from the grid; as such, the development of these fields has been designed for the use of onsite generation equipment. Even for those fields close to grid access areas, the norm over the years has been to equip the fields with onsite generation due to the unreliable supply situation of the national grid.

Most fields use gas-fired gensets to provide onsite electricity. Diesel gensets are used for startup and standby electricity generation requirements (standby when gas supply fails or there is a shutdown of the primary power supply system due to scheduled and/or forced maintenance). According to a market survey by Frost and Sullivan, oil and gas fields in Nigeria are usually equipped with two diesel gensets ranging in capacity from 500-1000 KVA to meet standby and cold startup requirements (Frost & Sullivan 2011). Only one of the gensets at a field is operated; the second is a backup genset in case the main set breaks down.

3.3.2 Database and Approach to Inventory Development

According to the information contained in the Nigeria National Petroleum Corporation (NNPC) statistics bulletin of 2011, there were 16 oil and gas companies with active production in the Nigerian offshore and onshore fields in 2011. Assumptions used for the analysis include the following:

- The main diesel genset is operated when needed and the spare is only operated when the main set is out of operation (due to forced or planned maintenance).
- Each field in Nigeria is equipped with gas-fired gensets, which produce electricity for field operations; diesel gensets in oil fields in Nigeria are primarily used for cold/black starts and as alternative generating sets when gas-fired engines are not available.
- It was assumed that these diesel gensets are operated for an average of about 440 hours per year. This average running hours comprises:
    - 52 hours per year for the usual running of the gensets for 1 hour each week to keep the system in good running condition,

  - Two weeks per year when the oil and gas facility is being maintained and the gas gensets are unavailable. This comes to 336 hours/year.

  - An estimated two weeks per year for forced shortages at the facility due to unforeseen circumstances (e.g., theft) has been assumed. During this period, the onsite diesel genset will be operated. This equates to another 52 hours/year.

- Based on information obtained from the Frost and Sullivan survey, the capacity of diesel gensets operating in the oil and gas sector ranges from 500 kVA to 2,000 kVA. It was thus assumed that the average capacity of diesel gensets in the oil and gas sector in 2011 is 1,250 KVA.

- An average power factor of 0.80 and an average capacity factor of 0.85 for the diesel gensets operating in this sector have been assumed.

Key assumptions that were utilized in the development of diesel genset inventory as well as the electricity generation estimates by diesel gensets in this sector are summarized in Table 6.

Table 6: Summary of Assumptions for Diesel Genset Inventory and Electricity Generation for the Oil and Gas Sector

	Parameter Name	Value	Comments
1.	Average Capacity of Diesel Gensets at an Oil and Gas Field (KVA)	1,250	From Ref. 10, it is known that the diesel gensets employed in this sector ranged between 500-2000 KVA in 2012. The midpoint of this range was used as the capacity of an average diesel genset in the sector.
2.	Average Power Factor for an Oil and Gas Field Site (%)	80	Based on discussions with stakeholders and discussions at the workshop.
3.	Average Fuel Efficiency of Diesel Gensets in the Sector (%)	30	Intermediate between residential (25%) and telecommunication (35%). This was used for the emission factor calculations and not the energy generated.
4.	Average Hours Onsite Diesel Gensets at the Oil and Gas Fields in Nigeria are Operated in a Year (hours/year)	440	Based on discussions with stakeholders and discussions at the workshop.
5.	Average Capacity Utilization (%)	85	Based on discussions with stakeholders and discussions at the workshop.

The data on activities at each of the companies in 2011 is summarized in Table 7.

Table 7: Nigerian Oil and Gas Field Information in 2011

	Type of Oil and Gas Company	No. of Fields	% of Annual Crude Production	Estimated No. of Diesel Gensets
A.	Joint Venture (JV)	226	79.7	226
B.	Production Sharing Companies (PSC)	24	16.2	24
C.	Service Contracts	1	0.5	1
D.	Independent/Sole Risk	14	3.5	14
E.	Others	16	0.0	16
	TOTAL	**281**	**100.0**	**281**

Given the fact that the range of these generating assets is between 500 kVA and 2,000 KVA, diesel gensets operating in the sector belong to the class with HP ≥ 600 HP.

Based on the assumptions above, electricity generation in the year 2011 by onsite diesel generators operating in the oil and gas sector was estimated at 105 GWh

Table 8: Electricity Generation by Diesel Gensets at Nigerian Oil Fields in 2011

	Oil Field Type	Energy (GWh)
1.	Joint Venture Fields	84.5
2.	Production Sharing Fields	9.0
3.	Service Contract Fields	0.4
4.	Independent/Sole Risk Fields	5.2
5.	Marginal Field and Others	6.0
	TOTAL	**105.1**

3.4 Diesel Gensets Inventory in the Residential sector

3.4.1 Data Sources

The inventory for the residential sector was developed with various sources of data and took into account feedback from a consultation meeting organized in Abuja. Data sources included the following:

- *The Harmonized Nigeria Living Standards Survey (HNLSS) - Nigerian Household Survey (NHS)* – The Harmonized Nigeria Living Standard Survey (HNLSS) 2009/2010 was an enlarged scope of previous National Consumer Surveys and also a follow-up of Nigeria Living Standard Survey (NLSS) 2003/2004 to include demography, health; and fertility behaviour, education and training; housing and housing condition; social capital; agriculture; household income, consumption and expenditure. The survey covered all 36 States of the Federation and the Federal Capital Territory (FCT) and was carried out in two parts. Part A measured welfare and was conducted in 77,400 households which is an average of one hundred households per Local

Government area. Part B measured consumption and covered 50 percent of the households covered under Part A. Part B of the survey asked respondents to estimate the expenditure on diesel and gasoline for electricity production. This is what was used to estimate energy generation from diesel gensets in the residential sector.

- Aba Electric Consumer Census: a consumer census commissioned by Geometric Power Limited, an independent power producer (IPP) to develop a detailed inventory of future consumers. The consumer census was designed and conducted within Aba Town in 2008. The census focused on urban consumers only and was designed to collect information regarding personal data, consumer category (residential, commercial, or industrial); house/business location and address; meter information, and PHCN billing number or other reference information; generator size; type, and fuel consumption. This survey was used to estimate the number of gensets rated above 600 hp.

This analysis also assumes that each household runs only one genset even when multiple gensets are owned by the household. In the survey carried out in Aba city, 20 percent of the respondents owned more than one generator.

3.4.2 Analysis of Data and Development of the Inventory

33,775 households were interviewed under Part B of the HNLSS. Out of this number, 2,901 (about 8.6 percent) reported owning gensets (diesel or gasoline). Out of this number, only sixteen percent (456 households) reported purchasing diesel or gasoline for electricity generation. This could mean several households do not run the gensets owned, or the gensets are operated by other users. For example, 4.5 percent of households that did not report ownership of gensets reported purchasing fuel for power production. However, the observed results could also reflect a weakness in the survey. In the state of Gombe, no household reported purchasing gasoline for any purpose. This is unlikely to be true even though Gombe was reported as only second to Jigawa state in terms of poverty rates (World Bank 2013). It should therefore be noted that there could be margins of error with the results of the survey but it was used in estimating genset usage in the residential sector. Applying this to the entire population using household weights, nearly 12 percent of households own generators in Nigeria (approximately 4.5 million).

In estimating energy output, ownership of a genset is less relevant than operating the genset and so the statistics on households that reported purchasing fuel for power production was used. Of the households that reported purchasing fuel for power production, nearly 468,000 reported expenditure on diesel (14%) and nearly 3 million reported expenditure on gasoline for power production. The total expenditure on diesel was converted from Nigerian Naira to US dollars using the average exchange rate of 148.4 Naira to a Dollar in 2009[5].

