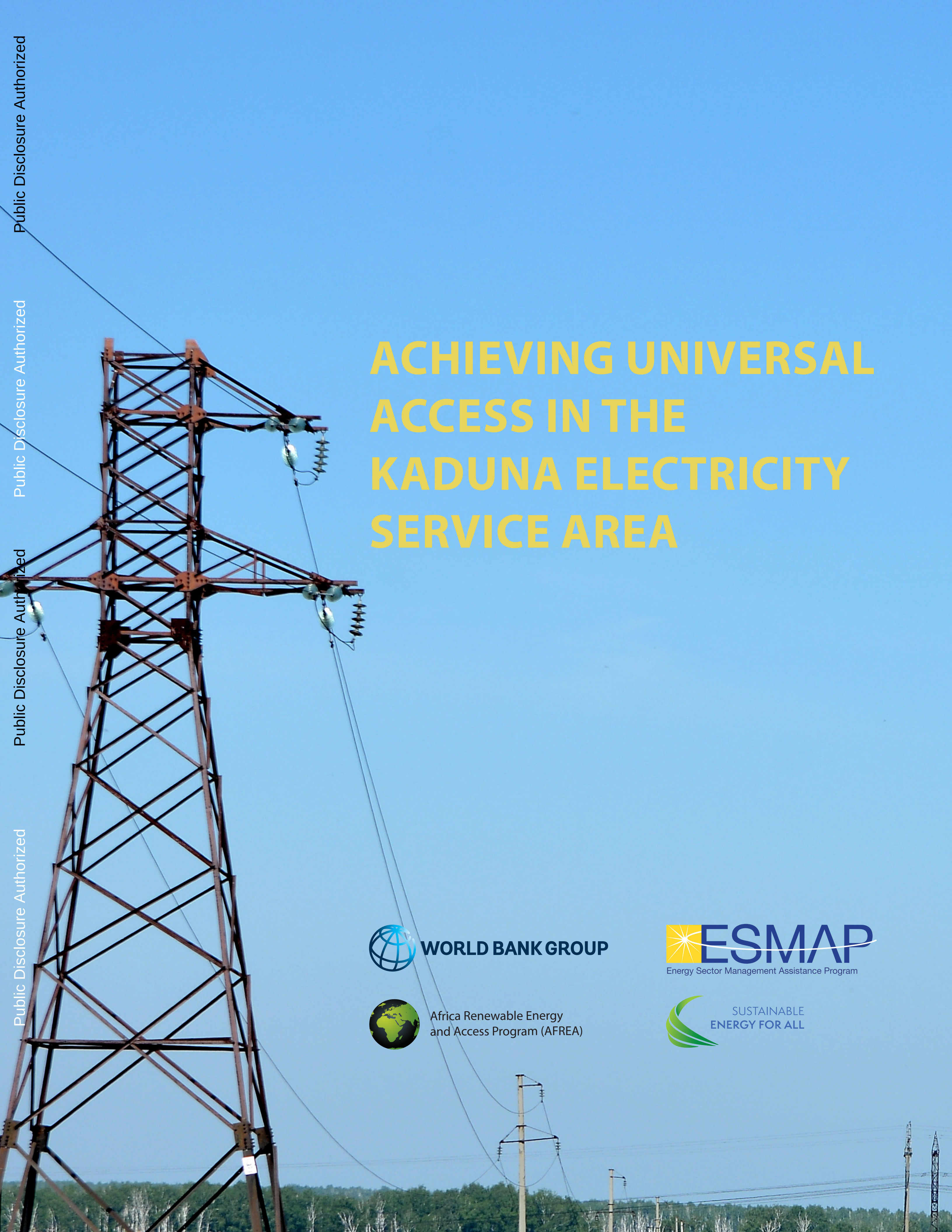


ACHIEVING UNIVERSAL ACCESS IN THE KADUNA ELECTRICITY SERVICE AREA

WORLD BANK GROUP

ESMAP
Energy Sector Management Assistance Program

Africa Renewable Energy and Access Program (AFREA)

SUSTAINABLE ENERGY FOR ALL

Preface

This Volume was produced under the Nigeria Electrification Access Program Development (NEAPD) Technical Assistance project for Kaduna Electric, which provides electricity services to the States of Kaduna, Kebbi, Sokoto and Zamfara in North West Nigeria. The Volume is combined by two reports: a GIS-based Least-Cost Plan and a related Investment Prospectus. Together, they present a technically sound electrification and investment plan for the achievement of universal access to electricity services in the Kaduna Electric service area by 2030. Both the Geospatial Plan and the Investment Prospectus were produced in close collaboration with Kaduna Electric, and the NEAPD project also strengthened the utility's capacity through training for the geospatial mapping of the electricity infrastructure and for distribution planning with GIS tools.

The Least-Cost Plan provides a geospatial and quantitative frame for the design and detailing of a well-coordinated and harmonized implementation program for grid and off-grid electrification over a fifteen-year timeframe (2015–2030). Building on the findings of the geospatial plan and a rapid readiness assessment, the Investment Prospectus proposes a year-by-year electrification program up to 2030 (including connections for schools and clinics) and details the investment needs, financing gaps and possible sources of funding with a focus on the first five years of implementation. The Prospectus also identifies key sector obstacles (related to the policy, institutional and financing frameworks) for the implementation of an access rollout plan and suggests possible areas requiring capacity strengthening through Technical Assistance.

As demonstrated by best practices in international experience, investments alone will not be sufficient to achieve universal access by 2030. They must be complemented by timely and effective enabling actions on several other fronts, especially the establishment of an enabling policy, targeted fixes to the institutional framework, and capacity strengthening of the key agents and institutions whose effective engagement is essential. Besides Kaduna Electric, the Federal Government of Nigeria (Ministry of Power and of Finance, and the Office of the Vice President), the Regulator, and several other key stakeholders have a key role to play if electricity services are to be provided to over 80 million Nigerians currently living in the dark and ensure shared well-being across the country.

While the analysis and recommendations presented in this Volume reflect and respond to the operating context and specific characteristics of Kaduna Electric utility, they also provide an input for the completion of the bold sector reform launched by the Federal Government of Nigeria in 2010. While highlighting the make or break challenges for scaling up access in the Kaduna Electric service area, the Volume also provides a roadmap for expanding access across the country in an efficient, effective, and timely manner.

Acknowledgements

This work could not have been possible without financial support from the Africa Renewable Energy and Access Program (AFREA), funded through the World Bank's Energy Sector Management Assistance Program (ESMAP)—a global knowledge and technical assistance program that assists low- and middle-income countries to increase their know-how and institutional capacity to achieve environmentally sustainable energy solutions for poverty reduction and economic growth. ESMAP is funded by Australia, Austria, Denmark, Finland, France, Germany, Iceland, Japan, Lithuania, the Netherlands, Norway, Sweden, Switzerland, the United Kingdom, and the World Bank Group. AFREA's mandate is to help meet the energy needs and widen access to energy services in Sub-Saharan African countries in an environmentally responsible way. AFREA is funded by the Netherlands. The report also benefited from funding from the Sustainable Energy for All (SE4All) global initiative.

Under the overall guidance of Rahul Kitchlu (Senior Energy Specialist), the *Least Cost Geospatial Implementation Plan for Grid and Off-Grid Rollout (2015–2030) for the Kaduna Electric Service Area* was prepared by the Earth Institute at Columbia University School of Engineering and Applied Sciences whereas the *Investment Prospectus for the electrification of the Kaduna Electric service area* by Economic Consulting Associates. Arun Sanghvi (Consultant) and Chiara Rogate (Consultant) supervised and coordinated the preparation of this Volume.

The team is grateful for the guidance provided by Rachid Benmessaoud (Country Director), Meike van Ginneken (Practice Manager, Africa Energy), Wendy Hughes (Practice Manager, Africa Energy), Rohit Khanna (Practice Manager, Energy Strategy and Operations), Erik Fernstrom (Practice Manager, Energy MENA) and Kyran O'Sullivan (Lead Energy Specialist). The team is also grateful to Sudeshna Banerjee (Lead Energy Specialist), Dana Rysankova (Senior Energy Specialist), and Yann Tanvez (Energy Specialist) for peer reviewing the reports and providing insightful comments, and to Jon Exel (Senior Energy Specialist) and Muhammad Wakil (Energy Specialist) for their valuable inputs. We would also like to thank Siet Meijer (Operations Officer) and the ESMAP team, particularly Heather Austin (Publishing Officer), Chita Obinwa (Program Assistant), Joy Medani (Team Assistant), and the colleagues in the World Bank Abuja Office for their support in preparing this Volume.

The team and the contractors would also like to thank the Management and staff of Kaduna Electric who provided strong and appreciated commitment, support and cooperation in the preparation of these reports.

PART 1

LEAST COST GEOSPATIAL IMPLEMENTATION PLAN FOR GRID AND OFF-GRID ROLLOUT (2015–2030) FOR THE KADUNA ELECTRIC SERVICE AREA

Advisory Service Document

Consultant Summary Report

Contents

viii **Abbreviations**

ix **Executive Summary**
xi Least-Cost Electrification Rollout for the Kaduna Service Area, 2015–2030
xv Off-Grid Electricity Access

1 **Chapter 1: Analytical Approach**
1 How the Model Functions: Calculations and Recommendations
2 Key Assumptions and Estimates
3 Preparing the Input Dataset

9 **Chapter 2: Model Results and Related Policy Conclusions**
9 Model Results: Electricity Access Program
19 Off-Grid Electricity Access Program
26 Electricity Access for Social Infrastructure
26 Sensitivity Test – Variation in Household Demand

29 **Appendices**
29 Appendix A: Least Cost Electrification Modeling
33 Appendix B: Geo-located Data for Demands
39 Appendix C: Grid Line Mapping and Related Training
46 Appendix D: Model Parameter Inputs
52 Appendix E: Training in Electrification Cost Modeling for Kaduna Electric
54 Appendix F: Review of VTF/Gates Foundation Data

Figures

viii **Figure 1** States in the Kaduna Electric service area (Kaduna, Zamfara, Kebbi, Sokoto)
ix **Figure 2** Map of proposed electricity systems (with number of locations in brackets)
xi **Figure 3** Existing grid lines and the prioritized grid expansion plan based on average cost per household for the KEDCO service area, 2015–2030.
xiii **Figure 4** Potential pre-electrification off-grid locations for programs of varying size.
1 **Figure 5** Demand points (blue) and existing grid (black) are combined to create a least-cost plan for electric grid extensions (red) and off-grid systems (green)
3 **Figure 6** VTS Settlement data (L); NMIS health and education facility data (R)
4 **Figure 7** Grid MV lines and transformers mapped by Kaduna Electric (Mar. 16, 2016)
13 **Figure 8** Map of proposed electricity systems (with number of locations in brackets)
14 **Figure 9** Percent households with grid connection by LGA before grid access program begins (~49% of the 2015 population, or 36% of the 2030 population).
14 **Figure 10** Percent households connected by LGA after 30% of grid access program (mostly LV intensification, achieving ~55% grid access for the 2030 population).
15 **Figure 11** Percent households connected by LGA after 60% of grid access program (after completion of about one-third of the MV grid extension program, achieving about 76% of grid access).
16 **Figure 12** Percent households connected by LGA after completion of the grid access program, achieving nearly 100% grid access.
17 **Figure 13** Component costs throughout the grid access program for Kaduna Electric
19 **Figure 14** Prioritized grid roll-out with MV cost and length per household as access (connections) increase
20 **Figure 15** Prioritized grid roll-out, enlarged area of Zamfara State, 2015–2030.
23 **Figure 16** Potential pre-electrification off-grid locations for programs of varying size
24 **Figure 17** Educational facilities with grid access (2015) and targeted for grid (2030) (these total more than 99% of all education facilities throughout the Kaduna Electric area)
25 **Figure 18** Health facilities with grid access (2015) and targeted for grid (2030) (these total more than 99% of all education facilities throughout the Kaduna Electric area)
30 **Figure 19** Electricity demand points (L); proposed least-cost grid (R) (e.g. SW Uganda).
31 **Figure 20** Model summaries (data and maps) presented through a web browser format.
32 **Figure 21** Sequential versus algorithmic approaches to grid extension planning
34 **Figure 22** Locations of polling places for Kaduna Electric coverage area (INEC, 2015)
35 **Figure 23** Gates Foundation settlement data for Kaduna Electric service area.
36 **Figure 24** Comparison of INEC 2015 and VTS/Gates Foundation data (Kaduna State).
37 **Figure 25** Satellite imagery shows greater accuracy of VTS/Gates data relative to INEC.
38 **Figure 26** NMIS location data for schools and clinics (nmis.mdgs.gov.ng).
40 **Figure 27** Customized OSMTracker layout (L); Kaduna Electric staff in field training (R)
41 **Figure 28** SEL/EI JOSM training and editing sessions (with support from KEDCO staff).
42 **Figure 29** SEL/EI training: smartphones in the field (L); JOSM in the classroom (R)
43 **Figure 30** Orange ovals show facilities that reported grid access (NMIS) but no grid was mapped (Kaduna Electric).

44 **Figure 31** 11 kV and 33 kV lines mapped by Kaduna Electric (Mar. 16, 2016)
45 **Figure 32** Transformers mapped by Kaduna Electric (Mar. 16, 2016)
49 **Figure 33** Poverty rates for Kaduna Electric service area (Oxford University / World Bank)
52 **Figure 34** Trainees with the SEL/EI team, April, 2016, Abuja, Nigeria.
55 **Figure 35** Non-geolocated village (B) near geolocated point (A) (rural Kebbi State)
55 **Figure 36** Non-geolocated points are typically within 1 km of a geo-located village
56 **Figure 37** Ten compounds in a dense rural area (251 meters total; ~28 m/compound; ~14 m/HH)
57 **Figure 38** Six compounds in a sparse rural area (324 meters total; ~65 m/compound; ~32 m/HH)

Tables

x **Table 1** Electricity access for Kaduna Electric area: 2015 status; investments for 2030.
xii **Table 2** Proposed grid and related components, by State, Kaduna Electric area, 2015–2030.
5 **Table 3** Population and Households by Access type (2015, Kaduna Electric Service Area)
6 **Table 4** Selection of key technical and cost parameters (costs in USD, time in years)
10 **Table 5** Electricity access for Kaduna Electric area: 2015 status; investments for 2030.
11 **Table 6** Projected grid extension metrics for the Kaduna Electric service area, 2015–2030
12 **Table 7** Cost Build-up per household
13 **Table 8** Proposed grid and related components, by State, Kaduna Electric area, 2015–2030.
16 **Table 9** Costs and Distances for MV Grid Extension, by Decile, under grid access plan
21 **Table 10** Costs per household and for full program, for pre-electrification off-grid access.
22 **Table 11** Potential pre-electrification off-grid sites, by State
23 **Table 12** Electrification status (2015) and proposed connections (2015–2030) for educational facilities (Kaduna Electric service area)
24 **Table 13** Electrification status (2015) and proposed connections (2015–2030) for health facilities (Kaduna Electric service area)
26 **Table 14** Sensitivity Results: recommendations for 100% access in 2030, households.
26 **Table 15** Sensitivity results: recommendations for 100% access in 2030, settlements
33 **Table 16** Polling units and registered voters in Kaduna Electric area (INEC 2015)
38 **Table 17** Education and Health Facilities in the Kaduna Electric Service Area (NMIS)
42 **Table 18** Assumptions about the rate of MV line mapping
43 **Table 19** Estimated Duration for MV line mapping for the Kaduna Electric system
46 **Table 20** Full list of NetworkPlanner Cost and Technical Parameters
50 **Table 21** Electrification Rate data (LSMS, 2012)

Abbreviations

GIS	Geographic Information System
GPS	Global Positioning System
GPX	GPS Exchange Format
IBEDC	Ibadan Electricity Distribution Company
INEC	Independent National Electoral Commission
JOSM	Java OpenStreetMap Editor
Kaduna Electric	Kaduna Electric Distribution Company
KEDCO	Kano Electricity Distribution Company
kV	Kilo-Volt
LGA	Local Government Area
LV	Low Voltage
MV	Medium Voltage
NBS	National Bureau of Statistics
NEAP	Nigeria Electricity Access Program
NMIS	Nigeria MDG Information system
NPC	National Population Council
OSM	OpenStreetMap
QGIS	Quantum GIS
PU	Polling Unit (as defined by INEC)
RMU	Ring Map Unit
SEL/EI	Sustainable Engineering Lab / Earth Institute
TA	Technical Assistance
TOR	Terms of Reference
XML	Extensible Markup Language

Executive Summary

This report describes activities and results for the second phase of the World Bank supported technical assistance Nigeria Electrification Access Program Development (NEAPD). This project's primary outputs are cost and technical modeling for electrification planning, as well as related training, by the Earth Institute at Columbia University School of Engineering and Applied Sciences (SEL/EI) team for the Kaduna Electricity Distribution Company, Nigeria. This document summarizes data collection efforts and describes in more detail the subsequent work from April through July, 2016. This later work included a two-week training for management-level Kaduna Electric staff in cost and technical modeling for grid and off-grid electricity access throughout the four-state Kaduna Electric coverage area using the SEL/EI web-based planning software, as well as data analysis and visualization using desktop GIS software. Following this training, using parameters vetted with local engineers and planners, the SEL/EI team completed technical and cost modeling for the utility's coverage area. The results of this technical and cost modeling are presented here, supplemented by thoughts on implementation strategies, including prioritized roll-out and off-grid systems.

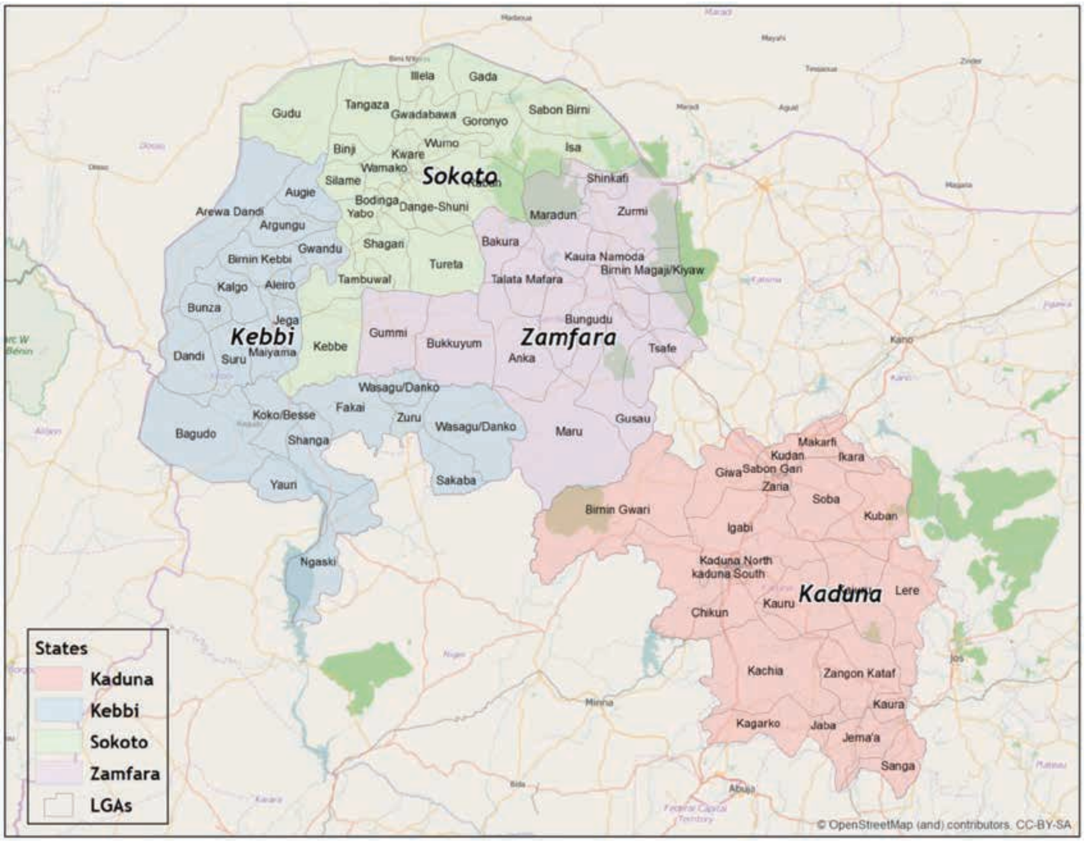
This is the final report by the Sustainable Engineering Lab, based at the Earth Institute at Columbia University School of Engineering and Applied Sciences (SEL/EI) for the World Bank supported Nigeria Electricity Access Program (NEAP) — Technical Assistance (TA) — Second Phase (NEAP-2). It describes the full scope of the TA, with summaries of work from the project's data collection phase and with emphasis on results from least-cost geo-spatial grid and off-grid electrification planning for the four-state service area of Kaduna Electricity Distribution Company (Kaduna Electric), located in the north-central region of Nigeria (see Figure 1).[1]

Kaduna Electric, headquartered in Kaduna City, has a coverage area including four states (Kaduna, Zamfara, Kebbi and Sokoto) estimated total 2006 population of about 16 million in an area of approximately 148,588 km^2 (~57,361 mi^2). This access planning occurs within the context of Kaduna Electric recent privatization and related challenges, which, similarly to other DISCOs in Nigeria, include: the long-standing need for additional electricity supply, the urgent need to improve revenue by distinguishing paying customers from non-paying electricity "consumers", and to provide grid access to large portions of the service area. Meanwhile, current growth estimates suggest that the total population of the four states will reach 39 million by 2030, adding around 1.5 million homes to the Kaduna Electric service area. Considering these needs—connections for current and future homes without grid access, and improvements to informal or unmetered connections—a universal electrification program is estimated to require ~5.8 million new points of electric access over the next 15 years using a combination of grid and non-grid technologies.