The weighted results show that the Lagos has the highest number of diesel gensets in the residential sector and also reported the highest expenditure on diesel purchases (Figure 9). This is indicative of the population and poverty levels of the states. Lagos State has the lowest estimated poverty rate of 22.9%,

[5] Historical exchange rate obtained from http://www.oanda.com/currency/historical-rates/

while Jigawa has the highest poverty rate at 77.5%. Poverty is particularly concentrated in the Northern part of the country, while the South West experiences the lowest poverty rates. (World Bank 2013)

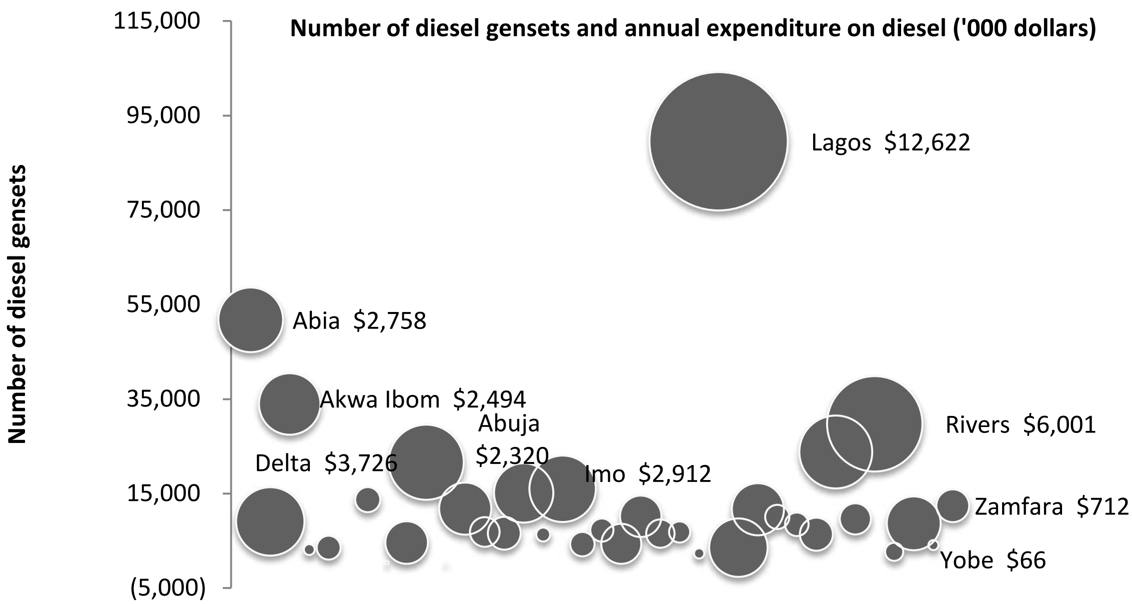

Figure 9: Distribution of diesel gensets and expenditure on diesel for power production

The following assumptions were used to estimate the fuel consumption and annual energy output of the gensets:

- Uniform average pump price of $0.95 per liter diesel across all states in 2009. This is an average of the 2008 and 2010 average prices reported in the World Development Indicators and was used to estimate the liters of diesel purchased.
- An average genset efficiency of 25% as consistent with the efficiency assumed for older gensets used in this study and the low carbon study.

The total energy output for diesel gensets is estimated at approximately 154 GWh. Table A- 3 and Table A- 4 in the Annex show the results by state. Using similar assumptions as for the diesel genset and a pump price of $0.53 per liter of gasoline, energy output from gasoline gensets is estimated at approximately 2,260 GWh. As was done in the low carbon study, the estimated energy generation from genset was varied by 40 percent. With this sensitivity, total captive generation in the residential sector is estimated between 1,450 GWh and 3,370 GWh.

The range is realistic compared with similar analysis like the load demand study which roughly estimated installed self-generation for the residential sector to be between 1000 MW and 2000 MW. The average observed grid unavailability for 11kV feeders was 47 percent (Tractebel Engineering Suez, Omega Systems 2009). In part A of the HNLSS, less than 2 percent of households reported using generators as the main source of lighting (NBS 2010). This implies most gensets are used for back-up supply. Assuming an average load factor of 45 percent[6], the installed capacity for gensets in the residential sector could be between 780 MW and 1,820 MW based on the estimated energy output which compares well with estimates in the load demand study.

3.5 Diesel Gensets Inventory in the Commercial Sectors

Two scenarios were considered for the commercial sector: (1) based on the load demand study; and (2) based on a survey by the Small and Medium Enterprises Development Agency of Nigeria (SMEDAN) carried out in collaboration with the Nigeria Bureau of Statistics (NBS).

The load demand study establishes a correlation between the commercial and residential loads and estimates the commercial sector to contribute 25% of unsuppressed demand with the residential sector contributing 55% of the same. Using this assumption with the analysis of the residential sector above, self-generation from gensets (total) in the commercial sector could be 904 GWh with a possible range of 660 GWh and 1,530 GWh (40 percent variation). If a ratio of diesel to gasoline gensets similar to that of the residential sector is used, energy generation from diesel gensets in the commercial and construction could be approximately 70 GWh. This estimate is based on the share of commercial load connected to the grid.

Other sources of data indicate that this could be an underestimation of the extent of genset usage in the commercial and construction sectors. In a preliminary survey report on the micro, small and medium enterprises (MSMEs) in Nigeria, it was estimated that nearly 23,000 small and medium enterprises (also referred to as the formal sector)[7] used alternative sources of power daily and nearly 13.9 million micro enterprises (also referred to as the informal sector)[8] used alternative sources of power daily (NBS, SMEDAN 2010). The results of the survey show significant usage of gensets (see Figure 10, Table A- 5 and Table A- 6 in the Annex).

Almost 14 million gensets are recorded in the survey operating between 1 and up to 20 hours a day. Nearly all (99 percent) of these gensets are used in the informal or micro scale enterprises and are thus likely to be operated on gasoline. Assuming an average capacity of 7.5 kVA and 2.5 kVA for the formal and informal sectors respectively, total annual energy generation from gensets could be 108 GWh and 13,270 GWh for the two sectors; a total of over 13,380 GWh (see Table A- 7 and Table A- 8 in the Annex).

The average genset sizes are obtained from the consumer survey carried out in the city of Aba where the average generator size for the residential sector was 2.5 kVA while the average genset size for the commercial sector was 7.5 kVA. It is further assumed that gensets in the micro enterprises are likely to be similar to household gensets. The average loading of the gensets during operation is assumed to be 40 percent (Cervigni, Rogers and Dvorak 2013) and the businesses are estimated to operate 250 out of 365 days.

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[6] Load factor for gensets estimated at 40% in areas where gensets are used for back-up power and 50% for gensets used full time. (Low carbon study for Nigeria, Cervigni, Rogers and Dvorak 2013)

[7] Small and medium enterprises are defined in the survey as business enterprises employing 10 to 200 persons.

[8] Micro enterprises are defined in the survey as employing 1-9 persons.

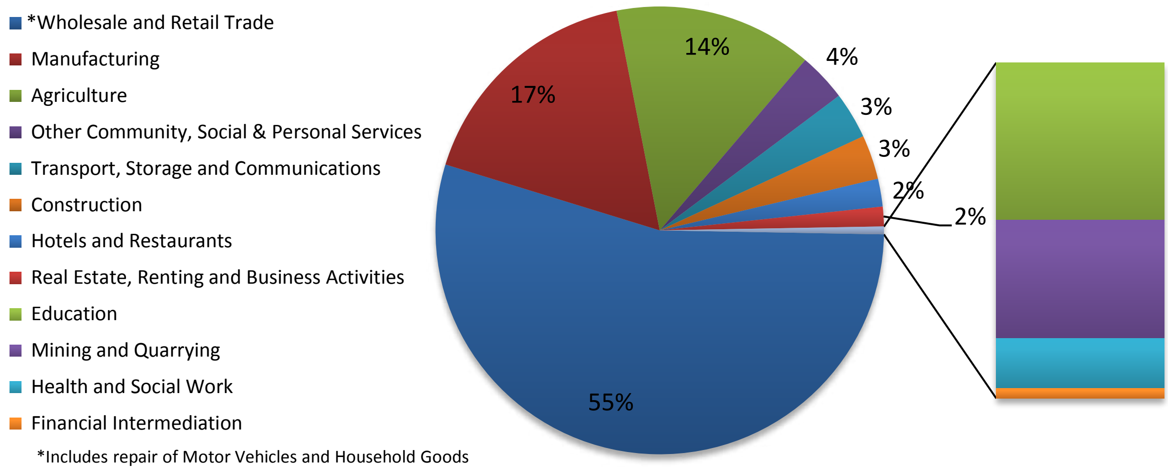

Figure 10: Distribution of gensets in micro, small and medium enterprises by sector

There was no data to directly estimate the share of generation from diesel gensets. However, it is likely that most of gensets used by small and medium enterprises are diesel operated due to the larger capacities. With this assumption, energy generation from diesel gensets could be approximately 108 GWh.