The number of connections would be even higher as ancillary demand points that are not accounted for in currently available data emerge over time, such as SMEs, irrigation points and others. The report is also based on the long view, with the broad assumption that key supporting infrastructure and systems, such as national-scale generation, fuel supply chain, and transmission, will be developed in parallel. If the lack of sufficient generation or other constraints are not addressed, and smaller-scale, early-stage electricity demands become more urgent, planning and investments associated with interim access measures through off-grid systems will become prominent.

This analysis provides a "planning grade" estimate of total costs and technical needs for universal electrification based on best available data. It is intended to support high-level planning and decision-making, including discussions among government agencies, utilities, and funding part-

Figure 1 States in the Kaduna Electric service area (Kaduna, Zamfara, Kebbi, Sokoto)



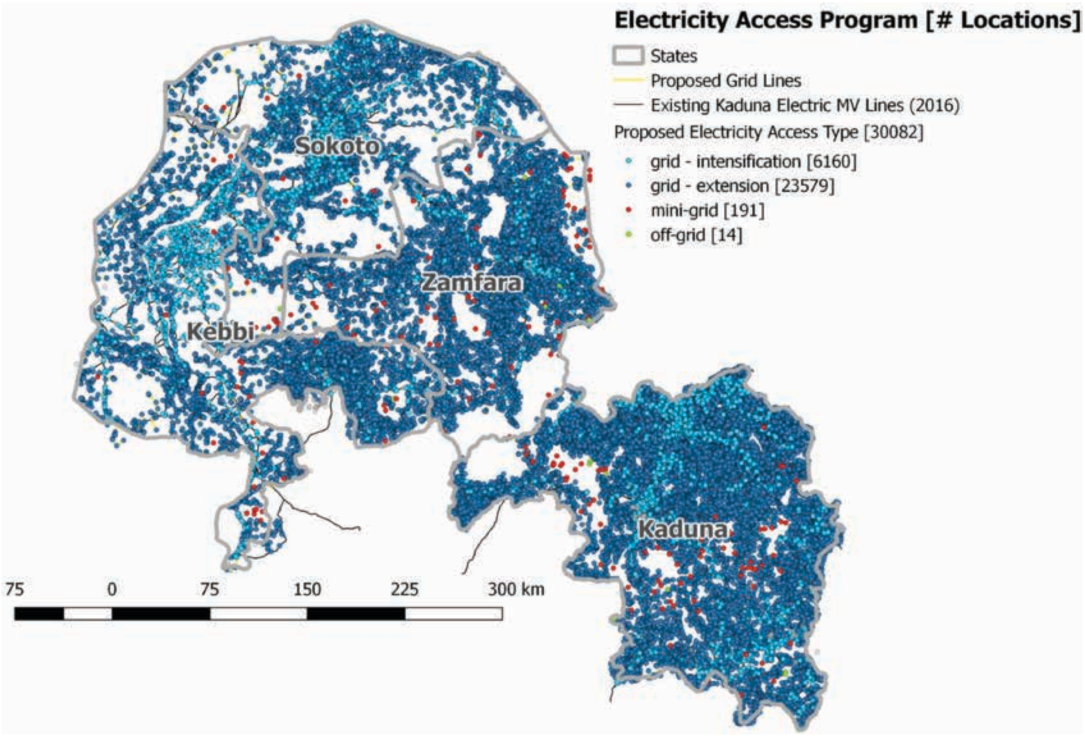
ners regarding budgets, policies, capacity building programs and other components of a multi-year electrification program. This analysis is not intended as an engineering design or construction program. Also, it focuses on the total costs and technical needs for universal electricity access over the 2015–2030 period as an aggregate. A key feature of geospatial least-cost plans is that they reflect local actual conditions. Their accuracy and effective implementation therefore requires the update of plans over time, as illustrated by international best practices. The update of GIS-based plans also provides a powerful monitoring system to track progress over the implementation of access programs.

The rate of implementation of this program, including the annual pace of household grid connections or solar home system provision, will depend upon associated infrastructure and supply chains (especially for grid connections), yearly investments, capacity within the utility to implement large-scale grid roll-out, and other issues that are beyond the scope of this assignment. These additional considerations are addressed in the investment prospectus, also supported by the World Bank.

It is also important to note how costs for different large-scale parts of the national and regional electricity grids are addressed in this analysis. The initial costs, or capex, presented in this report include only the capital and operational costs of the *distribution infrastructure* owned and managed by the local utility (Kaduna Electric). Upstream costs, those related to generation and transmission, are included in this analysis only as recurring costs, represented by the cost of power per kilowatt-hour as purchased from the bulk supplier (also called the "bus-bar" cost), not as additional capital expenditures. Furthermore, the cost of power used in this model was obtained from discussions with the utility and World Bank officials, who had direct access and practical working knowledge of up-to-date "bus-bar" electricity cost.

The least-cost geospatial plan for scale up of electricity access in the Kaduna Electric service area

Figure 2 **Map of proposed electricity systems (with number of locations in brackets)**



broadly outlines a program for achieving universal electricity access in a systematic, efficient and least-cost manner. While a broader discussion has in recent years has defined a multi-tier framework for quantifying electricity access , in this report the household electricity demand is derived from utility estimates of what a grid-connected household would consume soon after electrification, rather than household consumption levels possible with technologies such as a solar lantern or a solar home system. In other words, the service standard (or "tier") is referenced to the range found in residential grid customers. With this framework, as shown in Figure 2, the analysis reveals that—given the demographic settlement patterns and relevant technical, economic and financial parameters provided primarily by domestic, Nigerian sources—grid connection is the least-cost technology to provide long-term electricity access to virtually all of the Kaduna Electric coverage area (> 99% of households) *by 2030*. Meanwhile, the analysis in this report also indicates the potential and scope for an off-grid program—designed, harmonized and coordinated with the grid rollout program—with both geospatial and temporal targeting over a fifteen-year timeframe (2015–2030). As emphasized earlier, the off-grid program could be significantly larger if the imperative of early and timely access was prioritized in the interim period before the grid arrives. The scope of an off-grid program could also adapt to the rapid change of as the cost structures (especially those of solar generation), business models and efficient appliances continue to rapidly evolve.

Least-Cost Electrification Rollout for the Kaduna Service Area, 2015–2030

The early phase of this project[2] focused on acquisition of key data inputs of three types, generally in close collaboration with Kaduna Electric:

- **Existing medium voltage grid data:** geo-located data for over 11,000 km of medium voltage grid lines, transformers, and related equipment, mapped by Kaduna Electric;
- **Data for populated places:** high resolution geo-located settlement data for the Kaduna Electric service area created for the Vaccination Tracking System (VTS)[3] with funding from the Bill & Melinda Gates Foundation. The geospatial analysis benefited from the availability, for the first time, of such a detailed/high resolution dataset for settlement geo-location;

Table 1 Electricity access for Kaduna Electric area: 2015 status; investments for 2030.

Current Grid Access (2015)				Grid Access Program (2015–2030)					
Type of Access (Households)		Population	Pct	Type of Planned Access	Population (Households)	Pct	Total CAPEX (M USD)	CAPEX per HH (USD)	CAPEX per HH (USD)
Connected	A) Customers	2,600,000	9%	A) Improved Connections for Customers [a]	2,600,000	7%	$105	$275	$370
		400,000			400,000				
	B) Consumers	11,500,000	40%	B) Improved Connections for Consumers [b]	11,500,000	29%	$685	$400	
		1,700,000			1,700,000				
Unconnected		14,500,000	51%	C) New Access: Intensification [c]	10,600,000	27%	$1,060	$670	$810
					1,600,000				
				D) New Access: Extension [d]	14,300,000	37%	$1,950	$920	
		2,200,000			2,100,000				
				E) Long-term off-grid [e]	~15,000	<<1%	~$1–2	$500–1,000	$500–1,000
					~2,500				
Total		**28,500,000**	**100%**	Total	38,900,000	**100%**	**$3,800**	**$650**	**$650**
		4,300,000			5,800,000				

Note:
[a] Kaduna Electric reports 383,000 customers (2016); Nearly all will need smart meters (~US$275 per connection), numbers and costs were provided by Kaduna Electric in April 2016.
[b] Kaduna Electric estimates ~1.5M HHs (2016) consume power but do not pay; a geospatial analysis estimates ~1.7M; all will need meters & improved connections (~US400 each for smart meter plus half the typical cost of a service drop)
[c] ~1.6M HHs are within range of the grid, but need a connection, meter, LV line, and short MV lines and/or equipment
[d] ~2.1M HHs are not within range of the existing grid, and so will need a significant MV line, transformer, LV line, meter and connection
[e] Note that the bulk of off-grid implementation (including mini-grids) is likely to occur under an interim access scheme, described in more detail in a later section of this report

- **Model input parameters:** infrastructure technical and cost parameters acquired primarily from Kaduna Electric engineers and system planning staff.

The data acquisition phase of the project started in December 2015 with the training of Kaduna Electric staff for the mapping exercise and ended with the completion of the utility's MV grid mapping work in March, 2016 and discussions with utility's staff during the GIS analysis and modeling training in Abuja in April, 2016. Modeling began soon after and was completed in July, 2016.

Table 1 summarizes the components and related costs of a universal access rollout program for the Kaduna service area over the 2015–2030 timeframe.

Some important high-level conclusions can be drawn from the quantitative results of the geospatial analysis:

- The total cost of a universal electrification program would be **US$3.8 billion,**[4] providing new or improved connections for **5.8 million** projected households (in 2030) at an average cost of US$650 per connection;
- The total cost for *new* grid connections (through grid intensification and extension) would be of US$3 million, providing access to ~3.7 million households by 2030, at an average cost of US$810/HH;
- The total cost for improving existing grid connections (both for customers and consumers) will be will US$800 million for ~2.1 million household connections at an average cost of US$370 per connection.

This fifteen-year electrification program through grid access includes four components:

a. **Customers**: Kaduna Electric estimates that it has ~400,000 pre-existing residential customers, representing ~9% of the current population in the coverage area, or 7% of the households projected for the service area in 2030. While these households already have Kaduna Electric accounts and pay for service, most lack meters and are therefore provided with estimated billing. Providing meters to each household will require an additional investment of around $105 million (~400,000 households at ~$275 per household).[5]

b. **Consumers**: Kaduna Electric also has many grid-connected "consumers" which receive service but are neither billed nor pay for electricity use. Consumers are estimated to be about 1.7 million households, representing 40% of current service area households (2015) and 29% in 2030. Converting these "consumers" into customers by improving connections and adding meters and accounts at a cost of ~US$400 per household[6] (~US$685 million total).

c. **LV Intensification**: This analysis estimates that, by 2030, 27% of projected homes will reside in locations that are currently within 1.5 km of an existing transformer.[7] Kaduna Electric can connect these with LV extensions, service drops and meters, at an estimated average cost of ~US$670 each, for a total of ~US$1.1 billion for ~1.6 million households.

d. **MV Grid Extension**: Households further than 1.5 km from a transformer will require extension of KEDCO's MV line at an estimated cost average of ~US$920) per household to connect ~2.1 million homes (~37% of projected households by 2030) for ~$1.95 billion. This is the single largest component of the electricity access program, both in numbers of households to be served and total costs.

Figure 3 Existing grid lines and the prioritized grid expansion plan based on average cost per household for the KEDCO service area, 2015–2030.

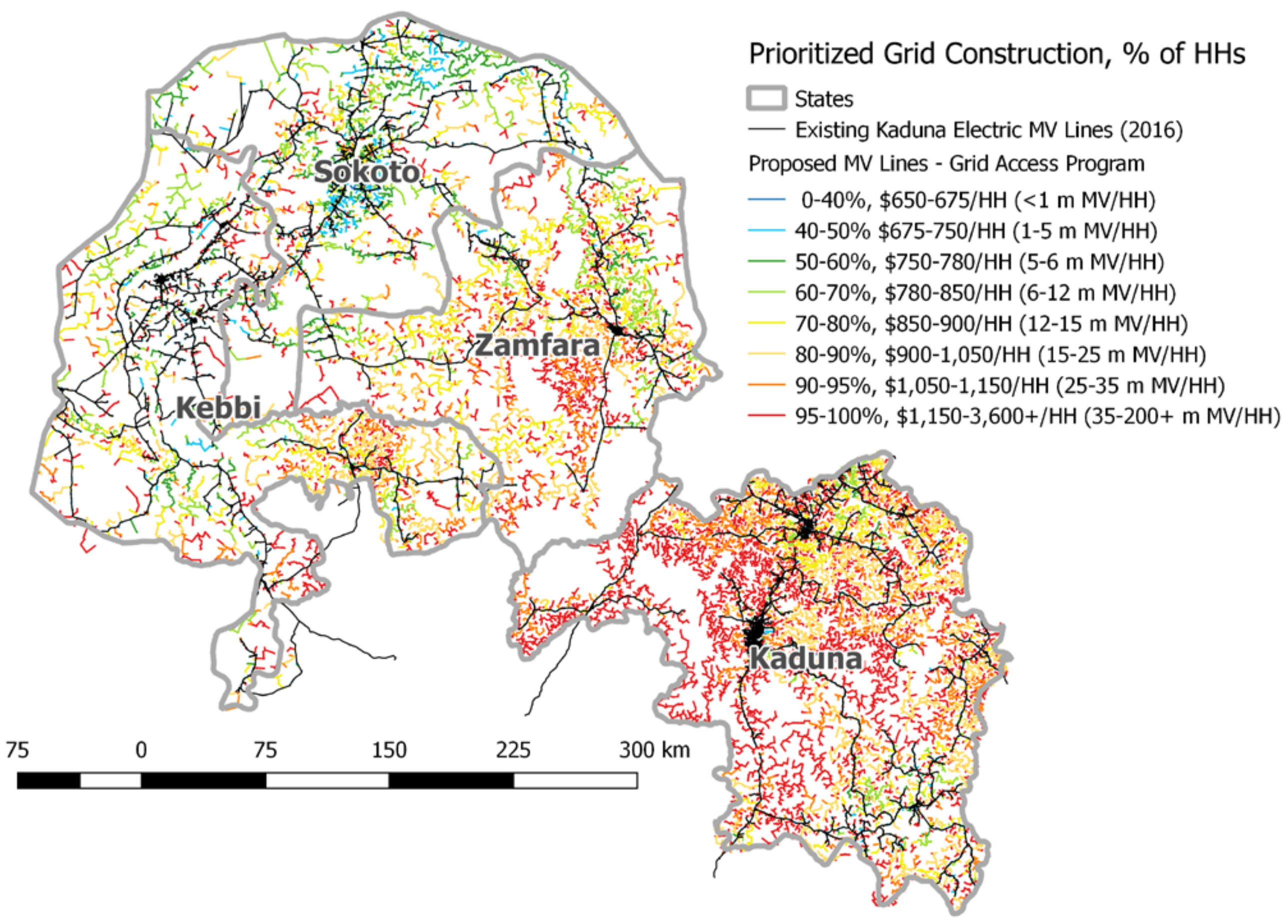


Table 2 Proposed grid and related components, by State, Kaduna Electric area, 2015–2030.

State	Number Connections Proposed		Grid Length Proposed						New Generation Needed (MW)		
	Extension	Intensification	Extension		Intensification		Full Grid Access Program		Extension	Intensification	Full Grid Access Program
			MV (km)	LV (km)	MV (km)	LV (km)	Total MV (km)	Total LV (km)			
Kaduna	578,000	652,000	14,300	16,800	1,630	15,500	15,900	32,300	230	260	490
Kebbi	408,000	334,000	6,200	12,100	500	9,300	6,700	21,400	160	130	290
Sokoto	575,000	414,000	4,500	16,800	700	11,200	5,200	28,000	270	200	470
Zamfara	568,000	188,000	8,100	16,900	280	4,800	8,400	21,600	210	70	280
Sub-total	**2,128,000**	**1,588,000**	**33,100**	**62,600**	**3,120**	**40,700**	**36,300**	**103,300**	**870**	**650**	**1,520**
Grand Total [or avg]	**3,720,000**		**[MV/HH 15.6 m]**	**[LV/HH 29.4 m]**	**[MV/HH 2 m]**	**[LV/HH 25.6 m]**	**[MV/HH 9.8 m]**	**[LV/HH 27.8 m]**	**[Capacity/HH 410 W]**		

In summary, the first three components (A, B and C) target a total of nearly 4 million homes, at relatively low cost of US$275–670 per household since this is expected to occur with little or no extension of MV line. Improved connections and grid intensification would already provide access to over 60% of the projected population by 2030. Homes reached by component D) MV Grid Extension have the same local connection and low voltage costs as component C, plus the additional, variable cost of medium voltage line extensions spanning distances between villages. This introduces substantial variation in per household connection costs in this component (D) due to geo-spatial factors such as the size and spacing between communities resulting in a range of between about US$700–1,100 per household.

This analysis also includes a cost-benefit prioritization of MV grid extension based on the objective of meeting the most electricity demand over the long term with the least investment. In practice, this means prioritizing connections to larger communities closer to the grid first, then moving out to reach smaller, more distant, and more dispersed communities. High priority grid extensions in dense areas require less MV line per household on average (~0–5 meters) at a cost of $600–800 per household. For latter parts of the MV grid extension program that target increasingly rural and remote areas, a greater MV line investment per connection will be required (10–25 meters on average), leading to household connection costs averaging $900–1,200. Figure 3 illustrates this prioritization, based on household connection costs, of grid roll-out for the Kaduna service area. While this map is not a construction design, it nonetheless provides insight into how grid extensions can be broadly prioritized and budgeted in a manner that responds to cost-benefit considerations.

Table 2 provides a breakdown by state of where the new grid-connected households, low and medium voltage line, and new generation are recommended, by state. The program would require about 36,000 km of additional MV line, approximately tripling the length of the Kaduna Electric's existing MV distribution network (currently 11,000–12,000 km in total). The vast majority of the MV line (90% or more) is planned for the grid extension phase, which accounts for the substantial cost difference between electrification of households by grid "intensification" versus grid "extension". Each state is recommended for about 1 million new connections, plus or minus 25%, depending on the state. Around 1.2 million new connections are recommended for Kaduna State while about 750,000 will be needed in Zamfara.

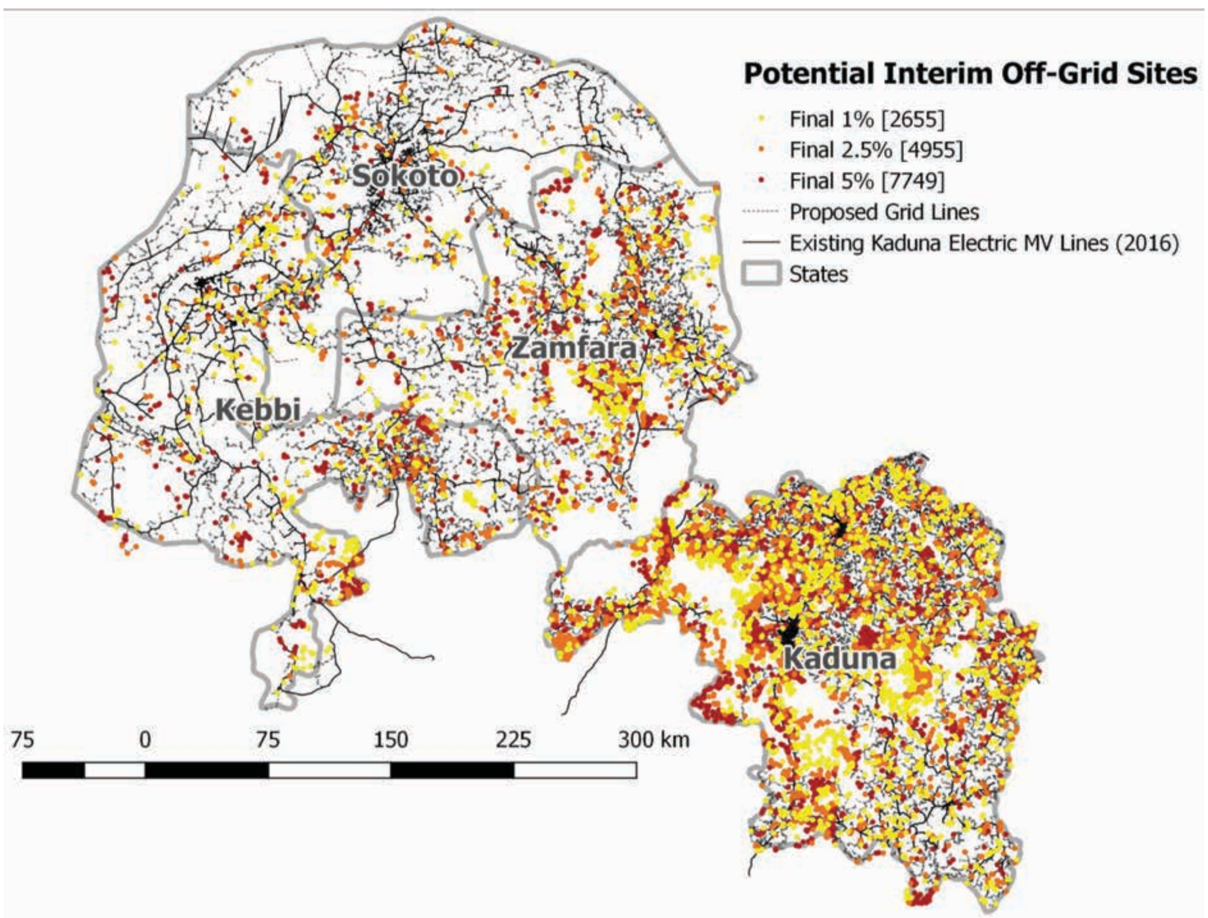
Table 2 data also illustrates that MV extension, with the exception of Kaduna State, would provide the bulk of new connections (2.1 million versus 1.5 million), although the difference is only remarkable for Zamfara State, where over about 568,000 new households will be connected through MV extension versus 188,000 through LV intensification. In the case of Kebbi and Sokoto States, the difference in connections provided by grid intensification and extension is in the order of less than 100,000 up to a little over 150,000 connections, respectively.

This grid extension program also implies a substantial increase in generation for the Kaduna Electric service area. The program would add ~4 million new residential customers to the utility's grid. It is estimated that each new urban household connection of average income would add about 1,800 kWh of electricity demand per household per year (requiring an additional ~ ~500–550 peak Watts of capacity), while poor rural homes would add about 600 kWh/year (~125–175 Wp). Poverty mapping data from an Oxford University study[8] commissioned by the World Bank was used to estimate the distribution of this range of household demand throughout the Kaduna Electric service area and resulted in a weighted average household demand of ~1,330 kWh/year. It is assumed that each new Kaduna Electric residential customer will add, on average, around 400 W of peak demand to the system. This will require about 1.5 GW of new generation, ~870 MW of which would be due to MV grid expansion, while the other ~650 MW would result from grid intensification, that is, almost 60% of new electricity demand will result from MV extension.

Off-Grid Electricity Access

The geospatial analysis identified grid technologies as the least-cost long-term solution for providing access *by 2030* for the overwhelming majority of the population and social institutions (> 99% of households, schools and clinics), while recommending the deployment of off-grid systems in few instances (component E, Table 1). However, the geospatial grid access rollout analysis also provides the basis for an off-grid plan complementing

Figure 4 Potential pre-electrification off-grid locations for programs of varying size.



grid developments, to be locally and technically designed.

Two target groups of beneficiaries are identified by the geospatial analysis for off-grid solutions:

A. Off-grid areas, where off-grid, rather than grid, is the recommended long-term, least-cost option.

These are households belonging to component E identified by the model, for which off-grid technologies (such as solar home systems or mini-grids, depending upon the locality) are identified as the least-cost solution by 2030.[9] These are either very small and/or remotely situated households and villages that are unlikely to be cost-effectively served by grid connectivity within the foreseeable future. The component may also include some homes that are not far from the existing grid, but their isolation from neighboring settlements and transformers raises the cost of grid connectivity greatly.

B. Pre-electrification for communities that will wait several years for grid access

The largest target of beneficiaries of an off-grid program is represented by those households and communities for which grid connection is the long-term, least-cost solution, but which will very likely be required to wait several years, if not longer, for the grid extension program to reach their community. These communities could be provided access in the interim with sufficient power for essential electricity services such as household lighting, and charging of mobile phones and other batteries and devices, and basic connectivity for schools and clinics to power computers, vaccine cold chain, and other services. Specific electrification technologies can be evaluated and selected—from options such as pico-solar, solar home systems (Tier 1 & 2) and diesel or hybrid mini-grids (Tier 3+)[10]—during a more detailed future program design at a cost ranging from $50–$1200 per household.

Figure 4 shows, for illustration purposes, the potential number and location of off-grid sites for final 1–5% of households targeted for grid access. These will also typically be smaller communities, furthest from the existing grid, and hence among the most expensive in terms of costs per connection. Considered from this perspective, the 7,749 locations that the least-cost grid prioritization has identified as the final 5% segment of MV extension, have very high costs per connection, in the range of US$1150–3,600, largely because long distances between communities means that they require between 35–200m of MV line per household. Thus, based on least-cost prioritization of grid roll-out, these connections will be expensive, and delayed compared to much of the grid access program, and thus could be suitable candidates for a pre-electrification program providing interim off-grid solutions.

However, this example illustrates only the very latest segment of MV extension—up to the final 5% of the grid access program—whereas the number of households not receiving a connection in the near to medium-term would likely be much larger. Thus, while the prioritized grid rollout plan can aide in the cost-effective identification of potential target sites for an off-grid program, the details of such a plan—including the actual number of beneficiaries, target areas, cost and timing, particularly for the pre-electrification component—will eventually depend upon other factors. These may include (i) the actual implementation and year-to year- sequencing of the grid rollout plan, undertaken by Kaduna Electric and to be approved by NERC; (ii) the adoption of an off-grid enabling policy and strategy in space and time for Tier 1&2 and Tier 3+ market penetration and scalability, comprising technical standards to ensure grid compatibility (in the case of interim solutions); and (iii) availability of public and private resources.

ENDNOTES

1. 2006 Population and Housing Census of the Federal Republic of Nigeria, National Population Commission, Nigeria.
2. This data collection phase of the project included collection of data sources locally, training for Kaduna Electric staff in GPS mapping of grid lines and equipment using smartphones, and subsequent mapping work undertaken by utility staff. This is described in more detail in the NEAP-2 Inception Report.
3. Vaccination Tracking System: vts.eocng.org
4. All costs throughout the text and tables of this document are in constant 2015 US dollars, unless otherwise noted.
5. Estimates of customer numbers and costs were provided by Kaduna Electric, April 2016. The utility aims at progressively installing smart meters.
6. These connections are expected to require more technical improvement in addition to meters.
7. Kaduna Electric estimates 1.5 km as the maximum radius around a transformer within which customers can be connected with only LV line.

8. Gething, P., Molini, V. (2015, June 10) Developing an Updated Poverty Map for Nigeria. Final Report. [No web address available.
9. Off-grid solutions would also be the least-cost solution in the *long-term*, that is for the time horizon considered for infrastructure planning, which is typically of 30 years or more.
10. These services are defined by the Multi-Tier Framework for electricity Access developed by the Bank under the Sustainable Energy for All (SE4All) engagement. The framework defines five different tiers of access and the household supply described above corresponds to Tier 2. For more information, visit: https://www.esmap.org/node/55526.

CHAPTER 1

Analytical Approach

This section introduces the SEL/EI analytical approach, providing a summary of the preparation of input dataset and subsequent technical and cost modeling for electrification planning for the Kaduna Electric coverage area. The following overview describes in brief the key assumptions, data types and processing steps, and model input parameters that had the greatest impact on the input dataset and model results. The technical steps in data preparation and the workings of the model itself are described in greater detail in the appendices.

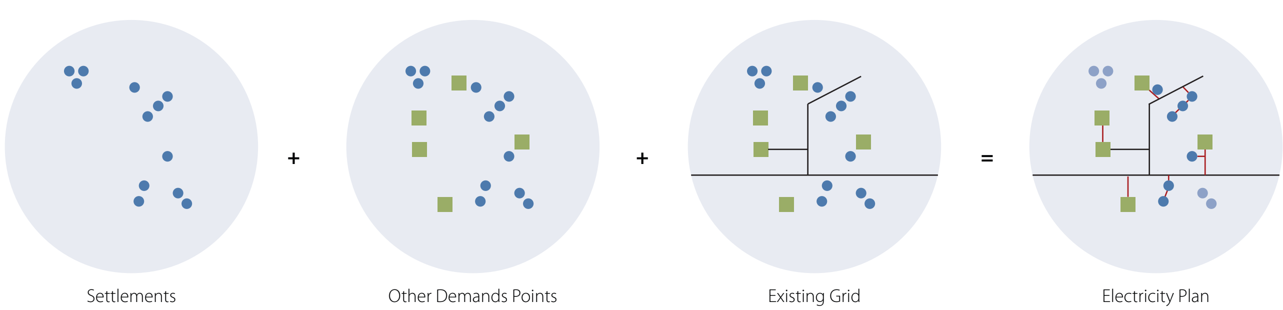
How the Model Functions: Calculations and Recommendations

In the simplest terms, our approach combines geospatial data for settlements and other demand points with information on the location of existing electricity infrastructure, and, using multiple costs and technical parameters, creates a cost-optimal system for grid and off-grid power (see Figure 5).

A few key points are crucial for interpreting the model results:

- **Population growth is projected to occur *within the same electricity access category*.** A geospatial analysis has identified portions of the population that have grid access, those near the grid, and those that are distant from the grid (see Estimate of Current Grid Access, p. 26). This model assumes that, as population grows, population increase occurs within an area with the same type of electricity access, on average. In other words, children of urban families with on-grid households are predicted to generally establish households as adults in on-grid areas; similarly, children of rural families in off-grid households are expected to generally establish rural households. Deviations from this pattern are assumed to be random, and thus average out. While, in truth, growing populations shift in unpredictable ways, this assumption is conservative in terms of cost estimates presented here, primarily due to the well-documented demographic shift throughout the developing toward urban areas,[1] where higher population densities and closer household spacing make electrification costs much lower, on average.
- **The model produces estimates and recommendations, *not detailed engineering designs*.**

Figure 5 **Demand points (blue) and existing grid (black) are combined to create a least-cost plan for electric grid extensions (red) and off-grid systems (green)**



The purpose of this modelling work is to create a quantitatively and geographically rigorous cost estimate and recommended electrification plan that will inform investments in electrification programs, and related government and utility budgeting, grants, lending programs. While the results illustrate geographic patterns of electrification and provide overall quantitative guidance, they are not intended to override or substitute for engineering designs based on local knowledge of technical, geographic, and economic factors.

- **The model compares all costs—*initial and recurring, with discounting, over a 30-year time horizon*—when evaluating technologies on a least-cost basis.** As a consequence, grid connection is often selected as the least-cost option even though the initial costs of a grid connection are higher than a diesel-powered mini-grid, since the latter typically has higher recurring costs.
- **All three electrification technologies—grid, diesel mini-grid, and solar systems—are compared at an *equal service standard*** (i.e. the same annual kWh consumption is assumed for all three technologies). This is to ensure an "apples to apples" cost comparison. This does not prevent future consideration of lower capacity, less costly non-grid options to meet basic needs (as is discussed in C —Model Results and Related Policy Conclusions)

Key Assumptions and Estimates

Some basic assumptions and estimates regarding electricity access and electrification in the Kaduna Electric service area played a fundamental role in this analysis, informing subsequent steps of preparing datasets, specifying model parameters, or running model scenarios. The most important ones are listed below:

- All demand points (settlements and facilities) were considered by Kaduna Electric planners to be "within low voltage range" of the grid if they were within 1 km (in urban areas) or 1.5 km (in rural areas) of a medium voltage grid line or transformer. This does not mean that a location has electric grid access—since this requires a low voltage (LV) line extension and connection—but it does mean that the location can be reached without extension of the medium voltage (MV) line. This assumption is crucial for calculations estimating populations within different "access categories": those with grid access now, versus those that can be reached by relatively low-cost "intensification" of the low-voltage line, versus more distant populations that require higher-cost "extension" of the medium voltage grid.
- **New household electricity connections were predicted to have an annual consumption within the range—specified by Kaduna Electric planning staff—of 600 kWh/year to 1,800 kWh/year.** While individual accounts may consume at levels below or above this range, Kaduna Electric selected these values as appropriate for average household demand values averaged over entire communities. Thus, for modelling purposes, the average household demand value for all households in a given location has been assigned a value within this range using geospatial information such as poverty mapping data and urban vs. rural designations to refine values locally. The weighted average household demand value for all households throughout the entire Kaduna Electric coverage area is 1,330 kWh/year. For only urban household connections, this value is 1,380 kWh/year; for rural households, it is 1,265 kWh/year.[2]
- **Lacking other domestic data sources, Kaduna Electric planners agreed that "night lights"[3] data could be used as a proxy to designate urban and rural areas.** This dataset reports light emitted from the earth's surface at night (primarily by electric lights) and detected by orbiting satellites and so can be used to differentiate urban and rural areas. For this study, use of night lights data led to an estimate that approximately 20% urban and 80% rural, in 2015.[4] Urban and rural differentiation is important for electrification planning for a variety of reasons, including the tendency of utilities to use different line types and experience different densities and costs per connection in urban and rural areas.

These assumptions and estimates establish a basis for subsequent calculations of current and future access, as well as other geospatial and quantitative processing steps, as described below and in the appendices of this report.

Preparing the Input Dataset

The data types, sources, and preparation steps for input data are described in the following section. While data collection is a significant effort, and some of this was conventional data "cleaning" in which datasets were reviewed and modified to address gaps or errors, *the majority of this preparatory work, and a substantial portion of the project work overall (perhaps 40–50%), focused on processing to integrate data of different types and to apply the assumptions listed above to make the dataset as a whole useful for modeling.*

Geo-located demand points

Geo-located demand points were of two main types:

1. **Data for populated places** was obtained from the Vaccination Tracking System[5] (VTS) used to support the polio eradication effort in Nigeria funded by the Bill and Melinda Gates Foundation. This source provided recent, ground-validated data for populated places to the level of villages and hamlets throughout the 4-state Kaduna Electric service area.
2. **Data for social infrastructure (education and health facilities)** was obtained from the Nigeria MDG Information System (NIMS).[6] (See Figure 6, and Appendix B: Geo-located Data for Demands for larger maps and technical details.)

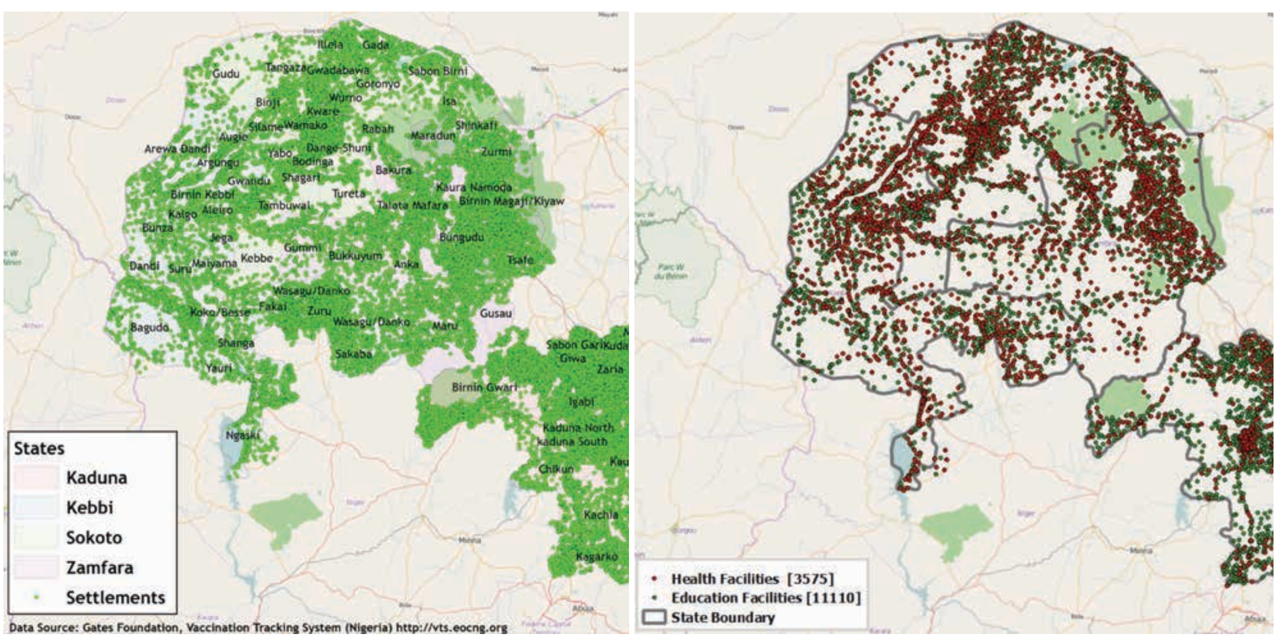
These datasets underwent the following additional preparatory steps:

- After download from the VTS site, duplicates were removed, and then the settlement point data was used—along with Nigeria's Living Standards Measurement Survey (LSMS) data,[7] and geo-located grid data—to estimate the number of households already connected to the grid.
- After download from the NMIS site, the number of full-time staff at each institution was used as a proxy for facility size and a basis for estimating electricity demand. If smaller demand points (schools, clinics) were within 1 km of a settlement point, the two were spatially merged and their electricity demands were summed. This combined residential and facility demand where both would likely be met with the same transformer or mini-grid system. In contrast, large facilities (hospitals) and facility points of all sizes further than 1 km from a settlement point were modelled as separate demand locations, to be served by separate transformers or systems.

Geo-located information on electricity grid and related equipment

Following training by SEL/EI, geo-located data for grid lines and equipment was mapped by Kaduna

Figure 6 VTS Settlement data (L); NMIS health and education facility data (R)



Electric throughout February and March, 2016 (see Figure 7).

This effort mapped a total of ~11,600 km of MV lines and ~ 8,300 transformers and created a complete, utility-validated dataset for its entire medium voltage distribution system. This is the first comprehensive, geo-spatially accurate map of the Kaduna Electric network. (See Figure 7, and for larger maps and technical details, see Appendix C: Grid Line Mapping and Related Training). After collection, the main preparation step for this data was to use the JOSM "simplify" function (a tool that removes redundant information) for the grid line shapefile before it was used an input for modelling.

Estimate of Current Grid Access

Table 3 provides an estimate of the population and number of households currently served by the Kaduna Electric grid. This estimate was created using a combination of geospatial analysis of the VTS/Gates Foundation data, World Bank LSMS data (2011 and 2012), and reported values from Kaduna Electric staff (see table notes, all non-noted values are calculated by difference). While this is a broad estimate, it suggests two main conclusions. The first is that nearly half (49%) of the Kaduna Electric coverage area already likely has some kind of grid access. Secondly, only about 20% of these connections (9% of the population overall) are currently recognized by Kaduna Electric as customers, while the others may be informal consumers, requiring new equipment and accounts, or other changes with associated costs, such as smart meters.[8] The costs of these improvements will be addressed later in this document.

Model Input Parameters

The open-source modelling software used for this effort (NetworkPlanner) employs over 70 separate cost and technical parameters (see Appendix A – Least Cost Electrification Modeling for the full list with notes for sources). The most important inputs—those with the greatest impact on model results—are summarized briefly in Table 4.