3.5.1 Estimation of Electricity Generation by Diesel Gensets

The data from the different sectors comes from different years and different sources so it is not accurate to compare or aggregate results across sectors. However, this was done to obtain a sense of the magnitude of energy generation from diesel gensets. For the telecommunication, manufacturing and oil and gas sectors where centralized data was available, self-generation from diesel gensets was estimated to be about 3,100GWh. This is likely to cover the bulk of captive generation in these sectors since most of the gensets used are run on diesel with others on gas (mainly in the oil and gas sector).

Self-generation from diesel gensets in the residential sector is estimated at 154 GWh with a possible range of 92 GWh to 215 GWh assuming a variation of 40 percent in energy output. For the commercial sector, self-generation from diesel gensets has been estimated to be between 70 GWh and 108 GWh. In total, estimated generation from diesel gensets could be between 3,262 GWh and 3,423 GWh (see Table 9).

Table 9: Electricity Production from Diesel Gensets in Nigeria's Economy

Sector	Energy consumption (GWh)
Telecommunications (2012)	1,646
Manufacturing (2007)	1,379
Oil and Gas (2011)	105
Residential (2009/2010)	154
Commercial (2009/2010)	70 - 108

The low carbon study estimated total self-generation at 16,360GWh in 2009 and this included generation from diesel, gas and gasoline generators. Self-generation for the sectors analyzed in this study is estimated between 5,240 GWh and 20,380 GWh. The high range is due to the significant difference in results from the two scenarios evaluated for the commercial sector. Using the load demand study as a basis, the energy generation was estimated 904 GWh while the analysis with the SMEDAN survey estimate energy generation at 13,380 GWh.

A load factor of 70% was assumed to estimate peak demand equivalent to the estimated range of energy from self-generation (Tractebel Engineering Suez, Omega Systems 2009). Under this assumption, the peak demand is between 855 MW and 3,324 MW (see Table 10). As these generators are located on-site, this estimated peak is without losses. Aggregate technical, commercial, and collection (ATC&C) losses in the transmission and distribution system are as high as 35 percent (World Bank 2014) but assuming technical losses to be 20 percent (Tractebel Engineering Suez, Omega Systems 2009), a 4,000 MW plant will be required to meet the estimated demand currently served by self-generation.

The installed capacity for off-grid generators will be higher than this estimate because most of such generators typically operate at low utilization factors (between 40% and 50% according to the low carbon study). The low carbon study estimated available self-generation capacity at 4,300 MW while the load demand study by (Tractebel Engineering Suez, Omega Systems 2009) roughly estimated installed self-generation capacity to be between 3,700 MW and 5,750 MW. While the two estimates represent different parameters, they show a significant amount of self-generation in Nigeria's generation mix as also demonstrated by this study. It is also worth noting that self-generation is a fraction of total suppressed demand. It is not directly related to the load demand but rather to generation and transmission system inadequacies.[9]

Table 10: Electricity generation and equivalent peak demand from estimated self-generation in Nigeria

	Energy generation (GWh)		Demand (MW)	
Sector	**Min.**	**Max.**	**Min.**	**Max.**
Telecommunications (2012)	1,646	1,646	268	268
Manufacturing (2007)	1,379	1,379	225	225
Oil and Gas (2011)	105	105	17	17
Residential (2009/2010)	1,450	3,370	236	550
Commercial (2009/2010)	660	13,880	108	2,264
TOTAL	**5,240**	**20,380**	**855**	**3,324**

[9] For example, some genset owners connected to the grid will only use their generators for lighting when the grid is unavailable rather than run the entire normal load. The total unserved load counts towards suppressed demand but not all of this is met through self-generation.

4 EMISSIONS OF BLACK CARBON AND OTHER CO-POLLUTANTS

4.1 Development of Emissions Factors

In calculating emissions in this study, the inventory detailed in the previous sections and electricity generation estimates were combined with appropriate emissions factors for each of the pollutants to estimate emissions in a base year of the data used for the inventory (e.g., 2007 for the manufacturing sector or 2010 for the residential sector).

Where possible, the emissions factors used in this study are based on parameters developed for the stock of diesel gensets available in the Nigerian economy and take into consideration characteristic parameters of the stock of diesel gensets (e.g., age, operational load factor, horsepower rating). In the absence of these local factors, international factors, including U.S. EPA emissions standards, were used for the estimates. These standards informed the split of the generator inventory into two groups according to the generator rating. For example, the manufacturing sector diesel genset inventory was developed along two HP ratings segments: (1) generators with horsepower ratings less than 600 HP; and (2) those with HP ≥ 600 (see Table 11).

Table 11: Emissions Factors in the U.S. EPA Emissions Standard for Tier 1-3 Engines

HP RATING EMISSIONS	< 600 HP lb/hp-hr	< 600 HP Kg/MWh	≥ 600 HP lb/hp-hr	≥ 600 HP Kg/MWh
PM-10	0.0022	1.3377	0.0007	0.4256
SO2	0.00205	1.2465	0.0004045	0.2459
NOX	0.031	18.8490	0.024	14.5928

SOURCE: Adapted from U.S. EPA Emissions Standards for Tier 1-3 Engines.[10]

To capture the age and maintenance practices in Nigeria, the U.S. EPA emissions factors were modified by drawing on the expertise of the International Institute for Applied Systems Analysis (Table 12). The information from IIASA was used to build the emissions factor database.

Table 12: Alternate emission factors

GENSET TYPE UNITS	NEWER/LARGER g/Kg	NEWER/LARGER Kg/MWh	SMALLER/OLDER g/Kg	SMALLER/OLDER Kg/MWh
PM-2.5	1.7	0.55	4.5	1.46
SO2*	3.1	0.72	3.1	1.00
NOX	19	4.39	29	9.38

*-the SO_2 emissions factor based on the reported sulfur content of diesel fuel in Nigeria (1550 ppm or 0.155% S.)
SOURCE: Communications with IIASA Colleagues (Z. Klimont, P. Purohit) and USEPA.

[10] The first, second, and third federal standards for new non-road (or off-road) diesel engines.

The emissions factors used for the study were derived from a combination of Table 11 and Table 12 factor in the following assumptions:

- The emission factors in Table 11, which are from U.S. EPA emissions standards for Tier 1-3 engines, are applicable to new engines.
- The fuel efficiency of average diesel gensets operating in Nigeria is 25 percent, while that for new diesel gensets has been assumed to be 35 percent;
- Diesel gensets according to their HP ratings in any of the inventories developed were divided into the following categories:
  - Old diesel gensets with HP < 600.
  - Old diesel gensets with HP ≥ 600.
  - New diesel gensets with HP < 600.
  - New diesel gensets with HP ≥ 600.
- NO_x and PM_{10} emission factors for new diesel gensets with HP < 600 and for HP ≥ 600 were derived from Table 12.
- SO_2 emission factors in Table 12 were considered inappropriate for use in estimating the emissions from electricity generation using the average diesel gensets in the various user sectors in Nigeria because the sulphur content in diesel fuel used as the basis for determining the emission factors in Table 12 is ≥ 2,500 PM, while the average sulphur content in diesel fuel in Nigeria is about 1,500 ppm. Given these considerations, SO_2 emission factors for diesel gensets in the two categories were determined as follows:
  - For new diesel gensets with HP ≥ 600 and HP < 600, the emission factors in Table 11 with average diesel fuel efficiency of 35 percent was adopted.
  - For old diesel gensets with HP ≥ 600 and HP < 600, the emission factors in Table 12 with average diesel fuel efficiency of 25 percent was adopted.
- NO_x and PM_{10} emission factors for old diesel gensets with HP < 600 and for HP ≥ 600 were derived from Table 11 - but with the assumption that such diesel gensets have an average fuel efficiency of 25 percent.

Given these assumptions, the emissions factors in Table 13 were developed.

Table 13: Emissions Factors for the Nigerian Diesel Genset Inventory Study

	Old Gensets	**(kg/MWh)**	**New Gensets**	**(kg/MWh)**
	HP < 600	**HP ≥ 600**	**HP < 600**	**HP ≥ 600**
PM-10	1.8728	0.5958	1.3377	0.4256
SO_2	1.0028	1.0028	0.7163	0.7163
NO_x	26.3886	20.4299	18.8490	14.5928

4.2 Estimation of Emissions

Emissions of CO_2, SO_2, NO_X, OC, and BC are calculated for electricity produced by diesel gensets. Key parameters for the estimation of emissions include the quantity of electricity produced by the diesel generators in the year and the emissions factors. The emissions factors presented in Table 22 have been used for this estimation.

In this estimation, generation by diesel gensets in each sector has been divided into two groups: (1) generation by diesel gensets with HP < 600; and (2) generation by diesel gensets with HP ≥ 600. The results for each sector and pollutant are presented in the following sections.

BC and OC are estimated using the speciation factors for the two pollutants. It has been assumed in this report that the BC contribution to PM2.5 is 60 percent for the larger, newer gensets found in the construction and telecommunications sectors and for the smaller (and some larger but new) gensets in the telecommunications sector. For all the other sectors, where older gensets are predominant (e.g. industrial, residential, and so forth), BC contributions of 40 percent have been assumed. For OC, the contribution to PM2.5 is 30 percent for newer gensets and 45 percent for smaller and bigger (but older) gensets.

4.2.1 Emissions from Diesel Gensets in the Manufacturing Sector

Table 14 shows the emissions estimates for CO_2, SO_2, NO_X, OC, and BC and the electricity generated for the two categories of HP ratings for the manufacturing sector.

Table 14: Electricity Generated and Emissions from Diesel Gensets in the Manufacturing Sector in 2007

	Parameters	Units	HP < 600	HP ≥ 600	Total
1.	Electricity Generation	GWh/Yr	867.2	516.6	1,383.8
2.	CO_2 Emissions ($E_{CO2,y}$)	$MMtCO_2$/Yr.	0.9	0.6	1.5
3.	SO_2 Emissions ($E_{SO2,y}$)	$ktSO_2$/Yr.	0.9	0.5	1.4
4.	NO_X Emissions ($E_{NOX,y}$)	$ktNO_x$/Yr.	18.7	10.6	29.3
5.	BC Emissions ($E_{BC,y}$)	ktBC/Yr.	0.6	0.1	0.8
6.	OC Emissions ($E_{OC,y}$)	ktOC/Yr.	0.7	0.1	0.9

Results from this analysis indicate that about 1.5 million tons of CO2, 1.4 kt of SO_2, 29.3 kt of NO_X, 0.8 kt of BC, and 0.9 kt of OC were emitted from diesel gensets operated in the manufacturing sector in 2007.

4.2.2 Emissions from Diesel Gensets in the Telecommunications Sector

The analysis indicates that approximately 1.3 million tons of CO2, 1.2 thousand tons of SO2, 30.3 thousand tons of NO_X, 1.2 thousand tons of BC; and 0.6 thousand tons of OC were emitted from diesel gensets operated in the telecommunications sector in 2012 (see Table 15).

Table 15: Electricity Generated and Emissions from Diesel Gensets in the Telecommunication Sector (2012)

	Parameters	Units	HP < 600	HP ≥ 600	Total
1.	Electricity Generation	GWh/Yr	1,481	164.6	1,645.5
2.	CO_2 Emissions ($E_{CO2,y}$)	$MMtCO_2$/Yr.	1.1	0.1	1.3
3.	SO_2 Emissions ($E_{SO2,y}$)	$ktSO_2$/Yr.	1.1	0.1	1.2
4.	NO_X Emissions ($E_{NOX,y}$)	$ktNO_x$/Yr.	27.9	2.4	30.3
5.	BC Emissions ($E_{BC,y}$)	kt BC/Yr.	1.2	0.04	1.2
6.	OC Emissions ($E_{OC,y}$)	ktOC/Yr.	0.6	0.02	0.6

4.2.3 Emissions from Diesel Gensets in the Oil and Gas Sector

Results from this analysis indicate that about 2.1 million tons of CO_2/year; slightly over 0.014 thousand tons of SO_2/year; slightly over 0.850 thousand tons of NO_X/year, about 0.010 thousand tons of BC, and about 0.007 thousand tons of OC were emitted from diesel gensets operated in the sector in 2011 (see Table 16).

Table 16: Electricity Generated and Emissions from Diesel Gensets in the Oil and Gas Sector (2011)

	Parameters	Units	HP < 600	HP ≥ 600	Total
1.	Electricity Generation (MWh)	GWh	-	105.1	105.1
2.	CO2 Emissions ($E_{CO2,y}$)	$MtCO_2$/Yr.	-	0.09	0.09
3.	SO2 Emissions ($E_{SO2,y}$)	$ktSO_2$/Yr.	-	0.01	0.01
4.	NOX Emissions ($E_{NOX,y}$)	ktNOx/Yr.	-	0.85	0.85
5.	BC Emissions ($E_{BC,y}$)	ktBC/Yr.	-	0.01	0.01
6.	OC Emissions ($E_{OC,y}$)	ktOC/Yr.	-	0.01	0.01

4.2.4 Emissions from Diesel Gensets in the Residential Sector

The results from the analysis indicate that about 0.16 million tons of CO2, 154 tons of SO2, 4,069 tons of NOX, 114 tons of BC, and 129 tons of OC were emitted from diesel gensets operated in the residential sector in 2010 (see Table 16).

Table 17: Electricity Generated and Emissions from Diesel Gensets in the Residential Sector (2010)

	Parameters	Units	HP < 600	HP ≥ 600	Total
1.	Electricity Generation (MWh)	GWh	154.2	-	154.2
2.	CO2 Emissions ($E_{CO2,y}$)	$MtCO_2$/Yr.	0.16	-	0.16
3.	SO2 Emissions ($E_{SO2,y}$)	$ktSO_2$/Yr.	0.15	-	0.15
4.	NOX Emissions ($E_{NOX,y}$)	ktNOx/Yr.	4.1	-	4.1
5.	BC Emissions ($E_{BC,y}$)	ktBC/Yr.	0.11	-	0.11
6.	OC Emissions ($E_{OC,y}$)	ktOC/Yr.	0.13	-	0.13

4.2.5 Emissions from the commercial sectors

Significant use of onsite diesel gensets for electricity generation also occurs in the construction and commercial sectors. It was not possible to obtain tangible information on the deployment of diesel gensets in these sectors. Various assumptions were used to estimate energy generation from diesel gensets. This resulted in about BC emissions ranging between 52 tons and 80 tons per year if it is assumed that all genset engines in this sector are rated under 600HP. Emission of other pollutants is shown in Table 18.

Table 18: Electricity Generated and Emissions from Diesel Gensets in the Commercial Sector (2010)

	Parameters	Units	HP < 600	HP ≥ 600	Total
1.	Electricity Generation (MWh)	GWh	70 - 108	-	70 - 108
2.	CO2 Emissions ($E_{CO2,y}$)	$MtCO_2$/Yr.	0.07-0.12	-	0.07-0.12
3.	SO2 Emissions ($E_{SO2,y}$)	$ktSO_2$/Yr.	0.07-0.11	-	0.07-0.11
4.	NOX Emissions ($E_{NOX,y}$)	ktNOx/Yr.	1.8-2.8	-	1.8-2.8
5.	BC Emissions ($E_{BC,y}$)	ktBC/Yr.	0.05- 0.08	-	0.05- 0.08
6.	OC Emissions ($E_{OC,y}$)	ktOC/Yr.	70 - 108	-	70 - 108

Stakeholder consultations yielded useful insights that can be used to obtain necessary information on some key sub-sectors of the commercial sector: the banking sub-sector (with potential data and information from a Shared Infrastructure Program by the Central Bank of Nigeria and the United Nations Development Program); the health sector (with information from the various hospitals and hospital management boards); organized markets (with the possibility of obtaining baseline information from a centrally managed genset systems at the Utako Market in Abuja and at the Ariara market in Aba); hotels (with information and data from the Nigerian Tourist Board); and secondary and tertiary educational institutions.