As can be seen in this list, while some parameters are specified for the dataset as a whole ("globally"), several parameters were specified for areas or indi-

Figure 7 **Grid MV lines and transformers mapped by Kaduna Electric (Mar. 16, 2016)**

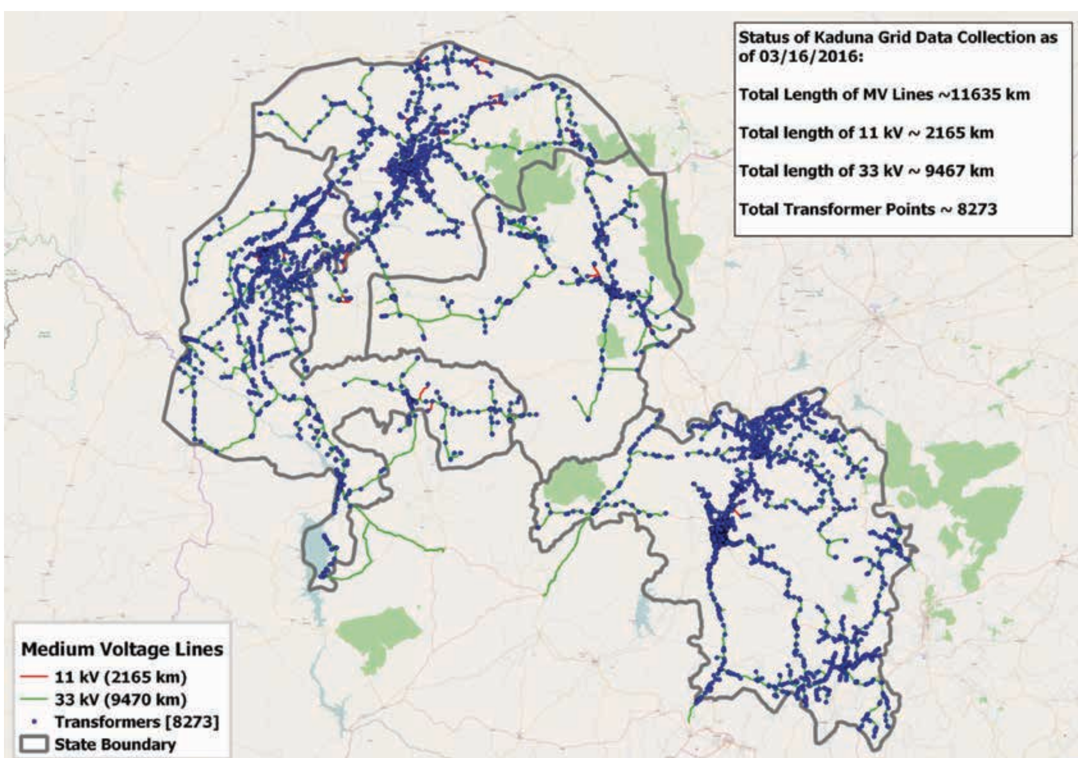


Table 3 Population and Households by Access type (2015, Kaduna Electric Service Area)

Electricity Access Status (2015)			
Type of Access		**Population (Households)**	**Percent**
Connected	**A) Customers**	2,600,000	9%
		(400,000) [a]	
	B) Consumers	11,500,000	40%
		(1v700,000) [b]	
Unconnected		14,500,000	51%
		(2,200,000)	
Total		**28,500,000** [c]	**100%**
		(4,300,000)	

Note:
[a] Kaduna Electric planners reported 383,000 customer accounts in 2016 (rounded, as this is changing continuously)
[b] Kaduna Electric planners broadly estimated that 1–1.5 M households had grid connections but did not pay in 2016 (making them "consumers"); the estimate here of 1.7 M was computed by difference between a geospatial computation of those with access, combined with LSMS data reporting grid access, minus the Kaduna Electric estimate of actual utility customer accounts.
[c] Total population for the four state Kaduna Electric coverage area is provided by the VTS / Gates Foundation dataset.

vidual locations ("locally") to capture the impact of spatial diversity on costs throughout the Kaduna Electric coverage area. This local specification of parameter values was typically achieved by combining quantitative guidelines and assumptions with geospatial datasets.

It is important to note, as stated previously, that these steps for preparing the dataset, particularly to combine initially separate geospatial and tabular data, are *very substantial* part of the work for a planning project such as this one. These preparatory steps typically require at least three sorts of skills and knowledge (which, because they rarely are held by the same individual, usually requires that modelling be a collaboration):

a. working, detailed knowledge of the range of costs (including labor and transport) related to grid, diesel, solar power systems (usually from utility and private sector planners and project implementers);
b. technical staff with sufficient skill with GIS software to clean and modify data, particularly to apply parameter values across many locations using geospatial criteria and queries (usually a GIS specialist);
c. technical staff with sufficient fluency with computer software to learn with moderate depth, the functioning of the model itself (usually an IT person, preferably with some programming experience).

To provide some examples: The location-specific calculation of annual household electricity demand requires a spatial calculation that employs three kinds of data: i) a poverty map from the World Bank, ii) "night lights" data to identify urban and rural areas, and iii) information on the range of household demand obtained from Kaduna Electric engineers. Similarly, "night lights" data were used to differentiate between urban areas versus rural areas, which spatially defines many cost differentials—lower cost MV line (11 kv), shorter distances between homes, and other factors make electricity distribution cheaper in urban areas, compared with higher cost MV line (33 kV), greater inter-household distances, and other factors.

Table 4 Selection of key technical and cost parameters (costs in USD, time in years)

Category	Parameter Omits Unused / Null Values	Parameter (July 2016)	Source 1 Kaduna Electric 2 Market Research 3 World Bank Data 4 Default Value /Int'l Comparison Others Are Noted Explicitly
Demand (household)	Household unit demand per household per year	Range, by location, (600–1800 kWhy/yr)	3, WB poverty data; night lights (Urb/Rur)
Demographics	Mean inter-household distance	15 m urban, 30 m rural	1
Distribution	Low voltage line cost per meter	$11.5	1
Distribution	Low voltage line equipment cost per connection	Urban $295 Rural $316	1
Finance	Time horizon	1~15 yr pop. growth ~30 yr recur. costs	ToR 4
System (grid)	Tistribution loss	15%	1
System (grid)	Electricity cost per kilowatt-hour	$0.075	1
System (grid)	Medium voltage line cost per meter	$12.9 urban $14.3 rural	1
System (grid)	Transformer cost per grid system kilowatt	$35 urban $40 rural	1
System (mini-grid)	Available system capacities (diesel generator)	Range (60 kVA min)	1
System (mini-grid)	Diesel fuel cost per liter	$0.67	1
System (mini-grid)	Diesel fuel liters consumed per kilowatt-hour	0.5	4
System (mini-grid)	Diesel generator cost per diesel system kilowatt	$150	4
System (mini-grid)	Diesel generator hours of operation per year (minimum)	2190	1
System (mini-grid)	Diesel generator lifetime	5	4
System (mini-grid)	Distribution loss	0.08	1
System (off-grid / SHS)	Peak sun hours per year	2007.5	2
System (off-grid / SHS)	Photovoltaic battery cost per kilowatt-hour	150	2
System (off-grid / SHS)	Photovoltaic battery kilowatt-hours per photovoltaic component kilowatt	8	4
System (off-grid / SHS)	Photovoltaic battery lifetime	4	1
System (off-grid / SHS)	Photovoltaic component efficiency loss	0.35	4
System (off-grid / SHS)	Photovoltaic panel cost per photovoltaic component kilowatt	800	2
System (off-grid / SHS)	Photovoltaic panel lifetime	20	4

ENDNOTES

1. This is explored globally and for specific regions in many publications from the World Bank (http://www.worldbank.org/en/topic/urbandevelopment/overview); United Nations Department of Economic and Social Affairs, Population Division, which has a theme on urbanization (http://www.un.org/en/development/desa/population/theme/urbanization/index.shtml), the United Nations Population Fund (http://www.unfpa.org/publications), and many academic researchers.
2. These values are not outside the range of international experience—the SEL/EI team has seen similar values in the islands of Eastern Indonesia—but they may be relatively high for the context of rural West Africa. An influential factor in the overall demand estimate was the request by Kaduna Electric planners that the SEL/EI team raise the upper limit of demand from the previous value of 1,600 kWh/HH-yr to 1,800 kWh/HH-yr. This raised the average value by perhaps 200–300 kWh/yr throughout the area. However, this difference does not have a significant impact on the model outputs, as is demonstrated in the section Sensitivity Test—Variation in Household Demand toward the end of this report.
3. Night Lights data is available for download here: ngdc.noaa.gov/eog/ (NOAA Earth Observation Group)
4. The actual numbers (18.7% urban and 81.3% rural) are likely overly-precise, given the limited accuracy of all data inputs.
5. Geolocated settlement information was downloaded from the VTS site (http://vts.eocng.org/), which also includes descriptions of the data. Correspondence with directors of this program in July, 2016, confirmed that they remain confident in the accuracy of the data in the Kaduna Electric service area, and are working toward completion of this data at a national scale by October of 2016.
6. The Nigeria MDG Information System is an online portal providing location and attribute data for social infrastructure. It was collected nationally in two rounds (2010 and 2014) led by the Office of the Senior Special Assistant to the President on the Millennium Development Goals (OSSAP-MDGs) with support from the Earth Institute, to inform decision making and implementation in development interventions aimed at achieving the MDGs. The site nmis.mdgs.gov.ng served NMIS data for download for years, but ceased functioning in early 2016.
7. LSMS data can be downloaded here (requires search): http://iresearch.worldbank.org/lsms/lsmssurveyFinder.htm.
8. As per discussions with the utility, Kaduna Electric aims at progressively deploying smart meters (April, 2016).

Chapter 2

Model Results and Related Policy Conclusions

The preceding sections have described the main data input types and steps to prepare the dataset as a whole for technical and cost modelling. The model inputs are as follows:

1. **Electricity demand points** (in .csv format), of two varieties:
   - **Settlements** (villages, towns, etc.), classified into urban and rural categories and with the population at each point reduced to reflect the estimate of households already connected;
   - **Social infrastructure** (education and health facilities, with demand estimated based on size, using number of full-time staff)
2. **Existing medium voltage (MV) lines** (in shapefile format), including:
   - 11 kV lines, which predominate in urban areas;
   - 33 kV lines, which predominate in rural areas
   - Transformers and other equipment (provided helpful information on the system, but were not used as a direct input into the modelling software
3. **Numerous modelling parameters** (~75 values in a configuration file in json format):
   - Costs of various electrification equipment (initial and recurring)
   - Technical specifications, particularly sizes, for equipment
   - Other factors (financial, demographic, etc.) mostly related to change over time.

Proceeding with this dataset, SEL/EI performs a least cost analysis to recommend an electricity system type—grid, off-grid or mini-grid—and a recommended electricity network to serve all electricity demands at all locations (see Appendix A – Least Cost Electrification Modeling). The following section describes the results, providing geo-spatial, cost and technical details for each of these grid and off-grid programs and components.

Model Results: Electricity Access Program

The most important, high-level conclusion of the geospatial least cost modeling is that, considering initial and recurring costs over the long term, ***virtually the entire population and social institutions of the Kaduna Electric service area (>99% of unconnected communities, schools and clinics) is recommended for grid connectivity*** *by 2030* (versus mini-grid or off-grid technologies). This is due to two main factors: a) the high penetration of the existing MV grid network, which lowers the distance and cost to connect settlements; and b) the relatively low initial and recurring costs of grid lines and service compared to the higher recurring costs for non-grid options (primarily diesel fuel and battery replacement). Despite the predominance of grid as the *long-term* least-cost option throughout the region, non-grid options can play an important role in providing electricity services for what may be several years as communities await the arrival of grid. The following sections provide quantitative and geographic detail for the recommended grid access program; the later section Off-Grid Electricity Access Program describes potential for a supplementary non-grid program.

Electricity Access Program: Cost Overview

Table 5 (which is an expansion of Table 3), provides a cost overview of the separate components of a proposed ~$3.8 billion grid access program to achieve 100% access throughout the Kaduna Electric coverage area by 2030. As shown in the left columns (orange shading), approximately half of the Kaduna Electric coverage area is estimated to already have grid connectivity as of 2015. The right columns (blue shading) divide the grid access program into four components, each with different costs per household connection.[1] Since households in component A are already connected utility customers, the remaining expense is the cost of new smartmeters, which Kaduna Electric plans to install for all households, at ~$275/household ($105 mn overall). Component B refers to the effort by Kaduna Electric to turn "consumers" into "customers" by improving connections—adding smartmeters, proper service lines, establishing accounts—for around 1.7 million homes, at an average cost of ~$400/HH ($685 mn overall). The next part of the program—component C, Intensification—represents new connections to homes that are within range of a transformer (1.0 km in urban areas; 1.5 km in rural areas), meaning that they can be connected with mostly low voltage line (and perhaps a small amount of medium voltage line and transformer, where needed), at an average cost of ~$670/HH (~$1 bn overall). Component D, Extension, in which medium voltage lines are extended to areas beyond the range of existing transformers, will require all aspects of a local, low voltage system and connections, plus varying amounts of MV line for each household, to reach about 2.1 million homes, at an average cost of ~$920/HH ($1.9 bn overall). Finally, component E, while the *long-term* off-grid program, is likely to be quite small, targeting about 2,000 households, at a cost of perhaps $500–1,000 each, a program for off-grid electricity access for communities awaiting grid may be much larger (see Off-Grid Electricity Access Program).

Around 63% of the households in the Kaduna Electric Coverage area will have grid access following components A-C (improvements in connections for customers and consumers, plus intensification in areas near the existing grid). The average costs of the improvements for existing connections (components A and B, taken together) is estimated to be around $370 per household, which will cover about 36% of the projected 2030 population. The average cost of new grid access (components C and D, aggregated) is estimated to be about $810 per household, covering the remaining 64% of the Kaduna Electric service area. The average cost across the entire grid access program is estimated at $650 per connection, to electrify the full projected population of ~39 million (5.8 mn households).

Table 5 **Electricity access for Kaduna Electric area: 2015 status; investments for 2030.**

Current Grid Access (2015)				Grid Access Program (2015–2030)					
Type of Access		Population (Households)	Pct	Type of Planned Access	Population (Households)	Pct	Total CAPEX (M USD)	CAPEX per HH (USD)	CAPEX per HH (USD)
Connected	A) Customers	2,600,000	9%	A) Improved Connections for Customers [a]	2,600,000	7%	$105	$275	$370
		400,000			400,000				
	B) Consumers	11,500,000	40%	B) Improved Connections for Consumers [b]	11,500,000	29%	$685	$400	
		1,700,000			1,700,000				
Unconnected		14,500,000	51%	C) New Access: Intensification [c]	10,600,000	27%	$1,060	$670	$810
					1,600,000				
				D) New Access: Extension [d]	14,300,000	37%	$1,950	$920	
		2,200,000			2,100,000				
				E) Long-term off-grid [e]	~15,000	<<1%	~$1–2	$500–1,000	$500–1,000
					~2,500				
Total		**28,500,000**	**100%**	**Total**	38,900,000	**100%**	**$3,800**	**$650**	**$650**
		4,300,000			5,800,000				

Note:
[a] Kaduna Electric reports 383,000 customers (2016); Nearly all will need smart meters (~US$275 per connection), numbers and costs were provided by Kaduna Electric in April 2016.
[b] Kaduna Electric estimates ~1.5M HHs (2016) consume power but do not pay; a geospatial analysis estimates ~1.7M; all will need meters & improved connections (~US400 each for smart meter plus half the typical cost of a service drop)
[c] ~1.6M HHs are within range of the grid, but need a connection, meter, LV line, and short MV lines and/or equipment
[d] ~2.1M HHs are not within range of the existing grid, and so will need a significant MV line, transformer, LV line, meter and connection
[e] Note that the bulk of off-grid implementation (including mini-grids) is likely to occur under an interim access scheme, described in more detail in a later section of this report.

A brief summary of the recommended grid access program's aggregate costs and technical details appears in Table 6, for both average sized households and an "average settlement". This table captures a second key insight form the modeling work: that the vast majority of the initial expenditures for the grid network, more than 80%, are expected to be for "local" costs such as low-voltage line, connection costs and transformers, while slightly less than 20% are expected to be spent on the medium voltage grid lines connecting separate communities. Each of the 3.7 mn new households connected through grid intensification and extension would require about 400 W of added generation capacity, resulting in a need for about 1.8 GW of additional generation to be added to the network by 2030. Finally, the levelized cost of electricity (LCOE) for the additions to the Kaduna Electric system would be around 16 US cents per kWh (about half of which is the US$0.7–8 kWh "bus-bar" cost of power, while the other half is mostly the amortized cost of the new extensions). The table notes that, on average, settlements are about 1.2 km apart, with about 125 connections per community, and cost approximately US $100,000 to connect, requiring around 50 kW of generation each.

Per Household Costs

The basic cost elements of household grid connections are of two types:

1. the costs of the service drop, meter and other costs related to the connection to the home, which are approximately the same from one household to another;
2. the costs of the LV line that spans between homes and MV extension that spans the distances between villages, both of which may vary significantly with spatial factors such as household and village density.

These fixed and variable components are presented as per-household cost build-up in Table 7, resulting in an average total of approximately US$810 per household, ranging from a low about US$620 per household toward a high of about US$1,400 per household. For most of the grid access program, the costs of connection and LV dominate, representing over US$600 of the total US$620–810 total cost. It is only for the more expensive connections that the MV line costs, reaching a maximum of US$700–800 per household, become an equal or greater part of the cost. In other words, the bulk of the cost of this grid access program will arise from the "last mile" of LV lines, service drops, and connections.

The variation in per household initial costs has a small demand component, but is primarily related to geo-spatial factors, most importantly the density of households and villages over the landscape. In rural areas, households are, on average, more distant from each other, raising LV costs, and communities are also more distant from each other, raising MV costs. The cost build-up shows that these two factors are the dominant variable costs in electrification by grid extension. In very rough terms, initial costs for the bulk of the grid connections in the service area tend to fall within a range of US$700–US$1,200 per household which, for ~3.7 million homes, results in a total initial cost of ~US$3 billion.

Table 6 Projected grid extension metrics for the Kaduna Electric service area, 2015–2030

Indicators for MV Extension Program	Units	Total	Per Household	Per Settlement
Proposed MV Line length	km	36,000	0.0098	1.2
Proposed New Grid HH Connections	Households	3,720,000		125
Number of Settlements Proposed for Grid	Settlements	29,700		
Total Initial Costs (MV + LV line and equip.)	USD	$3,010,000,000	$810	$101,200
Initial Cost For MV Grid Network	USD	$538,000,000	$140	$18,100
Initial Cost For LV Grid Network	USD	$2,473,000,000	$670	$83,100
New Generation Needed [a]	kW	1,490,000	0.40	50
Levelized Cost per kWh for Grid	USD/kWh	$0.16		

Note:
[a] Peak demand plus 15% distribution losses

Table 7 Cost Build-up per household

Cost Category	Notes	Low	Average	High[a]
Connection Equipment	Meter, service drop, poles ($295 urban, $316 rural)	$295	$305	$316
Low Voltage Line (at ~ $11/meter) (varies with household density)	15 m/HH urban, 30 m/HH rural. (Weighted avg: 28)	$265	$322	$345
Transformer (varies with demand, ~$40/ kVA)	200–500 kVA per household. (Weighted avg of 350)	$8	$13	$19
Medium Voltage Line (at $14/meter) (varies with village density)	2 to 45 meters (and above) per HH. (Weighted avg of 10). 20% added.	$50	$169	$756
Total cost		**$618**	**$810**	**$1,425**

Note:
[a] This column reports an approximate average for the last 10% of the grid access program.

Table 8 provides a breakdown by state of where the new grid-connected households, low and medium voltage line, and new generation are recommended. The program would require about 36,000 km of additional MV line, approximately tripling the length of the Kaduna Electric's existing MV distribution network (currently 11,000–12,000 km in total). The vast majority of the MV line (90% or more) is planned for the grid extension phase, which accounts for the substantial cost difference between electrification of households by grid "intensification" versus grid "extension". Each state is recommended for about 1 million new connections (through grid intensification and extension) plus or minus 25%, depending on the state. For instance, around 1.2 million new connections are recommended for Kaduna State while about 750,000 will be needed in Zamfara.

Table 9 data also illustrates that MV extension, with the exception of Kaduna State, would provide the bulk of new connections (2.1 million versus 1.5 million), although the difference is only remarkable for Zamfara State, where over about 568,000 new households will be connected through MV extension versus 188,000 through LV intensification. In the case of Kebbi and Sokoto States, the difference in connections provided by grid intensification and extension is in the order of less than 100,000 up to a little over 150,000 connections, respectively.

This grid extension program also implies a substantial increase in generation for the Kaduna Electric service area. The program would add ~4 million new residential customers to the utility's grid. It is estimated that each new urban household connection of average income would add about 1,800 kWh of electricity demand per household per year (requiring an additional ~ ~500–550 peak Watts of capacity), while poor rural homes would add about 600 kWh/year (~125–175 Wp). Poverty mapping data from an Oxford University study[2] commissioned by the World Bank was used to estimate the distribution of this range of household demand throughout the Kaduna Electric service area and resulted in a weighted average household demand of ~1,330 kWh/year. It is assumed that each new Kaduna Electric residential customer will add, on average, around 400 W of peak demand to the system. This will require about 1.5 GW of new generation, ~870 MW of which would be due to MV grid expansion, while the other ~650 MW would result from grid intensification, that is, almost 60% of new electricity demand will result from MV extension.

Electricity Access Program: Geo-Spatial Overview

Figure 8 presents in visual form the model's main recommendation—that *over the long term* grid extension (blue points) is recommended for virtually all localities (>99%), while non-grid systems (red and green points) are rare and target sparsely populated areas.

The ~2,500 households targeted by Network-Planner for grid or mini-grid service in specific polling sites amounts to far less than 1% of the total electrification program, and thus should, from a policy and planning perspective, be considered along with a broader alternative, non-grid program, discussed in the section titled Off-Grid Electricity Access Program.