4.3 Summary of Sector Emissions

The telecommunications sector is a major source of BC emissions from the use of diesel gensets (1.22 kilotons per year based on 2012 estimates). BC emissions from the manufacturing sector in 2007 were estimated at 0.76 ktBC/year. As the base years are different for the different sectors, it is difficult to compare results across sectors.

An inventory developed to support the IPCC's 5th Assessment Report estimated anthropogenic black carbon emissions for Nigeria at approximately 67 kilotons per year in 2010.[(26)] [11] This inventory includes emissions from the energy (including gas flaring), industrial, transportation, residential, and agriculture sectors. The inventory from the telecommunication, oil and gas and manufacturing sectors analyzed is

[11] The MACCity anthropogenic and biomass burning emissions inventory for year 1960 to 2010, at a 0.5° resolution. This inventory included all sectors except the combustion of agricultural wastes (e.g., burning rice stubble) and biofuels (e.g., cow dung, charcoal).

approximately 2.01 kilotons,[12] which represents about three percent of Nigeria's anthropogenic BC emissions. Other sources of BC emissions include transportation, gas flaring, etc. While the residential and commercial sectors contribute significantly to energy generation from gensets, the low share of diesel gensets in these sectors translates to low BC emissions. Total emissions from these two sectors are estimated at about 0.2 kilotonnes.

4.4 Data Gaps and Recommendations for Bridging Gaps

The data used in developing diesel genset inventories for each of the four sectors covered in this report were developed through desk-based research that focused on publicly available information. The database used for inventories in the manufacturing and residential sectors was from earlier sector surveys; all other data was extracted from research and study publications as well as discussions with local sector experts. Additionally, basic assumptions had to be made. A number of data/information gaps were identified in the course of this study that, if filled, could improve the inventory of diesel gensets in the country as well as emissions estimates. These are described below.

4.4.1 The Manufacturing Sector

The key source of data for the diesel genset inventory is the 2007 survey by the Manufacturing Association of Nigeria (MAN). A review of the database showed that useable data/information was available for 602 manufacturing companies representing about 36 percent of such enterprises in Nigeria in 2007. The survey dataset also contained information on diesel consumption for each generator identified in the survey. The following information/data gaps were identified:

- ***Genset Fuel Efficiency*** – The dataset did not have information on hours of operation of the gensets, so average fuel efficiency was used to estimate the electricity generated. Establishing typical grid unavailability data is an important next step.

- ***Age of Gensets*** – This is an important parameter that has significant impacts on the performance of the generating sets, which in turn impacts emissions. Since this data was not explicitly provided in the survey, a general assumption was made that the majority of facilities in the manufacturing sector are old. This is likely to overestimate the emissions for newer gensets.

- ***Diesel Fuel Density, Sulfur Content, and Net Calorific Value*** – These are important characteristic properties of diesel fuel used in the estimation of electricity generation and emissions. Further work is needed to generate more reliable estimates of emissions. Potential sources of data include the National Automotive Council and the Nigeria National Petroleum Corporation.

[12] Note that the years of analysis in the various sectors are different and summing the results across the sectors is only meant to give an indication of the magnitude.

4.4.2 The Telecommunications Sector

The information and data used to develop the diesel genset inventory were obtained mostly from a sector report covering Nigeria and Ghana. This single source contains macro information on the sector. A more robust and reliable database on the sector would involve activity-level data from mobile network operators in the country.

The following is a list of parameters that need to be collated from the MNOs:

- Number of operating diesel gensets at each site.
- The capacity (KW) of each of these diesel gensets at each site.
- Average weekly diesel consumption by each genset at each site.
- Grid availability and estimate of hours per day each diesel genset is operated to generate electricity.
- Fuel efficiency of each operating genset at each site.
- Power factor at each of the sites.

4.4.3 The Oil and Gas Sector

The basic data and information for developing the diesel engine inventory in the oil and gas sector were taken from the 2011 NNPC Statistical Bulletin and a market survey by Frost and Sullivan.

The assumptions made to facilitate the development of diesel genset inventories in this sector came mostly from secondary and tertiary sources; there is a need to validate these assumptions from primary data sources.

4.4.4 The Residential Sector

The key database used for the inventory of diesel gensets was the Harmonized Nigeria Living Standards Survey. This was useful in estimating generation from diesel gensets because respondents were specifically asked to estimate diesel expenditure for power production. However, it may be necessary to verify some of the data. For example, in the state of Gombe, no household reported purchasing gasoline for any purpose. This is unlikely to be true even though Gombe was reported as only second to Jigawa state in terms of poverty rates (World Bank 2013).

The next National Household Survey is in the planning stage as is the next population census. The average run hours of gensets per day at each site or the average hours that grid electricity is unavailable at each site/day could be useful in checking estimates of fuel purchase.

4.4.5 The Commercial Sectors

The survey by the Small and Medium Enterprises Development Agency of Nigeria (SMEDAN) and the National Bureau of Statisctics (NBS) provides a good foundation for estimating the number of gensets used in the construction and commercial sectors. However, beyond the number of gensets, there is little information to use in estimating energy output. Follow up surveys in this sector should include questions on obtaining estimates of hours of operation, type and quantity of fuel purchased and size of gensets.

Additionally, for future work, the commercial sector could be further disaggregated to make it easier to contact central bodies for data.

4.4.6 Emissions Factors

It would also be beneficial to develop local emissions factors for emissions from gensets operated in the sectors analyzed in this report. Genset marketing operations in the country could potentially provide emissions factors for new engines sold in the Nigerian market.

5 CONCLUSIONS AND RECOMMENDATIONS

This study has estimated the diesel gensets inventory and emissions from the generation of electricity with such gensets in Nigeria, within the constraints of available literature and data. The approach used could help initiate a dialogue with interested stakeholders like the Federal Ministry of Environment as well as analysts and researchers; however, it is limited in its utility for arriving at policy recommendations.

It was necessary to make a number of assumptions to develop an inventory of gensets and associated emissions in Nigeria. This study provides an order of magnitude estimate of about 2 kilotons for annual black carbon emissions from the use of diesel gensets in three sectors where the quality of data is relatively better, namely: telecommunications, oil and gas and manufacturing. This estimate is approximately 3 percent of anthropogenic emissions in Nigeria.

Emissions from the residential, commercial and construction sectors were roughly estimated at 0.2 kilotons but more accuracy is needed which will require further data collection and analysis. It was estimated that these sectors could contribute significantly to genset usage but most of the gensets are operated with gasoline. As fuel subsidies on gasoline are revised, the number of diesel gensets could increase. It is therefore worth analyzing these sectors in further detail.

Indications during stakeholder discussions in Abuja suggested that there are several potential sources of data that could be tapped for future studies. However, it was difficult to obtain data and where data was available; there were a number of missing data points. This calls for improved data collation and coordination amongst the curators of data (the NBS) and data custodians.

There are no emission standards for gensets and to develop any such standards, it would be helpful to develop locally-tailored emissions factors for the existing inventory of old gensets as well as for new gensets that are regularly injected into the national stock. Further work could bridge data gaps identified could assist policy makers address the use of gensets in Nigeria but ultimately, the high unit cost of electricity from gensets is a main driver for power sector reform.

5.1 Recommendations

Given the results of this desktop study and the data gaps discussion, the following recommendations are made to improve the quality of the diesel genset and emissions inventories in the near term:

- Focus efforts on validating the assumptions used in this study and where possible, deploy sector specific surveys or follow-up surveys. As an example, data from the manufacturing, oil and gas, and telecommunication sectors show significant impact on BC emissions and could be improved and used to drive discussions with regulators.

- Engage the major telecommunications operating companies in gathering data and information to support a sector-wide diesel genset inventory and emissions dataset.

- Reach out to sector specialists, such as those who participated in the stakeholders' workshop in Abuja, to help scope and source relevant data and information on diesel genset use across the economy and to validate assumptions.

- Encourage the Manufacturers Association of Nigeria (MAN) to update the 2007 manufacturing sector survey and to include additional parameters identified in this desktop study that are needed to develop a robust diesel genset inventory.

- Develop a national emissions factor inventory for Nigeria. The following data is needed to support this: old and new diesel genset use as well as different capacity categories typically used for onsite power generation in all sectors. A way to do this could be to select different categories of diesel gensets and carry out stack emissions testing on each to ascertain more reasonable emission factors for various air pollutants.

Improving data collection on diesel genset use and emissions are first steps toward developing emissions standards for new and in-use gensets and regulations to manage emissions from diesel gensets. By strengthening the analysis and evidence base, the results could help inform policy and further bolster the case for improving the reliability of power supplies to customers.

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ANNEX 1: DATA AND RESULTS

Table A- 1: Diesel Genset Inventories for HP<600 in the 11 Power Distribution Zones in Manufacturing Sector (2007)

	Power Distribution Zone	Installed Capacity (MVA)	Diesel Consumed (kliters/wk)	Available Capacity (MW)	Generation (GWh)	Number of Diesel Gensets
1.	Ikeja	68.3	595.3	49.3	83.4	211
2.	Eko	33.8	394.3	26.0	55.2	90
3.	Ibadan	11.0	156.3	8.4	21.9	32
4.	Benin	2.4	10.1	2.0	1.4	6
5.	Jos	6.7	26.4	5.5	3.7	13
6.	Port Harcourt	14.4	86.6	10.6	12.1	43
7.	Enugu	17.8	841.1	13.1	117.8	72
8.	Kano	22.4	119.8	16.5	16.8	62
9.	Yola	-	-	-	-	None Reported
10.	Abuja	-	-	-	-	None Reported
11.	Kaduna	-	-	-	-	None Reported
	Total	176.8	2,229.9	131.4	312.2	529

SOURCE: Manufacturers Association of Nigeria (MAN), “Power and Energy Audit for Member Factories Nationwide”, 2007

Table A- 2: Diesel Genset Inventories for HP≥600 in the 11 Power Distribution Zones in Manufacturing Sector (2007)

	Power Distribution Zone	Installed Capacity (MVA)	Diesel Consumed (k-liters/wk)	Available Capacity (MW)	Generation (GWh)	Number of Diesel Gensets
1.	Ikeja	44.3	168.4	34.6	23.6	9
2.	Eko	90.7	386.5	69.6	54.1	29
3.	Ibadan	47.8	32.8	38.3	4.6	9
4.	Benin	2.8	13.9	2.3	2.0	2
5.	Jos	36.5	23.9	30.1	30.1	5
6.	Port Harcourt	9.3	36.7	6.0	5.3	3
7.	Enugu	-	-	-	-	!
8.	Kano	81.2	651.5	63.3	91.2	16
9.	Yola	-	-	-	-	None Reported
10.	Abuja	-	-	-	-	None Reported
11.	Kaduna e	-	-	-	-	None Reported
	Total	264.8	1,280.9	142.6	184.1	73

SOURCE: Manufacturers Association of Nigeria (MAN), “Power and Energy Audit for Member Factories Nationwide”, 2007

Table A- 3: Number of and Expenditure of Households on Diesel and Gasoline for Power Production

	DIESEL		GASOLINE	
State	Number	Expenditure ('000 US$ - 2009)	Number	Expenditure ('000 US$ - 2009)
Abia	51,770	2,758.13	145,416	17,178.82
Adamawa	9,108	3,085.07	18,987	4,907.05
Akwa Ibom	33,980	2,493.90	113,075	26,640.68
Anambra	3,113	77.74	38,353	3,324.16
Bauchi	3,540	377.07	10,086	948.33
Bayelsa	-	-	25,776	4,869.41
Benue	13,675	415.55	5,450	451.09
Borno	344	5.65	30,817	2,525.08
Cross-river	4,620	1,196.09	32,006	2,736.86
Delta	21,645	3,725.74	191,262	17,556.77
Ebonyi	330	2.43	4,437	298.00
Edo	11,827	1,792.00	72,637	7,324.32
Ekiti	6,880	579.10	45,821	5,945.00
Enugu	6,628	711.56	21,418	2,743.25
Abuja	15,161	2,320.12	67,489	15,006.22
Gombe	6,347	127.77	-	-
Imo	15,980	2,912.14	109,322	18,653.00
Jigawa	4,314	393.86	612	13.05
Kaduna	7,278	354.35	43,384	18,641.07
Kano	4,385	1,057.20	13,687	7,670.80
Katsina	10,198	1,131.80	18,424	1,216.09
Kebbi	6,551	530.33	4,517	474.16
Kogi	6,897	295.35	40,152	3,706.80
Kwara	2,321	69.51	14,668	1,463.12
Lagos	89,525	12,622.44	1,149,504	225,154.84
Nassarawa	3,559	2,252.58	19,794	2,325.99
Niger	11,657	1,790.79	15,131	975.97
Ogun	10,065	386.92	149,906	29,453.95
Ondo	8,496	365.63	55,377	9,771.01
Osun	6,395	719.65	16,881	2,109.39
Oyo	23,804	3,502.39	181,138	22,823.11
Plateau	9,615	641.28	15,253	1,646.12
Rivers	29,779	6,001.20	248,976	53,219.70
Sokoto	2,642	216.94	2,421	917.34
Taraba	8,683	1,913.57	18,679	1,424.68
Yobe	4,063	66.27	2,035	1,899.29
Zamfara	12,437	712.10	35,950	3,285.76
TOTAL	467,612	57,604	2,978,840	519,300.30

SOURCE: Part B - Harmonized Nigeria Living Standards Survey, 2009/2010

Table A- 4: Fuel consumption and Energy Generation from Diesel or Gasoline Gensets

	DIESEL		GASOLINE	
State	**Liters**	**Energy (MWh)**	**Liters**	**Energy (MWh)**
Abia	2,903,299	2,758.13	145,416	17,178.82
Adamawa	3,247,440	3,085.07	18,987	4,907.05
Akwa Ibom	2,625,163	2,493.90	113,075	26,640.68
Anambra	81,836	77.74	38,353	3,324.16
Bauchi	396,920	377.07	10,086	948.33
Bayelsa	-	-	25,776	4,869.41
Benue	437,426	415.55	5,450	451.09
Borno	5,943	5.65	30,817	2,525.08
Cross-river	1,259,038	1,196.09	32,006	2,736.86
Delta	3,921,833	3,725.74	191,262	17,556.77
Ebonyi	2,561	2.43	4,437	298.00
Edo	1,886,312	1,792.00	72,637	7,324.32
Ekiti	609,579	579.10	45,821	5,945.00
Enugu	749,009	711.56	21,418	2,743.25
Abuja	2,442,232	2,320.12	67,489	15,006.22
Gombe	134,493	127.77	-	-
Imo	3,065,411	2,912.14	109,322	18,653.00
Jigawa	414,593	393.86	612	13.05
Kaduna	372,999	354.35	43,384	18,641.07
Kano	1,112,839	1,057.20	13,687	7,670.80
Katsina	1,191,369	1,131.80	18,424	1,216.09
Kebbi	558,242	530.33	4,517	474.16
Kogi	310,896	295.35	40,152	3,706.80
Kwara	73,172	69.51	14,668	1,463.12
Lagos	13,286,775	12,622.44	1,149,504	225,154.84
Nassarawa	2,371,137	2,252.58	19,794	2,325.99
Niger	1,885,041	1,790.79	15,131	975.97
Ogun	407,280	386.92	149,906	29,453.95
Ondo	384,877	365.63	55,377	9,771.01
Osun	757,528	719.65	16,881	2,109.39
Oyo	3,686,727	3,502.39	181,138	22,823.11
Plateau	675,033	641.28	15,253	1,646.12
Rivers	6,317,053	6,001.20	248,976	53,219.70
Sokoto	228,356	216.94	2,421	917.34
Taraba	2,014,281	1,913.57	18,679	1,424.68
Yobe	69,757	66.27	2,035	1,899.29
Zamfara	749,584	712.10	35,950	3,285.76
TOTAL	60,636,035	57,604	2,978,840	519,300.30

SOURCE: Estimated from Table A-3

Table A- 5: Use of gensets in small and medium enterprises (formal sector)