The following four maps (Figure 9 through Figure 12) illustrate the increasing grid access, in percent household connections by LGA, throughout the grid access program. This program is expected

Table 8 Proposed grid and related components, by State, Kaduna Electric area, 2015–2030.

State	Number Connections Proposed		Grid Length Proposed						New Generation Needed (MW)		
	Extension	Intensification	Extension		Intensification		Full Grid Access Program		Extension	Intensification	Full Grid Access Program
			MV (km)	LV (km)	MV (km)	LV (km)	Total MV (km)	Total LV (km)			
Kaduna	578,000	652,000	14,300	16,800	1,630	15,500	15,900	32,300	230	260	490
Kebbi	408,000	334,000	6,200	12,100	500	9,300	6,700	21,400	160	130	290
Sokoto	575,000	414,000	4,500	16,800	700	11,200	5,200	28,000	270	200	470
Zamfara	568,000	188,000	8,100	16,900	280	4,800	8,400	21,600	210	70	280
Sub-total	**2,128,000**	**1,588,000**	**33,100**	**62,600**	**3,120**	**40,700**	**36,300**	**103,300**	**870**	**650**	**1,520**
Grand Total or [average]	**3,720,000**		**[MV/HH 15.6 m]**	**[LV/HH 29.4 m]**	**[MV/HH 2 m]**	**[LV/HH 25.6 m]**	**[MV/HH 9.8 m]**	**[LV/HH 27.8 m]**	**[Capacity/HH 410 W]**		

Figure 8 Map of proposed electricity systems (with number of locations in brackets)

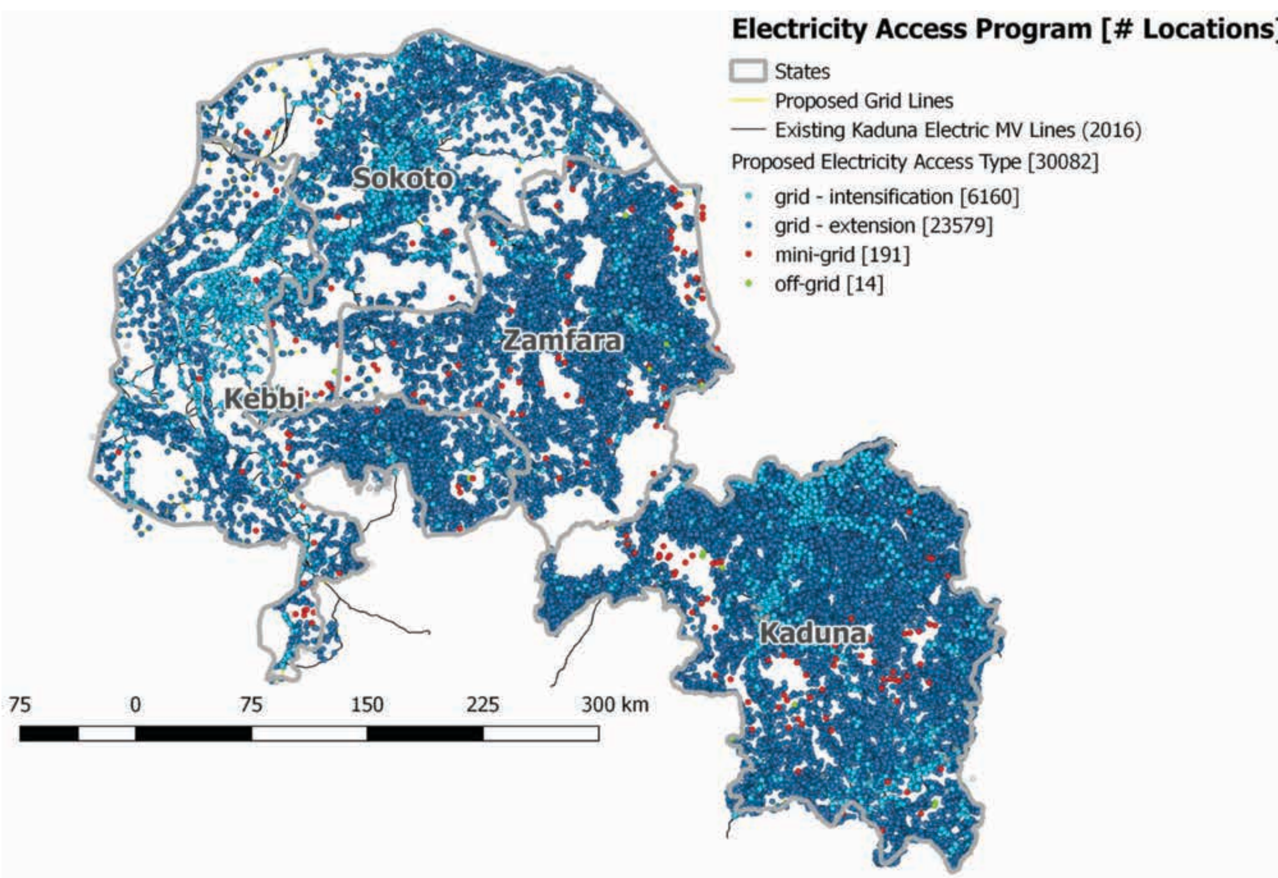


Figure 9 Percent households with grid connection by LGA before grid access program begins (~49% of the 2015 population, or 36% of the 2030 population).

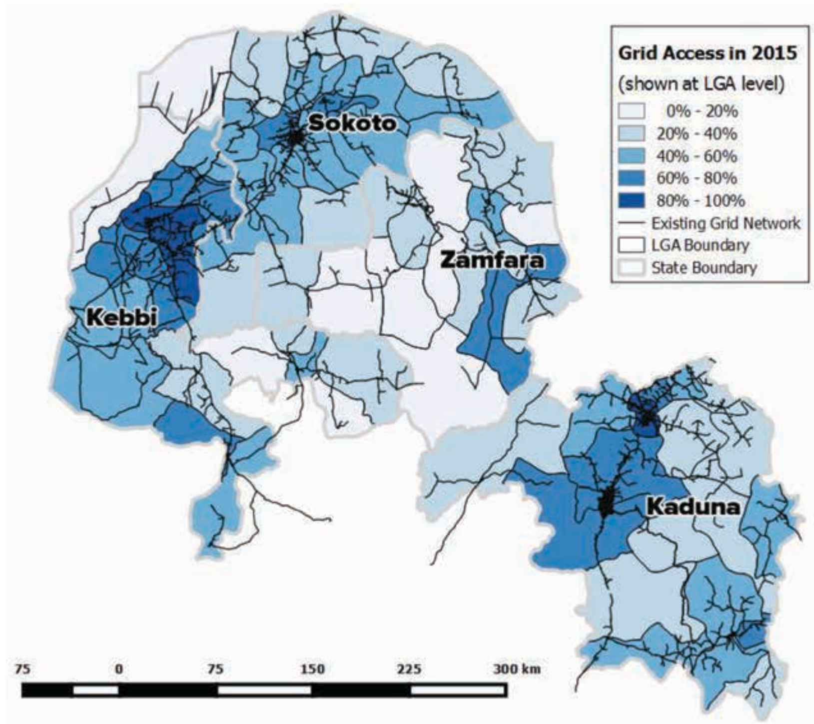


Figure 10 Percent households connected by LGA after 30% of grid access program (mostly LV intensification, achieving ~55% grid access for the 2030 population).

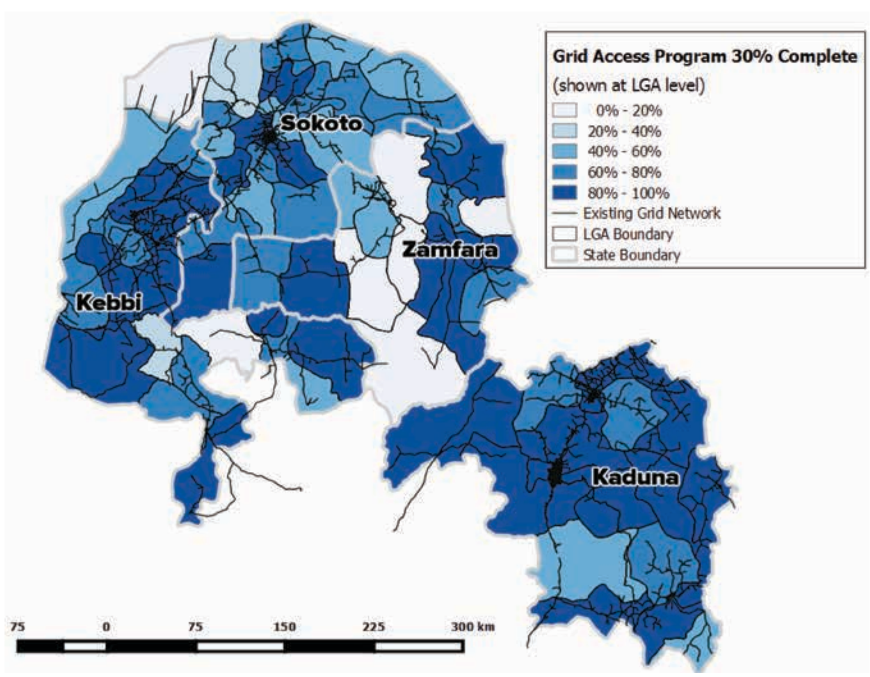
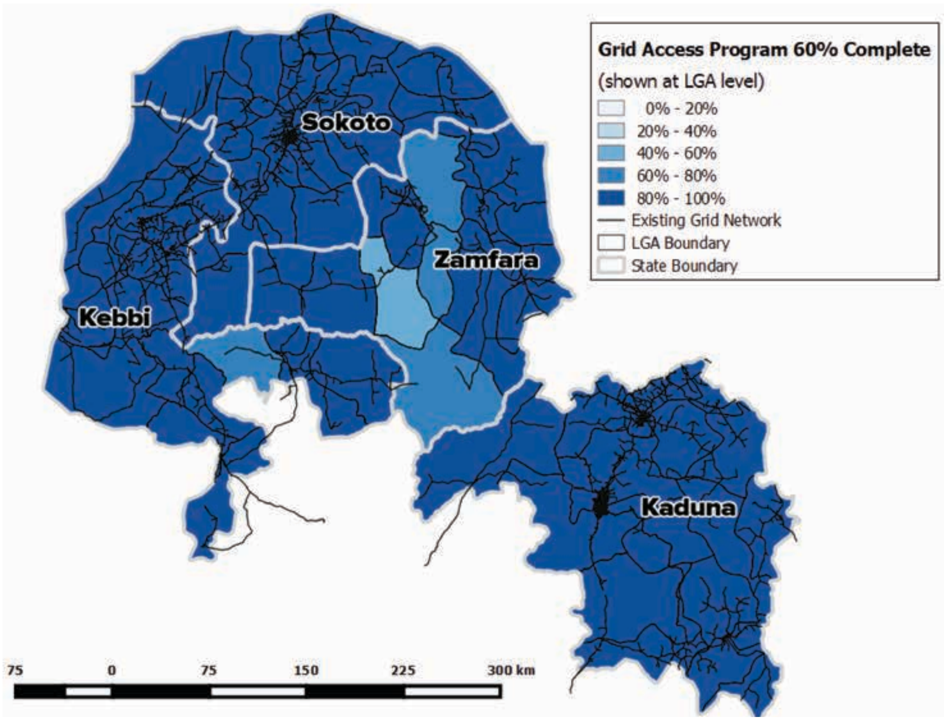


Figure 11 **Percent households connected by LGA after 60% of grid access program (after completion of about one-third of the MV grid extension program, achieving about 76% of grid access).**



to take ~15 years (from 2016–2030). The sequence and rate of specific grid extension projects depends upon investment and planning factors beyond the scope of this analysis.

Prioritization of Grid Roll-Out and Cost "Build-Up"

In addition to these aggregate national and state-level metrics for grid extension, the SEL/EI analysis also quantifies variation in unit costs of grid extension to assist planners with prioritization of grid construction in specific geographic areas (grid "roll-out"). In this analysis, an algorithm assigns a ranking for each grid segment which prioritizes lines that meet higher electricity demand with the shortest MV line extension. Table 9 provides cost and technical information in prioritized "deciles" (10% increments) of households connected, illustrating the growing cost as the grid extends to reach smaller, more distant communities, thus raising the amount of medium voltage line needed to stretch between communities.

As stated previously, this analysis does not create a year-by-year investment program or detailed engineering design. The costs of the full grid program are presented in this section broken down into increments based on the percentage of households connected. These should not be interpreted as specific investments targeted for specific years, or a time-bound implementation plan, as these sorts of budgeting decisions involve other concerns—such as the availability of funds in annual budgets, and the practical capacity of Kaduna Electric or private contractors to implement grid extension over time. Instead, the information is provided to support budget planning and decision making that must consider questions such as how much grid extension to invest in (compared with other possible investments such as non-grid electrification or even other infrastructure).

Figure 13 provides similar information in graphical form, emphasizing two additional factors: a) the separate cost components that contribute to the total cost per household of MV and LV grid extension

Figure 12 Percent households connected by LGA after completion of the grid access program, achieving nearly 100% grid access.

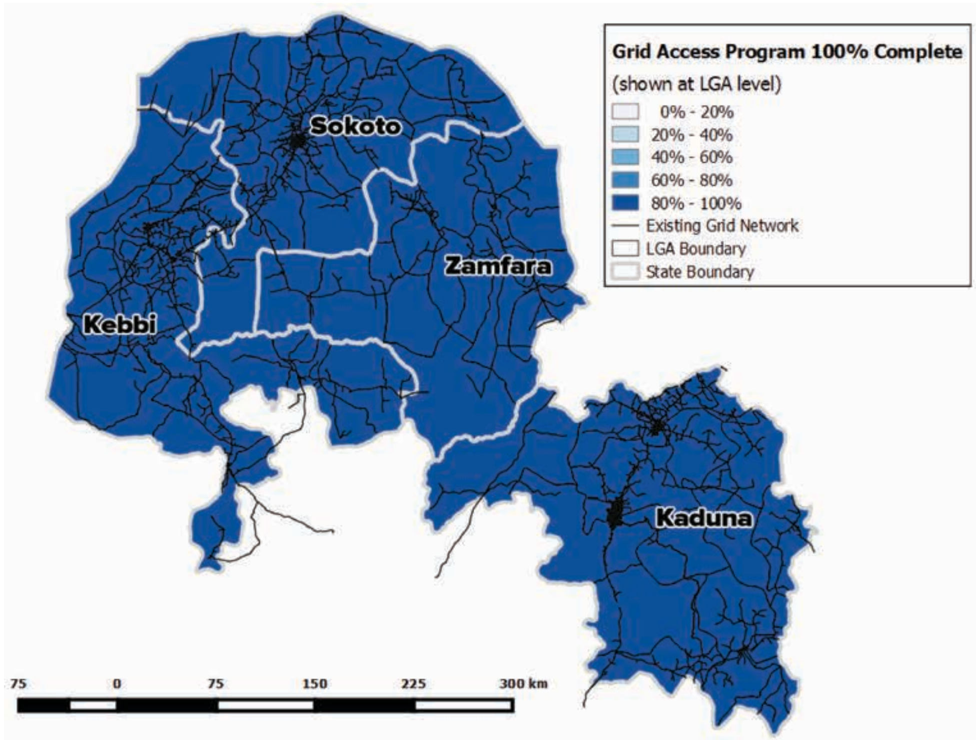
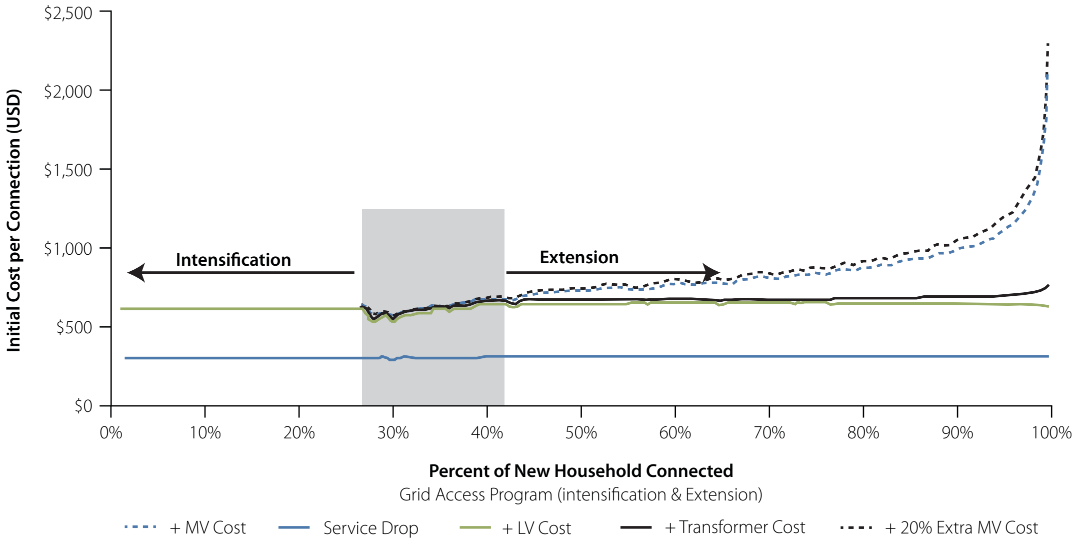


Table 9 Costs and Distances for MV Grid Extension, by Decile, under grid access plan

Decile	Number of Connections	Pct reached by Grid	Total Initial Cost	Pct of total grid expenditures		Total MV Line Added	Pct of MV Line Added		Per HH Cost	New MV Line per Conn.
	(Qty)	Pct (cum.)	USD Million	Pct	Pct (cum.)	km	Pct	Pct (cum.)	USD	m
1 [a]	372,000	10%	$240	8%	8%	200	0.5%	0.5%	$640	0.5
2 [a]	372,000	20%	$240	8%	16%	200	0.5%	1%	$640	0.5
3 [a]	372,000	30%	$240	8%	24%	200	0.5%	2%	$640	0.5
4	371,000	40%	$240	8%	31%	130	0.4%	2%	$640	0.4
5	372,000	50%	$270	9%	40%	1,120	3%	5%	$720	3.0
6	372,000	60%	$290	10%	50%	2,220	6%	11%	$770	6.0
7	371,000	70%	$310	10%	60%	3,460	10%	21%	$820	9.3
8	372,000	80%	$330	11%	71%	4,950	14%	34%	$880	13
9	372,000	90%	$370	12%	83%	7,420	20%	55%	$990	20
10	372,000	100%	$510	17%	100%	16,370	45%	100%	$1,370	44
Total	**3,716,000**		**$3,010**	**100%**		**36,250**	**100%**			
Avg	**372,000**		**$300**	**10%**		**3,630**	**10%**		**$810**	**9.7**

Note:
[a] The first 27% of grid intensification is treated as a single aggregate, so figures for the first three deciles are the same, an average of that portion of the grid access program.

Figure 13 **Component costs throughout the grid access program for Kaduna Electric**



(including connection costs, LV costs, and MV costs, similar to the household cost "build-up" presented in Table 7 previously); and b) the importance of variation in MV costs specifically as part of the overall cost profile (the latter point will be explored in more detail in the subsequent section Sensitivity Test—Variation in Household Demand, p. 52). The figure shows, in green, the very "local" costs of grid extension, including the service drop and meter, low voltage line and transformer, all investments which are made within the community being electrified, and which, based on the assumptions of the preliminary modeling work do not change substantially throughout the MV grid extension program.[3]

This figure begins at the left with a flat cost curve, extending from the first household connections (0%) through to about 27%. This portion of the figure represents the "intensification" phase, meaning that it predominately consists of LV connections within range of the existing grid for the existing unconnected population as well as additional population growing in this area. Given the assumption that growing populations will, on average, stay within the same access category, it is assumed that these households will remain largely within range of the grid, requiring only additional connections.

To the right, in the range of 26–43% households connected, the gray rectangle represents a transition phase, from a phase that is mostly grid intensification into a phase that is mostly grid extension.

Moving further rightward, beyond 40% of household connections, the figure shows the portion of the electrification program in which most connections are made through grid extension. This shows the gradually increasing costs of grid electrification that occur outside of any one community, the MV costs that extend over the landscape between settlements. These MV costs are shown in two lines: one represents the basic model assumptions, as vetted with the Kaduna Electric staff, while the top curve (in red) represents the addition of the 20% "correction factor" intended to address the fact that the model calculate straight-line distances between communities when in fact the paths can curve with surface features, roads and topography. The figure illustrates at least two important points. First, it shows the increasing importance of the costs of MV line per household as the MV extension program proceeds. MV line costs remain below one-third of the per household cost up to the point of connecting 80% of the households as the length of MV line per household remains below 5 meters, then grows to around half, or more, of the total cost per household in the latter 5–10% of the access program, when MV per household requirements rise to 20–45 meters per household.