SECTOR	Number of gensets operating between: 1 - 5 Hrs	6 - 10 Hrs	11 - 15 Hrs	16 - 20 Hrs	Total
Agriculture, Hunting, Forestry and Fishing	303	226	131	108	768
Mining and Quarrying	62	67	16	24	168
Manufacturing	2,166	2,247	801	794	6,009
Building and Construction	81	97	29	32	239
*Wholesale and Retail Trade;	2,046	1,501	383	280	4,210
Hotels and Restaurants	573	700	579	421	2,272
Transport, Storage and Communication	473	245	38	82	838
Financial Intermediation	906	906	256	256	2,323
Real Estate, Renting and Business Activities	399	402	124	62	987
Education	972	486	184	67	1,709
Health and Social Work	889	876	426	576	2,767
Other Community, Social and Personal Services	255	240	87	46	627
TOTAL	9,124	7,993	3,054	2,747	22,918

* Includes Repair of Motor Vehicles and Household goods
SOURCE: (NBS, SMEDAN 2010)

Table A- 6: Use of gensets in micro enterprises (informal sector)

SECTOR	Number of generators operating between: 1 - 5 Hrs	6 - 10 Hrs	11 - 15 Hrs	16 - 20 Hrs	Total
Agriculture	1,506,604	238,535	111,818	135,509	1,992,465
Mining and Quarrying	14,089	1,956	7,697	3,870	27,613
Manufacturing	1,865,802	321,442	123,290	72,232	2,382,765
Construction	325,681	82,399	30,968	6,029	445,078
*Wholesale and Retail Trade	5,617,042	1,255,228	30,064	275,540	7,577,874
Hotels and Restaurants	182,980	62,847	9,845	21,352	277,025
Transport, Storage and Communications	338,766	87,508	16,206	24,201	466,681
Real Estate, Renting and Business Activities	130,950	39,044	17,627	8,778	196,399
Education	31,484	3,166	-	535	35,184
Health and Social Work	3,287	1,743	-	3,853	8,884
Other Community, Social and Personal Service	339,768	88,047	22,126	36,393	486,334
TOTAL	10,356,453	2,181,914	769,642	588,294	13,896,302

* Includes Repair of Motor Vehicles and Household goods
SOURCE: (NBS, SMEDAN 2010)

Table A- 7: Estimated Energy Generation from Gensets in Small and Medium Scale Enterprises Shown by Sector

	Energy generation over:				
SECTOR	**3 Hrs**	**8 Hrs**	**13 Hrs**	**18 Hrs**	**Total**
Agriculture, Hunting, Forestry and Fishing	545	1,085	1,022	1,166	3,818
Mining and Quarrying	112	322	125	259	817
Manufacturing	3,899	10,786	6,248	8,575	29,507
Building and Construction	146	466	226	346	1,183
*Wholesale and Retail Trade;	3,683	7,205	2,987	3,024	16,899
Hotels and Restaurants	1,031	3,360	4,516	4,547	13,454
Transport, Storage and Communication	851	1,176	296	886	3,209
Financial Intermediation	1,631	4,349	1,997	2,765	10,741
Real Estate, Renting and Business Activities	718	1,930	967	670	4,285
Education	1,750	2,333	1,435	724	6,241
Health and Social Work	1,600	4,205	3,323	6,221	15,349
Other Community, Social and Personal Services	459	1,152	679	497	2,786
TOTAL	16,423	38,366	23,821	29,668	108,278

* Includes Repair of Motor Vehicles and Household goods

SOURCE: Estimated using data from NBS, SMEDAN Survey Data, 2010

Table A- 8: Estimated Energy Generation from Gensets in Micro Scale Enterprises Shown by Sector

	Energy generation over:				
SECTOR	**3 Hrs**	**8 Hrs**	**13 Hrs**	**18 Hrs**	**Total**
Agriculture, Hunting, Forestry and Fishing	867,804	366,390	279,098	468,319	1,981,610
Mining and Quarrying	8,115	3,004	19,212	13,375	43,706
Manufacturing	1,074,702	493,735	307,732	249,634	2,125,802
Building and Construction	187,592	126,565	77,296	20,836	412,289
*Wholesale and Retail Trade;	3,235,416	1,928,030	1,073,440	952,266	7,189,152
Hotels and Restaurants	105,396	96,533	24,573	73,793	300,295
Transport, Storage and Communication	195,129	134,412	40,450	83,639	453,630
Financial Intermediation	-	-	-	-	-
Real Estate, Renting and Business Activities	75,427	59,972	43,997	30,337	209,733
Education	18,135	4,863	-	1,849	24,847
Health and Social Work	1,893	2,677	-	13,316	17,887
Other Community, Social and Personal Services	195,706	135,240	55,226	125,774	511,947
TOTAL	5,965,317	3,351,420	1,921,026	2,033,144	13,270,907

* Includes Repair of Motor Vehicles and Household goods

SOURCE: Estimated using data from NBS, SMEDAN Survey Data, 2010

Table A- 9: Table M: Oil and Gas Field Activity Information by Company in 2011

	Name of Oil and Gas Company	Number of Fields	Percentage of Total Annual Crude Oil Production	Estimated Number of Diesel Gensets
A.	JV COMPANIES			
1.	SPDC	90	29.72	90
2.	MPNU	26	18.17	26
3.	CNL	40	16.25	40
4.	TOTAL E & P	17	8.12	17
5.	NAOC	38	6.42	38
6.	TEXACO	9	0.64	9
7.	PAN OCEAN	6	0.45	6
Sub-Total		226	79.77	226
B.	PRODUCTION SHARING COMPANIES			
1.	ADDAX	18	3.84	18
2.	ESSO	2	4.49	2
3.	NAE	2	0.61	2
4.	SNEPCO	2	7.29	2
Sub-Total		24	16.23	24
C.	SERVICE CONTRACTS			
1.	AENR	1	0.47	1
Sub-Total		1	0.47	1
D.	INDEPENDENT/SOLE RISK			
1.	NPDC	11	3.42	11
2.	DUBRI	1	0.02	1
3.	WALTERSMITH	1	0.07	1
4.	BRITANIA U	1	0.01	1
Sub-Total		14	3.52	14
E.	OTHERS			
1.	Including Other Independent/Sole Risks + Marginal Fields	16	0.01	16
GRAND TOTAL		281	100.00	281

SOURCE: NNPC, "2011 Annual Statistical Bulletin", CP&S, NNPC, Abuja, 2012

ANNEX 2: EQUATIONS FOR EMISSIONS CALCULATIONS

(a) Emissions of CO2 from the Operations of Diesel Gensets

$$E_{CO2,y} = \frac{A_y * 0.0036 * CC_d * 44}{Eff_{dg,y} * LHV_d * 12} \quad (1)$$

And,

$$A_y = \sum_i^m MWh_{i,y} + \sum_j^n MWh_{j,y} \quad (2)$$

Where:

$E_{CO2,y} = Emissions\ of\ CO2\ \ from\ Diesel\ Gensets\ in\ the\ Manufacturing\ Sector\ in\ year\ y\ \left(\frac{tCO2}{Yr}\right)$

$MWh_{i,y} = Electricity\ Generation\ by\ Diesel\ Gensets\ i\ in\ the\ Pertinent\ Sector\ with\ HP < 600\ \left(\frac{MWh}{Yr}\right)$

$MWh_{j,y} = Electricity\ Generation\ by\ Diesel\ Gensets\ j\ in\ the\ Pertinent\ Sector\ with\ HP \geq 600\ \left(\frac{MWh}{Yr}\right)$

CC_d = Carbon Content of diesel utilized for Electricity Generation in Nigeria

$Eff_{dg} = Efficiency\ of\ the\ Diesel\ Gensets\ Operating\ in\ the\ Pertinent\ Sector$

$LHV_d = Lower\ Heating\ Value\ of\ diesel\ used\ in\ Nigeria\ for\ Electricity\ Generation\ \left(\frac{TJ}{tDiesel}\right)$

(b) Emissions of NOX from the Operations of Diesel Gensets

The estimation equations for calculating NO_X emissions are given by:

$$E_{NOX,y} = \sum_{k=1}^{2} \sum_{l=1}^{P,Q} \frac{HP_{k,l,y} * EF_{NOX,k,l} * H_{k,l,y}}{2{,}204.62} \quad (3)$$

Where:

$$E_{NOX,y} = Emissions\ of\ NOX\ from\ Diesel\ Gensets\ per\ Year\ y\ \left(\frac{tNOx}{yr}\right)$$

$HP_{k,l,y} = Horse\ Power\ Rating\ Group\ k\ for\ Genset\ l\ in\ Year\ y\ (HP)$

$EF_{NOX,k,l} = NOX\ Emission\ Factor\ for\ Gensets\ in\ HP\ Group\ k\ for\ Genset\ l\ \left(\frac{lb\ NOX}{HP-hr}\right)$

$H_{k,l,y} = Hours\ of\ Operation\ of\ Genset\ in\ HP\ Group\ k\ for\ Genset\ l\ \left(\frac{hours}{yr}\right)$

P = Gensets in the Group with HP < 600; Q = Gensets in the Group with HP ≥ 600

Also,

$$HP_{k,l,y} = 0.746 * \; KW_{k,l,y} \tag{4}$$

Where:

$KW_{k,l,y} = The\ Generating\ Capacity\ of\ Gensets\ in\ HP\ Group\ k\ for\ Genset\ l\ in\ year\ y\ (KW)$

Inserting equation (4) into equation (3) gives:

$$E_{NOX,y} = \sum_{k=1}^{2} \sum_{l=1}^{P,Q} MWh_{k,l,y} * \; EF_{NOX,k} \tag{5}$$

Where,

$MWh_{k,l,y} = Electricity\ Generated\ by\ Genset\ l\ in\ Group\ HP\ k\ in\ year\ y\ (\frac{MWh}{Yr})$

$EF_{NOX,k} = NOX\ Emission\ Factor\ for\ Gensets\ in\ HP\ Group\ k\ (\frac{tNOX}{MWh})$

(c) Emissions of SO2 from the Operations of Diesel Gensets

The estimation equations for calculating SO_2 emissions can be derived in a similar token as presented in (b) and is given by:

$$E_{SO2,y} = \sum_{k=1}^{2} \sum_{l=1}^{P,Q} MWh_{k,l,y} * \; EF_{SO2,k} \tag{6}$$

Where,

$EF_{SO2,k} = SO2\ Emission\ Factor\ for\ Gensets\ in\ HP\ Group\ k\ (\frac{tSO2}{MWh})$

(d) Emissions of Black Carbon (BC) and Organic Carbon (OC) from the Operations of Diesel Gensets

The approach used for the estimation of BC and OC emissions took the following steps:

Step 1: Estimate the quantity of $PM_{2.5}$ using the following equations:

$$E_{PM2.5,y} = 0.99 * \; \sum_{k=1}^{2} \sum_{l=1}^{P,Q} MWh_{k,l,y} * \; EF_{PM10,k} \tag{7}$$

Step 2: Calculate the emissions of BC and OC using the following equations:

$$E_{BC,y} = \; E_{PM2.5,y} * \; SF_{BC} \tag{8}$$

$$E_{OC,y} = E_{PM2.5,y} * SF_{OC} \tag{9}$$

Where:

$$E_{PM2.5,y} = PM2.5\ Emissions\ from\ Diesel\ Gensets\ in\ the\ Pertinent\ Sector\ in\ year\ y\ (\frac{tPM2.5}{Yr})$$

$$EF_{PM10,k} = Emission\ Factor\ for\ PM10\ by\ Gensets\ in\ HP\ Group\ k\ (\frac{tPM10}{Yr})$$

$$EF_{PM2.5,k} = Emission\ Factor\ for\ PM2.5\ by\ Gensets\ in\ HP\ Group\ k\ (\frac{tPM2.5}{Yr})$$

$$SF_{BC} = Speciation\ Factor\ of\ BC, which\ is\ the\ Fraction\ of\ BC\ in\ PM2.5$$

$$SF_{OC} = Speciation\ Factor\ of\ OC, which\ is\ the\ Fraction\ of\ OC\ in\ PM2.5$$

Using the emission factors estimates in Table 20, emissions of black Carbon and organic carbon from the PM-10 will be based on the following:

- An assumption that 99 percent of the PM-10 estimates is PM-2.5 has been utilized in Equation 7.
- BC and OC are estimated using the speciation factors for the two pollutants.
- It has been assumed in this report that the BC contribution to $PM_{2.5}$ is 60 percent for the larger, newer gensets found in the construction and telecommunications sectors and for the smaller (and some larger but new) gensets in the telecommunications sector. For all the other sectors, where older gensets are predominant (e.g. industrial, residential, and so forth), BC contributions of 40 percent have been assumed. For OC, the contribution to $PM_{2.5}$ is 30 percent for newer gensets and 45 percent for smaller and bigger (but older) gensets. This simple assumption has been used due to the poor information on the age of the diesel genset stocks in most user sectors.

(e) Estimating energy generation from fuel consumption

$$Energy\ (MWh) = \frac{Fuel\ density\ (kg/l) \times Net\ Calorific\ Value\ (kJ/kg) \times Genset\ Efficiency\ (\%)}{1000 \times 3600}$$

		DIESEL	**GASOLINE**
AVG. FUEL DENSITY	*KG/LITER*	0.844	0.741
AVG. NCV	*KJ/KG*	43,380.00	44750
AVG. ENERGY EFF OF DIESEL GENSET	*%*	25%	25%

SOURCE: IEA 2010 (Oil Information 2010)

ANNEX 3: AGENDA AND ATTENDANCE FOR THE STAKEHOLDERS WORKSHOP HELD AT THE FEDERAL MINISTRY OF ENVIRONMENT, ABUJA – SEPTEMBER 10, 2013

Chair: Engr (Mrs) Bahijjahtu Abubakar, National Coordinator, Renewable Energy Programme, Federal Ministry of Environment

Agenda

9:30-9:45	Registration
9:45-10:00	Opening remarks by:
	Mrs Abubakar, National Coordinator, Renewable Energy Programme, Federal Ministry of Environment
	Erik Fernstrom, Lead Energy Specialist, Africa Region, World Bank
10:00-10:45	Presentation of study objectives, methodology, assumptions, and results
	Dr. Felix Dayo, Triple E Systems Inc,
10:45-12:00	Discussions
12:00-1:00	Lunch break
1:00-2:00	Group consultations with participants
2:00- 2:15	Closing Remarks:
	Samuel Oguah, Environmental Specialist, Climate Policy and Finance Department, World Bank

ATTENDANCE LIST FOR WORLD BANK CONSULTATION WORKSHOP TO DISCUSS BLACK CARBON EMISSIONS INVENTORY –September 10, 2013

	NAME	ORGANIZATON & POSITION
1.	Engr. A. J. Maina	NCC, PM
2.	Obinna Obuezue	Airtel, RTM-North
3.	Agube, B.B.	NNPC/RED
4.	Okoro Festus	PPP
5.	Michael Oye	BOI
6.	Alain Gaugris	World Bank
7.	Engr. Olisa M. Okoli	TCN HQ. Maitama
8.	Okpe Sunday, A.	M.A.N
9.	Bilesanmi Yusuf, O.	B9 Technologies Ltd.
10.	Akinrubi Paul, O.	NNPC/GID
11.	Afoke Bakpa	EMTS
12.	Anewole Anebisi	EMTS
13.	Agatha Nnaji	Geometric Power
14.	Mohammed Baba	NIPC
15.	Laraba Adamu	NIPC
16.	Gilbert Obodo	MTN, Energy Optz
17.	Com. Azubuike Enwe	Medical and Health Workers Union
18.	Segun Adaju	Blueocean Energy
19.	Obiora Ugwo	Omnipoint Global Res.
20.	Prof. Felix Dayo	Triple E. System Inc. USA, CEO
21.	Samuel Oguah	World Bank
22.	Roy Chatterjee	MD Emel Power
23.	Khadijah Akanbi	NERC
24.	Engr. Chidi Ike	PTFP
25.	Emeka Ogbodo	PTFP
26.	Ibiso Graham Dagles	PTFP
27.	Dr. M. M. Sugungun	NNPC
28.	Osisa M. Ede	GP-C/PS
29.	Wilson Umeh	GP
30.	Chris Newson	SPN
31.	Hannah Kabir	CREEDS
32.	Erick Fernstrom	World Bank
33.	Mrs. Abubakar	FMEnv
34.	Abdulmumuni Yakubu	FMEnv

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