Perhaps the most important insight that can be gained from both Table 9 and Figure 13 relates to the high costs and MV line requirement of the final decile of the grid access program. Note from the table that *nearly half of all MV line added to the Kaduna Electric system (45%) would occur in connecting the last 10% of households*, where the MV per household rises to over 40 meters / household. Note from the figure that the household cost curve shows a rapid and dramatic increase in the final portion of grid extension. This rapid rise helps to illustrate the tendency of grid extension to become far less cost-effective in the final stages of a universal access program, where a single household connection may cost $1,400 or more. Essentially, the model is reporting that grid (compared to off-grid options) is indeed the least-cost technology for the communities in the last 10% of the roll-out program, considering all initial and recurring costs over the long term. Nonetheless, the grid is still relatively high cost for these households. Not only are these connections high costs, but these are also the communities that will likely need to wait the longest for grid connection. *This may suggest alternate electrification strategies for the most remote areas, such as mini-grids or solar home systems, which could provide power instead of the grid, or for a temporary period as these locales await grid extension.* As will be discussed in the later section (Off-Grid Electricity Access Program) this analysis will recommend that policy makers and planners consider an interim program to serve these communities that would be highest cost, and in the latest stages of grid roll-out, with off-grid systems, perhaps at a lower service standard (in terms of kWh/yr delivered to the home) in order to meet basic energy needs at lower costs per household.

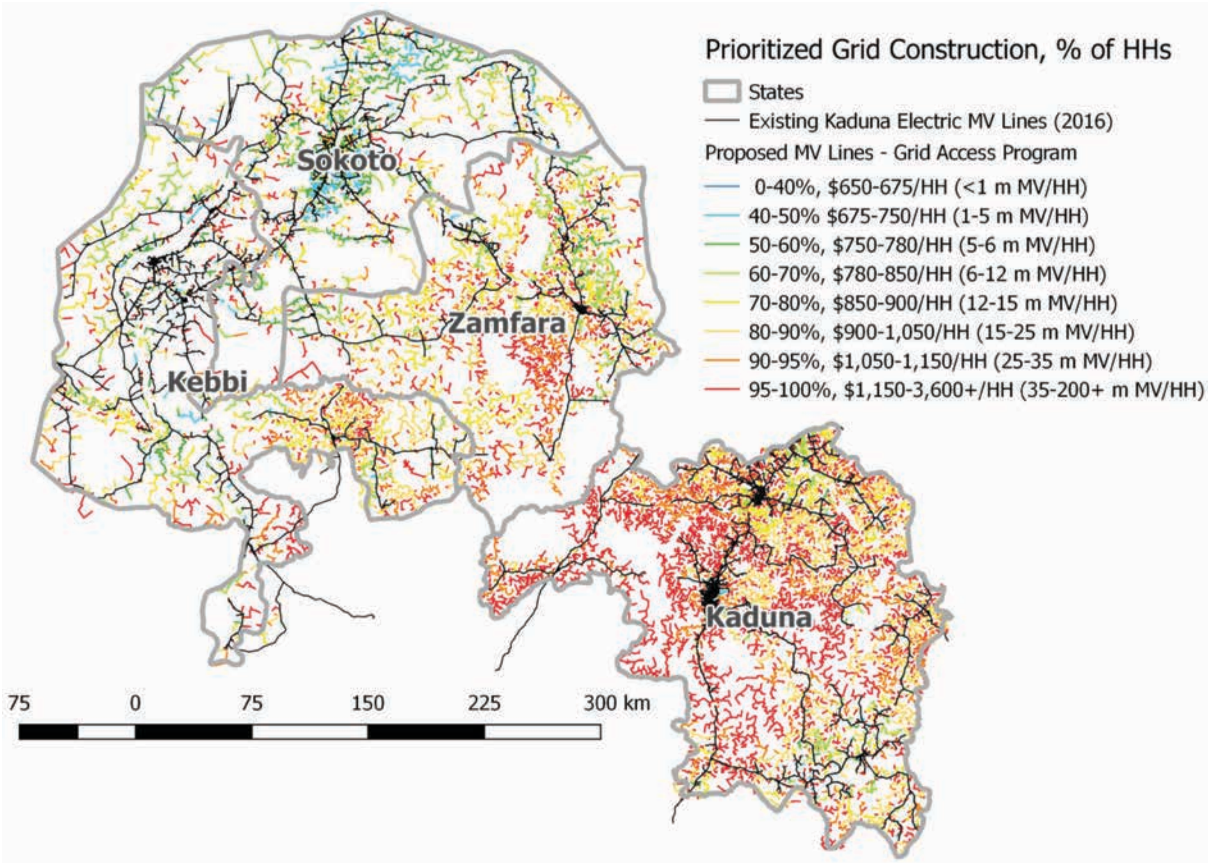
Figure 14 shows a map view of the grid roll-out program, prioritized based on this cost-benefit ranking, for the Kaduna Electric service area—components C and D of the investment program—divided into deciles based on average costs per household connection. This map illustrates that, from a cost-benefit perspective, investments in grid are recommended to place higher priority on denser parts of Sokoto state (in blue) followed by much of Kebbi and Zamfara (in green and yellow). Kaduna state (in orange and red), is generally prioritized last in the roll-out, perhaps because grid coverage is fairly extensively built out already, leaving few low-cost, high impact communities to electrify in the short term.

This per household cost metric offers a means to prioritize extensions which meet a greater electricity demand per unit of investment, and thus are more cost-effective. This figure illustrates how initial phases of grid construction are more likely to reach communities that are closely spaced, nearer to the existing electricity grid, and have higher demand. These are the areas where less medium voltage line is needed per household and hence per household connection costs are lower (~$600–700 per connection). Later phases reach remote, rural communities where the required MV/household is much higher, resulting in higher unit costs (~$1,000 per household or more). As described above, even though grid is the least-cost solution for these communities over the long term, the high costs suggest that they would be good candidates for interim non-grid service (see Off-Grid Electricity Access Program, p. 46).

It is important to emphasize that this analysis provides a *plan* for universal electricity access from 2015–2030, not a *design* for grid construction. This grid roll-out plan describes which locations should be connected, and the relative prioritization of connections, in a cost-benefit sense, and an *estimate* of overall costs and technical needs (equipment, added generation, etc.). It does not show an annual timeline for grid construction, yearly expenditures, or the specific pathways of future grid extensions, locations of transformers, etc. A more detailed design would require important additional factors, including: a) an investment plan, clarifying the investments needs for the electrification program (with a specific focus on the first five years of implementation), possible sources of funding, and their efficient use, to construct new lines and make connections (such an investment prospectus has been commissioned by the World Bank, for which this analysis will be an input); and b) input from local engineers to determine the paths of lines and best sequence of connections in response to local factors such as available electricity supply and local geography topography, right-of-way, etc. (this is anticipated as part of the implementation program to follow the investment prospectus).

These maps are based on GIS data that can be viewed at higher levels of magnification, providing a clearer illustration of specific grid extension recommendations for local areas. Figure 15 shows the same results for an enlarged area in the eastern part of Zamfara State, along the border with Niger. In this area, it appears that the most cost effective grid construction is not necessarily the extensions close to what appears to be a dense area of concentrated lines (lower-left, orange and red segments)

Figure 14 **Prioritized grid roll-out with MV cost and length per household as access (connections) increase**



but rather that investment could be more cost-effectively applied to the longer extensions heading northward from the line termini in the center of the figure (green lines).

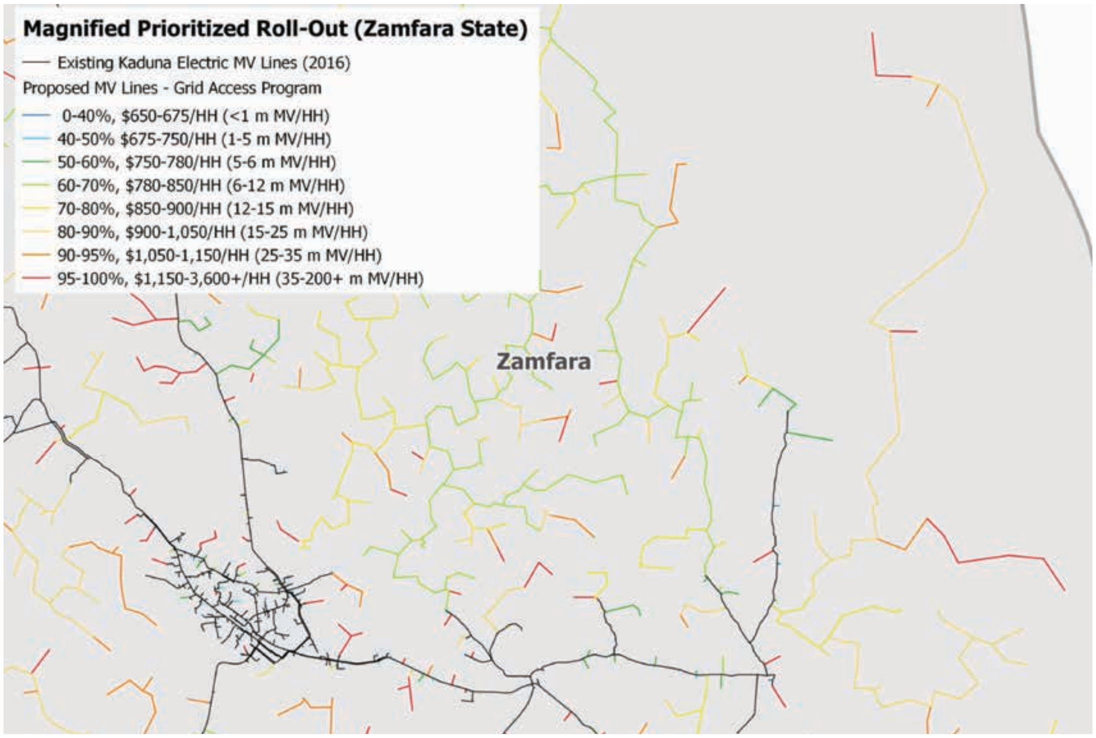
This figure also helps to emphasize the difference between a prioritized grid expansion plan created here, versus a true construction design. To give only one example of the sort of practical consideration that makes the two different: utilities and project implementers are likely to plan construction work at the level of the "feeder" (i.e., constructing extensions to all locations along a given line at once). However, this model's output incrementally prioritizes each connection *segment* along the line in a manner that might imply construction of some parts of a feeder in different phases. These kinds of investment and construction decisions are beyond the scope of a high-level analysis such as this. But this dataset and analysis do provide rich data to support such detailed decision-making.

Off-Grid Electricity Access Program

The geospatial analysis identified grid technologies as the least-cost long-term solution for providing access *by 2030* for the overwhelming majority of the population. There are few instances (component E, Table 5) where in the long term deployment of off-grid systems is recommended. The geospatial rollout scenario for the grid also provides the basis for quantitative thinking on where the grid would be most cost-effective to build out first and an off-grid program could help bring access to those unlikely to be served by the grid in the near term. Furthermore, the timing of grid rollout cannot be precisely anticipated due to the need for complementary infrastructure, creating space for off-grid solutions.

This section explores service standard options, as well as the costs and scale of possible off-grid deployments. The scope of an off-grid program will

Figure 15 **Prioritized grid roll-out, enlarged area of Zamfara State, 2015–2030.**



vary with many factors, including policy choices, the level of private sector engagement, and support from international development partners.

Two target groups of beneficiaries are identified by the geospatial analysis for off-grid solutions:

A. Areas where off-grid, rather than grid, is the recommended long-term, least-cost option.

These are households belonging to component E in Table 5, for which off-grid technologies (such as solar home systems or mini-grids, depending upon the locality) are identified by the model as the least-cost solution by 2030.[4] These are either very small and/or remotely situated households and villages that are unlikely to be cost-effectively served by grid connectivity within the foreseeable future. The component may also include some homes that are not far from the existing grid, but their isolation from neighboring settlements and transformers raises the cost of grid connectivity greatly.

There is no map of every household in the Kaduna Electric service area, and even if there were, it would not be accurate for long, if only for the simple reason that people move and populations grow, particularly over a 15-year time horizon. *Unless a geo-spatial location dataset records locations of every single household, even an excellent dataset will, by necessity, aggregate the smallest villages and isolated homes to some degree.* This modeling work was based on a geo-located population dataset that should be considered an outstanding resource: the VTS/Gates Foundation data for Nigeria is very recent, covers extremely small settlements, and has been carefully vetted by comparing field tracking with satellite imagery. A close comparison of freely available satellite imagery with data points from VTS/Gates Foundation data (see Appendix F: Review of VTF/Gates Foundation Data) suggests that a very small percentage of households have been counted at the community level, meaning that settlement points include populations from some dispersed households which are included, but not themselves geo-located. This is quite reasonable, given the impracticality of a mapping effort that would assign latitude/longitude coordinates to every household. We estimate that this is well below 1% of the total population, but a firm quantitative figure is beyond the scope of this analysis.

B. Pre-electrification for communities that will wait several years for grid access

The largest group of potential beneficiaries of an off-grid program is likely to be households and communities for which grid connection is the least-cost solution, but will likely be required to wait several years for the grid rollout program to reach them. Those who must wait the longest under a cost-benefit prioritized roll-out plan are more likely to be small, rural, remote communities which are, on average, poorer. Moreover, economically vibrant communities closer to the grid may also be a viable interim off-grid possibility where economic demand density for access may be high and potentially grid-compatible mini-grids might make sense. The primary reason for providing an interim solution to these communities is therefore a combination of factors: *the urgency of need, the opportunity cost of not having access, and in some cases the high cost and likely delays involved in reaching populations towards the later stages of grid rollout*[5]. For these late-stage rollout geographies, even small amounts of electricity—which is practical at reasonable per household cost using pico-solar solutions, solar home systems or mini-grids—may lead to a relatively high benefit for the investment. These communities could be provided access in the interim with sufficient power for essential electricity services such as household lighting, and charging of mobile phones and other batteries and devices, and basic connectivity for schools and clinics to power computers, vaccine cold chain, and other services. For this reason, donors, government, utilities, the private sector, and other decision-makers may choose to implement off-grid service *at a lower service standard* when faced with very high costs of grid connections, even if grid is least cost when all electrification options are compared *at the same service standard*. More detailed local knowledge of rural, sparsely populated areas can provide more specific estimates of these very basic power needs for each location. Specific electrification technologies can be evaluated and selected during a more detailed future program design at a cost ranging from as little as ~$50-$1200 per household, with the lower end of the cost range applying to pico-solar (solar lanterns) and solar home systems (Tier 1 & 2) and the higher end for solar-battery, diesel or hybrid mini-grids (Tier 3+)[6]. Given implementation bottlenecks and other infrastructure constraints, even communities targeted for earlier phases of grid roll-out may still face delays in connections. These communities might benefit from mini-grids designed for a higher service standard. This may include higher per household consumption levels, low voltage distribution wiring approaching or equal the utility's standard, and grid-compatible metering. In this later case, initial investments per household are likely to be at the high end of the cost range for Tier 3+ options presented above.

For illustrative purposes, we explore the costs and technical features of a pre-electrification program, taking into account the urgency of electricity needs and the estimated timing for service provision together with the information available on households' location. We estimate alternate possible programs that would provide electricity service to the last 1%, 2.5% or 5%[7] of the households in the electricity access program for 5–10 years as they await grid connectivity. Those in the last stages of grid rollout will typically be smaller communities, furthest from the existing grid, and hence among the most expensive in terms of costs per connection by grid. In order to provide some specifics we consider here the 7,749 locations that the least-cost grid prioritization has identified as the final 5% to receive grid connectivity. They have very high initial costs per connection (US$1,150-3,600), largely because MV extensions over long distances between communities require investments of 35 – 200m of MV line per household.

Table 10 Costs per household and for full program, for pre-electrification off-grid access.

Service Standard	Service Standard		Average Initial Cost / HH	Off-Grid as Percentage of Grid Access Program		
				~1%	~2.5%	~5%
(kWh/yr)	(Wh/day)	System Type	USD	40,000 HHs	100,000 HHs	200,000 HHs
120	330	Mini-grid	$1,100	$44,000,000	$110,000,000	$220,000,000
60	160	Mini-grid	$600	$24,000,000	$60,000,000	$120,000,000
30	80	Solar Home System	$300	$12,000,000	$30,000,000	$60,000,000

Since off-grid systems (mini-grids and solar home systems) do not require medium voltage grid lines stretching between communities, the costs for off-grid systems scale, for the most part, linearly with the number of connections and "service standard" (the assumed annual household demand, in kWh). Table 10 explores a plausible range of costs for programs of different sizes—varying both the service standard (in kWh) and number of connections under consideration.

A service standard of 120 kWh/HH-year, one-fifth of the "grid connected poor" level of 600 kWh/year described in the section Model Input Parameters can be met by a mini-grid with a per household cost ranging from US$1,000–$1,200 (an average of US$1,100 per connection is used here), or US$500–$700 (US$600, on average) for a mini-grid providing 60 kWh/HH-year. Similarly, a solar home system, providing perhaps 30 kWh/HH-year, is assumed to cost between US$200–$400 (US$300 average). This range of costs, when applied to programs targeting the final 1%, 2.5% and 5% of the grid access program—as interim alternatives to grid access—suggest a wide range of possible costs, from US$10–15 million at the lowest service standard and program size, to over US$200 million at the highest.

Considering the geo-spatial features of such a program, Table 11 provides estimates for the number of locations (village settlements) and total number of household connections, by state, for interim off-grid system programs providing service for 1%, 2.5% and 5% of the electricity access program.

Figure 16 provides a broad geographic overview of potential locations for interim off-grid systems, based upon electricity service provided to the final 1%, 2.5% or 5% of the grid access program. An important insight of this map is the predominance of the off-grid systems in Kaduna State, and secondarily in Zamfara.

The above discussion illustrates only the very latest segments of MV extension—up to the final 5% of the grid access program. The number of households not receiving a connection in the near to medium term would likely be much larger. Other constraints (generation and related fuel supplies, in particular) could introduce further uncertainties in the timing of grid roll-out. So, in another scenario as many as half the households which the least-cost model targets for new grid connections may be provided with off-grid electricity service in the near term of the next 5 years. Since scaled deployment of such technologies could occur faster, they would not be constrained by requisite parallel expansion of generation and transmission. An indicative cost estimate for off-grid access for these households would be ~$600 per household (assuming a median service standard of 60 kWh/year). A programmatic approach of this kind for half of the households targeted for grid—which would equal 1.8–2 million homes, or 30-35% of the total service area population in 2030—would cost $1.1–1.2 Billion. Some of this investment would indeed subsequently reduce the full cost of distribution infrastructure when the grid arrives.

Thus, while the prioritized grid rollout plan can aide in the cost-effective planning of both grid and off-grid programs (including the pre-electrification component), the execution of these programs—including relative prioritization of intensification vs MV line extension; the actual number of beneficiaries and target areas, identified from demand growth; the cost, timing and geographic targeting of grid expansion, will eventually depend upon other factors. These factors may include (i) the availability of resources for implementation and year-to year-sequencing of the grid rollout plan, undertaken by

Table 11 **Potential pre-electrification off-grid sites, by State**

	Final 5%		Final 2.5%		Final 1%	
State	**# Locations**	**# HHs**	**# Locations**	**# HHs**	**# Locations**	**# HHs**
Kaduna	5,200	120,000	3,321	61,000	1,728	23,000
Kebbi	909	23,000	571	12,000	330	5,000
Sokoto	352	8,000	239	5,000	126	2,000
Zamfara	1,288	34,000	824	16,000	471	7,000
Grand Total [a]	**7,749**	**186,000**	**4,955**	**93,000**	**2,655**	**37,000**

Note:
[a] The total household figures in final row of this table do not exactly equal the household figures in the final three header columns of the previous table due to rounding.

Figure 16 Potential pre-electrification off-grid locations for programs of varying size

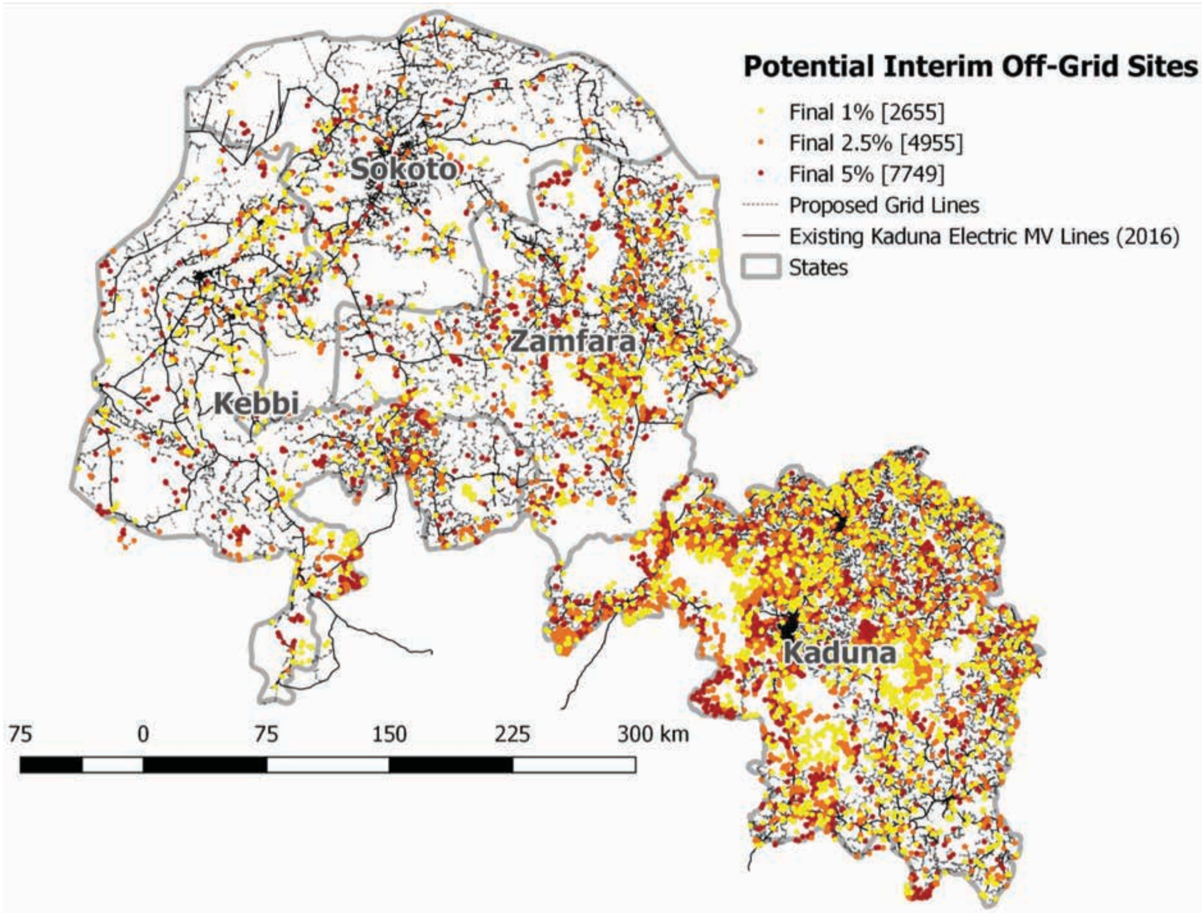


Table 12 Electrification status (2015) and proposed connections (2015–2030) for educational facilities (Kaduna Electric service area)

		Connected to grid (2015)		Connected or w/in 1.5 km of existing grid (2015)		Connected or w/in 1.5 km of existing (2015) and proposed grid (2030)		Will need non-grid power (> 1.5 km from existing & proposed grid)	
Education Facilities	Total	#	%	#	%	#	%	#	%
Total (all facilities)	11,052	1,583	20%	5,997	54%	10,947	99%	117	1%
Primary	9,485	926	10%	4,647	49%	9,478	100%	88	1%
Junior & Senior	1,382	593	43%	1,163	84%	783	57%	9	1%
Vocational & Technical	53	18	34%	38	72%	35	66%	5	9%
Unknown Type	190	46	24%	149	78%	102	54%	15	8%

Table 13 **Electrification status (2015) and proposed connections (2015–2030) for health facilities (Kaduna Electric service area)**

		Connected to grid (2015)		Connected or w/in 1.5 km of existing grid (2015)		Connected or w/in 1.5 km of existing (2015) and proposed grid (2030)		Will need non-grid power (> 1.5 km from existing & proposed grid)	
Health Facilities	Total	#	%	#	%	#	%	#	%
Total Number (all facilities)	3,557	870	24%	2,103	59%	3,537	99%	25	1%
Hospital	162	120	74%	159	98%	42	26%	1	1%
Dispensary	487	34	7%	199	41%	453	93%	5	1%
Clinic, Basic/ Primary Health Centre	1,558	554	36%	1100	71%	1,004	64%	5	0%
Health Post	1,316	157	12%	614	47%	1,159	88%	9	1%
Unknown Facility Type	52	5	10%	31	60%	34	65%	5	10%

Figure 17 **Educational facilities with grid access (2015) and targeted for grid (2030) (these total more than 99% of all education facilities throughout the Kaduna Electric area)**

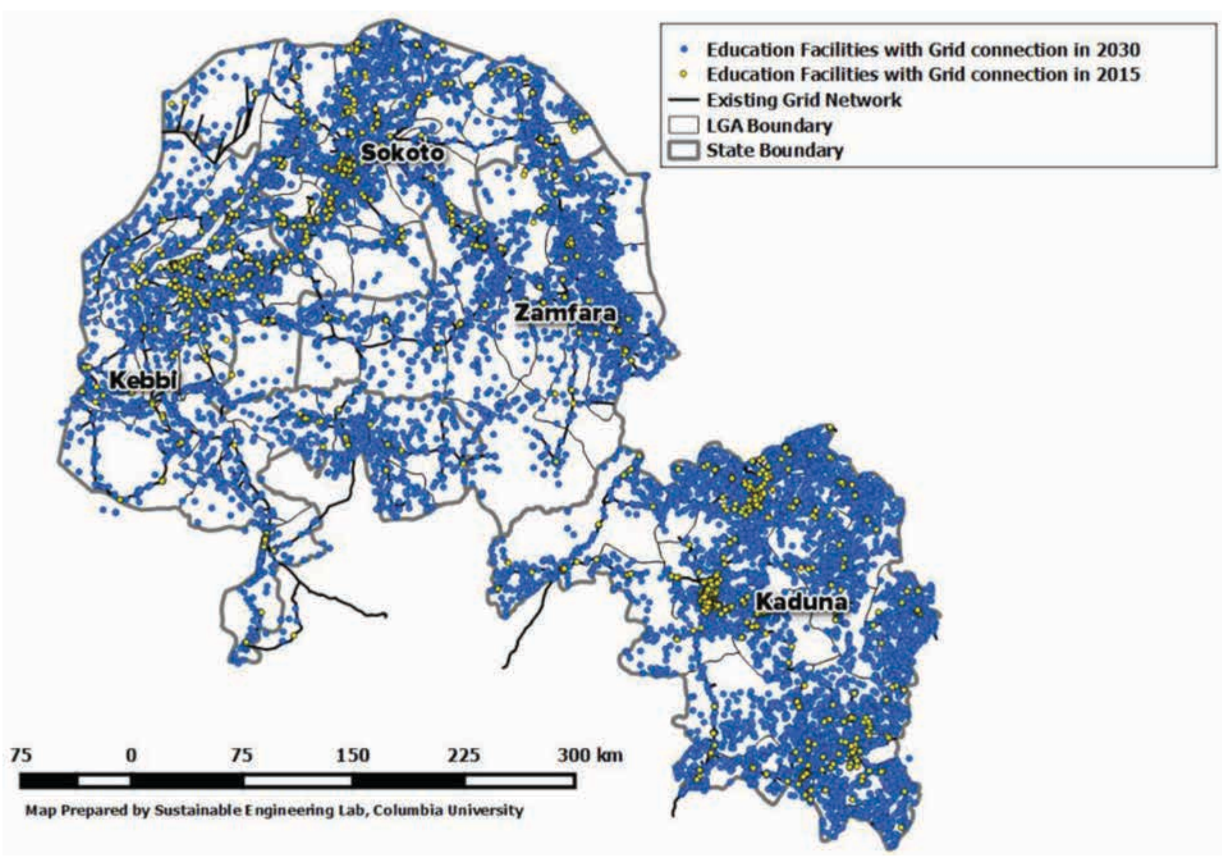
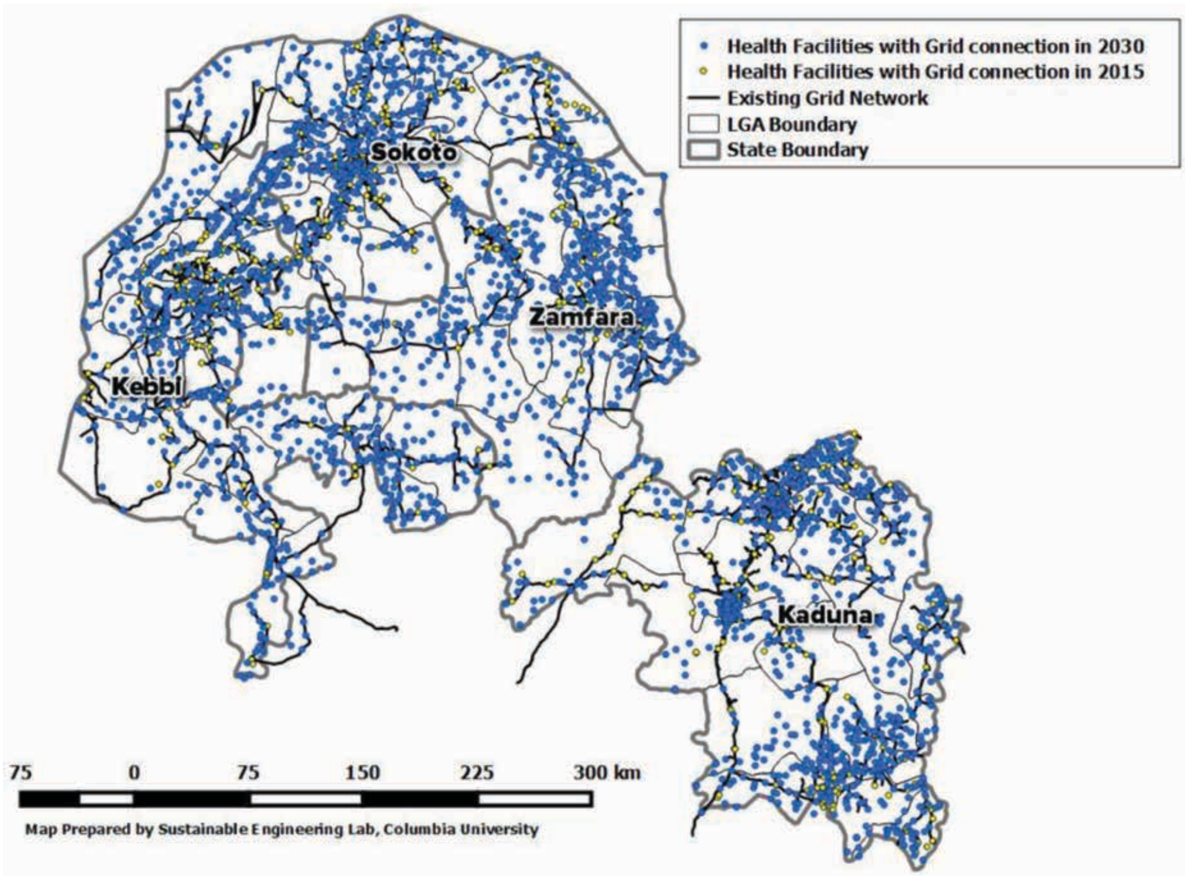


Figure 18 Health facilities with grid access (2015) and targeted for grid (2030) (these total more than 99% of all education facilities throughout the Kaduna Electric area)



Kaduna Electric and to be approved by NERC; (ii) lessons learned from scaled off-grid programs; and (iii) the adoption of an off-grid enabling policy and strategy in space and time for Tier 1&2 and Tier 3+ market penetration and scalability, comprising technical standards to ensure grid compatibility (in the case of interim solutions).

The complexity and scale of such an electrification program, particularly the geographic targeting of grid and off-grid system implementation, would require an unusually high degree of planning and coordination to ensure efficient implementation and avoid redundant investments. Hence a key recommendation of this report is the establishment of a web-based data platform that allows near real-time visibility (via roughly monthly updates) for specific details of the implementation of the grid and off-grid programs. Such a platform would be available to a wide group of stakeholders from government, electric utilities, and private sector implementers. This platform would provide up-to-date information for:

a. areas targeted for grid intensification, extension of MV lines, or mini-grid installation (noting technical standards, such as grid-compatibility), and smaller pico solar systems (lanterns and home systems);
b. the construction status for all lines and equipment, and access status for areas and communities, including which are already funded for procurement and implementation, which are under construction, where construction is recently completed and awaiting commissioning, and which have received service;
c. aggregate information on demand and demand growth based on consumption figures and the number of households associated with non-residential demands nearby (supporting data-driven planning for not only residential but also ancil-

Table 14 Sensitivity Results: Recommendations for 100% access in 2030, households.

Scenarios with Varying HH Demand		Total HHs Modeled	Recommended Number of Households, by System Type					
			Grid	% Grid	Mini-grid	Off-grid	Total Non-Grid	% Non-grid
Very Low	50%	2,129,829	2,118,528	99.5%	7,367	3,934	11,301	0.53%
Low	75%	2,129,829	2,126,054	99.8%	3,226	549	3,775	0.10%
Base Case	Base – 100%	2,129,829	2,127,772	99.9%	1,983	74	2,057	0.06%
High	150%	2,129,829	2,129,026	100.0%	803	0	803	0.02%
Very High	200%	2,129,829	2,129,534	100.0%	295	0	295	0.01%

Table 15 Sensitivity results: Recommendations for 100% access in 2030, settlements

Scenarios with Varying HH Demand		Total Settlements Modeled	Recommended Number of Settlements, by System Type					
			Grid	% Grid	Mini-grid	Off-grid	Total Non-Grid	% Non-grid
Very Low	50%	23,784	22,882	96%	379	523	902	3.8%
Low	75%	23,784	23,442	99%	250	92	342	1.4%
Base Case	Base – 100%	23,785	23,580	99%	191	14	205	0.9%
High	150%	23,784	23,683	100%	101	0	101	0.4%
Very High	200%	23,784	23,740	100%	44	0	44	0.2%

lary demand from associated commerce, industry and agriculture).

Electricity Access for Social Infrastructure

Considering electrification for social infrastructure, such as schools and clinics, we not that while these locations are certainly a vital part of any universal access plan, electricity access for them is not likely to require an entirely separate electrification program, since the overwhelming majority of these sites will be covered by the grid extension program modeled to meet residential needs. Geo-located social infrastructure data collected for the Nigeria MDG Information System (NMIS)[8] indicate that, as of 2015, over 70% of the most important institutions, such as hospitals, already have grid connections to the existing network, but that, overall, only 20–30% of clinics, primary and secondary schools are already connected. For those that are not already connected, 99% of all education facilities (10,947 of 11,052) (see Table 12) and 99% of all health facilities (3,537 of 3,557) (see Table 13) will fall within 1.5 km of MV grid lines proposed to be constructed from 2015 to 2030 to meet residential needs.

The following maps provide visual support to this conclusion: Figure 17 illustrates the education facilities that have grid access as of 2015 (yellow) and those that are targeted for grid access as of 2030 (blue). It is critical to note that those educational facilities with grid (2015) and recommended for grid (by 2030) will total more than 99% of all facilities nationwide.

Figure 18 illustrates the same for health facilities: those that have grid access as of 2015 (yellow) and those that are targeted for grid access as of 2030 (blue). As with educational facilities, those health facilities with grid (2015) and recommended for grid (by 2030) will total more than 99% of all facilities nationwide. For less than 1% of facilities belonging to the Kaduna service area off-grid solutions would be the least-cost technology option for the long term.

Sensitivity Test – Variation in Household Demand

Household demand is typically the most critical modeling parameter for affecting modeling and electrification planning. This is because it fundamentally impacts the relative cost-effectiveness of various technologies with very different balances of initial and recurring costs. Grid electrification typically has relatively high initial costs (for wire, transformers, connections) but lower recurring costs (since the "bus-bar" cost of power tends to be low due to larger and more efficient generation, typically from cheaper sources, like hydro, coal and natural gas). In contrast, solar photovoltaic systems tend to have lower initial costs, at least for small, remote communities, since they do not require medium voltage lines, but solar has relatively high recurring costs due to the need to continually reinvest in battery storage. Mini-grids typically offer an intermediate option to meet demands that are too high to be met cost-effectively served with solar home systems, but not large enough to justify connection to the full grid.

The effect of varying household demand can be seen in the type of system recommended by the model: high household demand typically favors grid electrification, and low demand favors non-grid options like mini-grids and off-grid / solar home systems. To probe this effect, SEL/EI has included a brief analysis of the sensitivity of the model's recommendations for system types with multiple scenarios with varying household demand. Table 14 and Table 15 show how changing household demand influences electricity system recommendations in the model outputs for the Kaduna Electric service area.

The main scenario outputs explored in the bulk of this report are identified here as the "100% demand" scenario, or the "base case" (row in blue font). For base demand scenario, the household electricity demand per year per household is in a range of 600–1,800 kWh, depending on the poverty rate, with an average of about 1,330 kWh/year. As explained elsewhere in this document, the model results for this demand value are essentially a recommendation of grid for virtually all locations, and over 99.9% of the area's households. The sensitivity analysis tested whether this would change if demand were to reduce the base case by 50% (to ~665 kWh/yr) or 75% (to ~1,000 kWh/yr), or raise it to 150% (~2,000 kWh/yr) or 200% (2,660 kWh/yr).

The tables show that, for all scenarios, ranging from 50% demand to 200% demand, between 99.5% and 100% of households are recommended for grid, and between 96% and 100% of settlements, as well.[9] The change in results from this variation in demand is extremely small, essentially within the range of error of all of the parameter values used in this model—including the cost values reported by Kaduna Electric staff, error in the population figures from the VTS/Gates Foundation settlement data, and other sources. In other words, within the limits of accuracy for the data sources used for this study, the recommendation the virtually all the Kaduna Electric coverage area be connected to grid is extremely stable across a four-fold variation in household demand values.

ENDNOTES

1. The clear division of the electrification program into distinct components is, of course, an approximation for explanatory purposes. In reality, the geography of communities and households will require substantial local variation in network patterns and costs, and the components presented here will blend together and overlap.
2. Gething, P., Molini, V. (2015, June 10) Developing an Updated Poverty Map for Nigeria. Final Report. [No web address available.
3. As explored in later sections, this assumption of unchanging costs for these components may not hold true, particularly for LV line costs, which show substantial variation throughout the country—a topic that will be factored into future model runs for certain provinces.
4. Off-grid solutions would also be the least-cost solution in the *long-term*, that is for the time horizon considered for infrastructure planning, which is typically of 30 years or more.
5. A third potential reason for undertaking pre-electrification efforts relates to reliability of the grid—specifically, that some may prefer an alternative to grid service to avoid load shedding. While this is no doubt true for many now connected to the grid, our understanding and assumptions have been: a) that problems with reliability will decline as the total supply of grid power on the national network increases and other reforms and system improvements continue; and b) due to overall wattage limitations and higher recurring costs of solar and diesel systems, off-grid users typically want access to the grid, even if intermittent, if possible.
6. These services are defined by the Multi-Tier Framework for electricity Access developed by the Bank under the Sustainable Energy for All (SE4All) engagement. The framework defines five different tiers of access and the household supply described

above corresponds to Tier 2. For more information, visit: https://www.esmap.org/node/55526.

7. Although 1%–5% is a somewhat arbitrary range, it is intended as a catch-all to include two groups: i) isolated households not captured perfectly by the VTS/Gates Foundation dataset; and ii) the very latest-stage, highest-cost grid recommended homes. The few communities that were determined during NetworkPlanner modeling to be recommended for off-grid or mini-grid systems for the long term totaled only 2,000 homes, which represents only a very small faction of even the smallest program envisioned here. It is, essentially, a rounding error.
8. The Nigeria MDG Information System is an online portal providing location and attribute data for social infrastructure collected nationally in two rounds (2010 and 2014) led by the Office of the Senior Special Assistant to the President on the Millennium Development Goals (OSSAP-MDGs) for the purpose of ensuring "informed decision making and implementation in local, state and federal interventions aimed at achieving the MDGs." (nmis.mdgs.gov.ng)
9. The reason these percentages differ is because very small settlements make up a much higher percentage of the settlement count than they do of the household count.

Appendices

Appendix A: Least Cost Electrification Modeling

A key tool used in this planning approach is **NetworkPlanner**, the Sustainable Engineering Lab's (SEL) web-based geospatial electricity cost modeling and planning software.[1] The tool allows users to explore cost tradeoffs of different electricity technologies and create quantitatively rigorous costs and technical estimates for electricity planning. Application of the NetworkPlanner tool and approach typically includes three broad stages of work.

Step 1: Data Gathering and Preparation

The electricity planning effort begins with gathering and preparation of relevant geospatial, cost, demographic and economic data in collaboration with government, utilities, and other key practitioners and stakeholders. This includes geo-referenced population figures, data representing both the planned and existing electricity grid, and detailed costs of electricity inputs and equipment. These data serve as the basis for computation of the fixed and ongoing costs for the grid and off-grid systems. (See Appendices B-D for further detail on these data gathering efforts.)

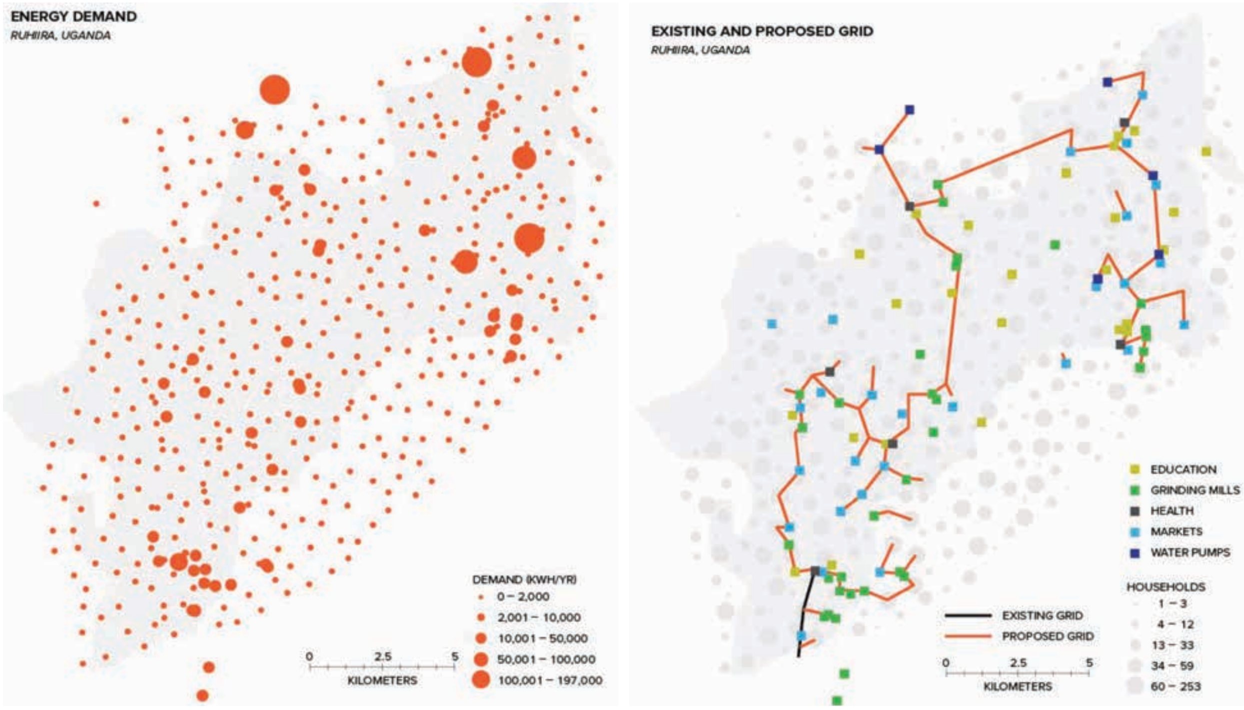
NetworkPlanner also draws upon other data types which may or may not have a spatial dimension but are essential for forecasting. The most important of these are electricity access rates, population growth rates, geographic information on urban versus rural areas, poverty and wealth data, and electricity demand values, particularly for the residential sector, which is typically the most important for questions of electricity access in under-served areas. These data must typically be combined in preparatory steps that utilize combinations of data, software skills, professional judgement and experience, and assumptions. (See the section Estimate of Current Grid Access in the body of this report, as well as Appendix D: Model Parameter Inputs for examples and details of this kind of data preparation.)

Step 2: Least-cost electricity grid and off-grid planning

Drawing upon the information obtained in the first step, the model then applies a range of user-defined parameters to project population, demand growth, and costs for power equipment independently for every point in the proposed system. It then performs a **least-cost comparison of on-grid, mini-grid, and off-grid electricity systems** for each settlement. The NetworkPlanner model first projects the expected population and electricity demand for each settlement, as shown by the Uganda example (Figure 19, left panel).

This is followed by a computation of technical system requirements to meet these electricity needs, as well as the fixed and recurring costs for electricity supply, for all points. Cost calculations are then made, **incorporating all initial and recurring costs over the long-term (30 years[2])** for all system types (grid, mini-grid, off-grid). The total costs (initial and recurring) for each point become the basis for the algorithmic identification of communities recommended for grid connectivity, as well as those locations for which mini-grid or off-grid (solar home system) is the least-cost option. Communities recommended for the grid are identified and the corresponding electricity network is mapped in Figure 19 (right panel). Finally, a cost-benefit analysis of all grid network segments considers the energy delivered (in kWh) compared to the total costs, and prioritizes segments that deliver more energy for lower investment. The result is a least-cost electricity plan. Locations where the grid is not recommended are instead assigned the least-cost non-grid alternative which may be mini-grid (typically diesel) or off-grid (typically solar photovoltaic home systems). For this analysis of

Figure 19 **Electricity demand points (L); proposed least-cost grid (R) (e.g. SW Uganda).**



the Kaduna Electric coverage area, these (very few) non-grid recommendations made by the Network-Planner software have been considered alongside a (much larger) component of isolated households and "transitional" off-grid connections.

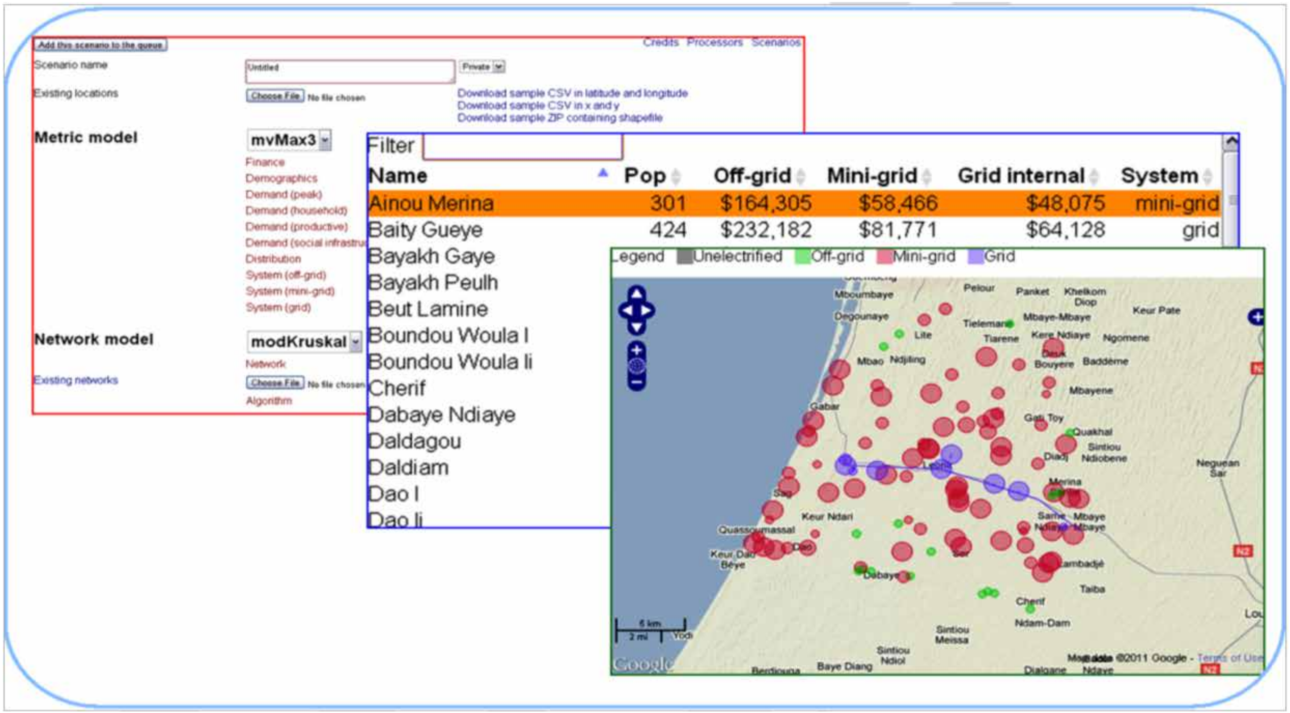
Key Metric: Meters of Medium-Voltage Line per Household (MV/HH)

Many costs related to electric power infrastructure are either the same for all households (e.g. the cost for a smart meter) or vary with electricity demand (the costs for transformers, solar panels, or a diesel engine). A key insight from and justification for geo-spatial electrification planning is that a few important costs related to electric grid infrastructure have a spatial dimension. The most important of these is the length of medium-voltage grid line required to connect communities, which creates a substantial cost differential between costs per households in dense / urban versus sparse / rural areas. The key metric this analysis employs to reflect this geo-spatial factor is ***meters of medium voltage line installed per household connection***, or **MV/HH** for short. MV/HH is a valuable metric, first, for understanding the cost-benefit trade-offs related to grid extension versus off-grid alternatives, and, second, for prioritizing grid extensions in a least-cost manner. In general, the medium-voltage line per household (MV/HH) is low in urban and peri-urban areas, reducing grid extension costs on a per household basis, and higher in remote and rural areas. When the metric MV/HH is used to select which communities should be reached by grid, and then to algorithmically determine the most cost-effective pattern of connections, the result is typically to concentrate connections and prioritize sequential extension within denser areas, which are lower cost, and continue onto more remote, less dense, higher cost areas.

Step 3: Data-rich outputs

NetworkPlanner provides data-rich reporting of results that can be the basis for detailed charts and maps. First, summary data and maps are presented immediately in the web-browser, allowing users to make rapid, high level assessments of outputs to guide decisions about revisions to subsequent model runs (Figure 20). For more detailed results, technical and cost data are provided in tabular format (comma separated variable) while map information

Figure 20 **Model summaries (data and maps) presented through a web browser format.**



is provided as shapefile outputs. These formats can be processed and revised locally according to specific project objectives.

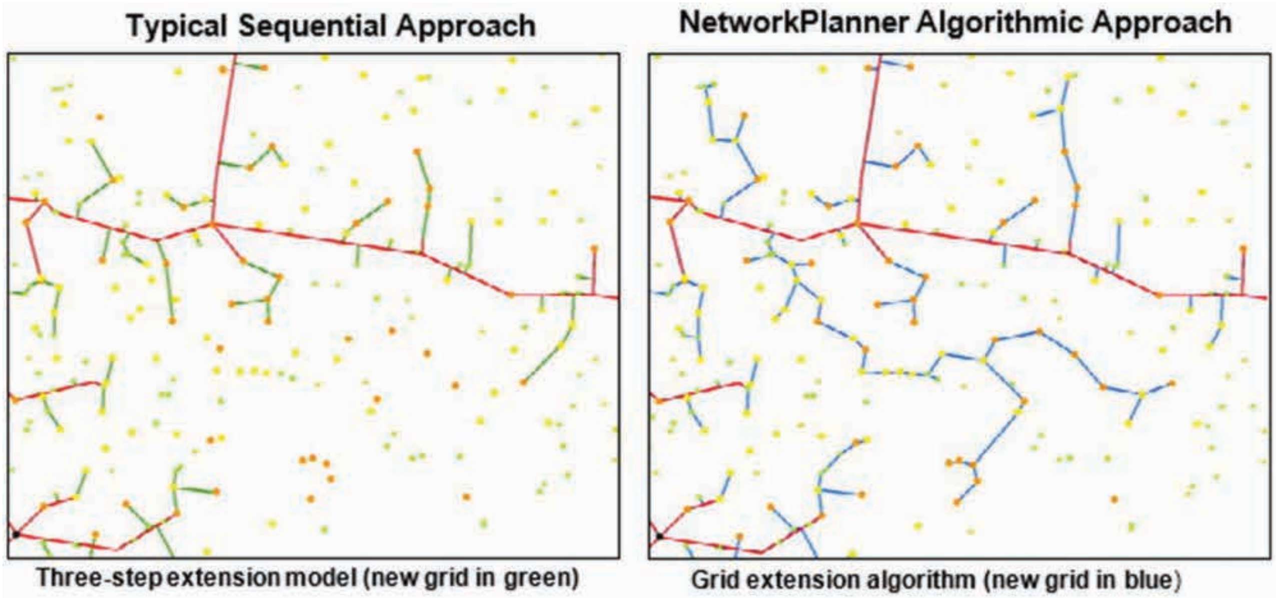
Benefits of the Geospatial, Data-Driven Approach

Despite the added computational steps, at a fundamental level, the analysis performed by this algorithmic is familiar to electrification planners and utility engineers: the software evaluates a combination of factors, including electricity demand, cost and distance from existing grid, to determine where grid extension is affordable. The key difference for a planner using the software is the increase in both the size of the datasets that can be considered, and the speed and scope of the analysis. Due a combination of factors—including a lack of detailed geospatial data, or difficulty in evaluating large datasets as a whole—most grid extension plans consider only incremental or "sequential" grid extension to connect locations near the existing grid, in a manner that cost-effective in the near term based on current infrastructure. In contrast, the NetworkPlanner model considers the entire set of populated places, however far from the grid, simultaneously and over a longer time horizon. The difference in the two approaches is captured in Figure 21.

The typical "sequential" approach looks for connections within a limited radius (usually 10–25 km) of existing MV lines. Longer extensions to major towns and cities are typically considered on an ad hoc basis, perhaps weighing political considerations and, most importantly, annual budgetary constraints. This limits the number of cost-effective opportunities, thus leaving large areas without grid access (see Figure 21, left panel). Non-grid options, such as mini-grids or solar home systems, tend to be considered in an ad hoc fashion as well. This approach is necessarily limited in scope, and neither grid or non-grid options are likely to be considered from a quantitatively rigorous, cost-benefit perspective, across the entirety of the un-electrified population. This tends result in slow progress toward universal electrification.

In contrast, the algorithmic approach taken by NetworkPlanner considers the dataset as a whole, allowing villages to be connected to neighbors according to the most cost-effective pattern of con-

Figure 21 Sequential versus algorithmic approaches to grid extension planning



nections over longer temporal and spatial scale. In effect the algorithm can evaluate not only where the grid is currently, but where it will expand in coming years. As a result, grid extensions typically reach further into un-electrified areas to connect larger villages that are cost-effective to serve, but distant from the current grid (see Figure 21, right panel). Meanwhile, areas that are not cost-effective for grid over the long term can be identified throughout the entire dataset, allowing planning for non-grid systems comprehensively, on a large scale.

The speed of the algorithm analysis also permits multiple model runs to be compared to determine sensitivity of the results to changes in different cost inputs, assumptions, and other factors. (Results of this approach are described in **Sensitivity Test – Variation in Household** Demand).

ENDNOTES

1. The system website (http://networkplanner.modilabs.org/docs/) offers details on the system, including sample datasets useful for training. This system has been upgraded to a more powerful, but less user-friendly version, accessible at: http://modelrunner.io/)
2. Thirty years is chosen as the duration for amortizing investments (2015–2045), not the duration of the electrification program, which is approximately 15 years (2015–2030).

Appendix B: Geo-located Data for Demands

Geo-located Settlements / Populated Places

The single most critical data type for effective electrification modeling is demand points, particularly residential demands. While it is obviously important that this dataset is both accurate and recent, ideally it will include five key additional characteristics:

1. **Geo-located:** All locations (settlements) include latitude and longitude coordinates, and these coordinates match visible settlements in satellite imagery.
2. **Include population information:** Preferably the data include both the population count and household number but one of the two will suffice; breakdowns by age and gender are not needed.
3. **Comprehensive:** The dataset should have as few geographic gaps as possible.
4. **High-resolution:** The location (settlement) points should include small towns and villages.
5. **Validated:** Depending on the users or clients for the electricity planning work, it is typically valuable, or even essential, to employ datasets or data source are approved or validated. For this reason, for electrification planning at the national level, government census datasets are typically favored. However, particularly when census data is scarce, out-of-date, or of low-resolution, datasets from multilateral development banks (World Bank, et al) and NGOs maybe be helpful as well.

For Nigeria, the starting point in searching for population data is the Nigerian National Population Commission (NPC). However, in the past, geolocated village level has not been possible to obtain from the NPC. Several other sources exist for geo-located settlements,[1] however these tend to lack accuracy, completeness, geo-location, or some other essential characteristic. Hence, SEL/EI has, with the support of the World Bank, sought different population data sources.

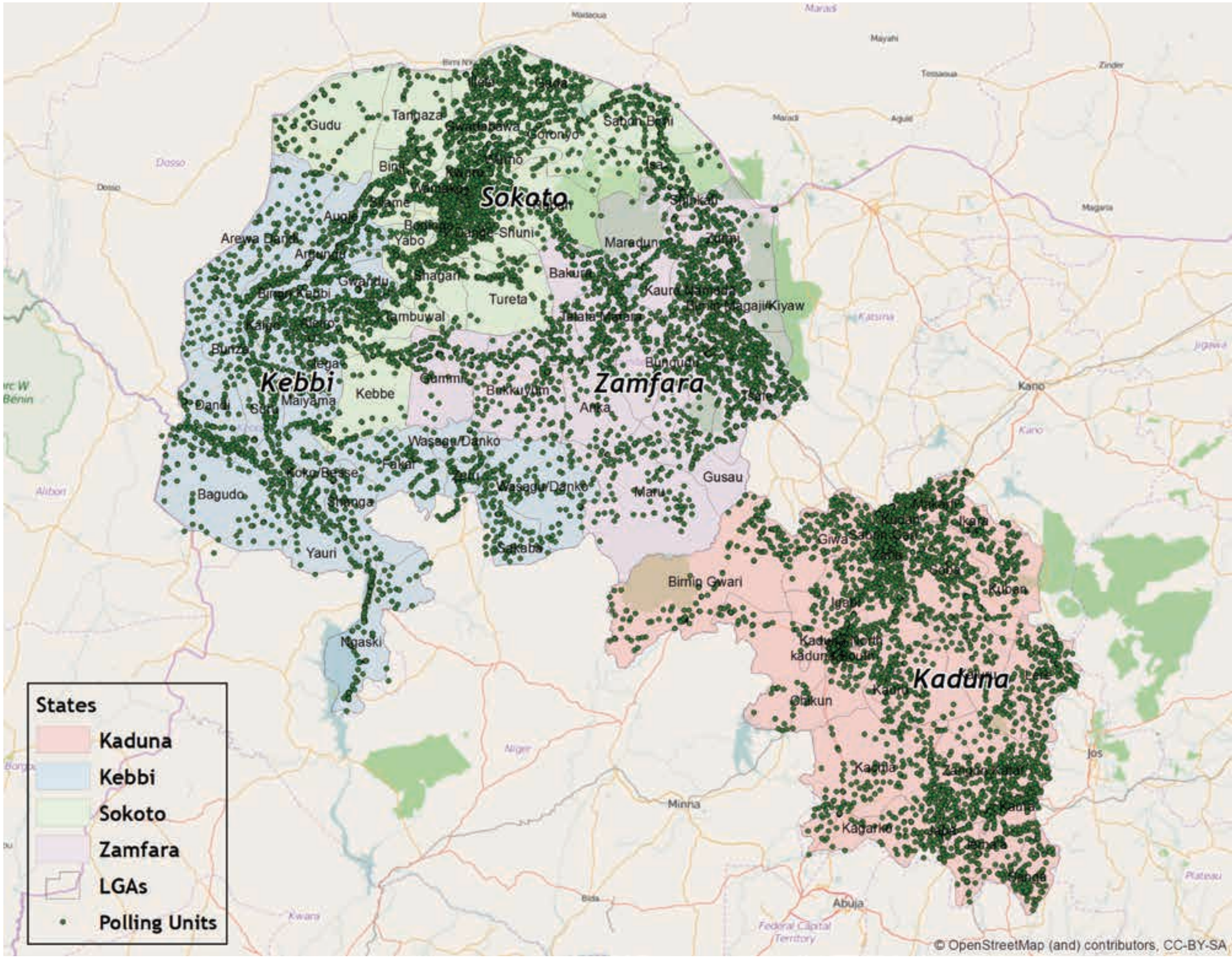
One important domestic source that merits attention is the national voter registry, created by the Nigeria Independent National Electoral Commission (INEC). Covering approximately 130,000 polling places and 8 million registered voters, is for various reasons currently the most promising government data source, despite the fact that it is not a population data source, per se. Discussions with researchers familiar with a wide range of geospatial datasets in Nigeria, combined with comparison of the INEC data with background satellite imagery, indicate advantages over other data sources in terms of the criteria listed above: INEC data includes lat/lon coordinates (geolocated) that match satellite imagery; it is fairly comprehensive, since most settlements have at least one polling unit (PU), PUs are very numerous, and maps show no prominent geographic gaps; INECT data is fairly high-resolution, since PUs typically serve between 500 and 1,500 registered voters; and the data comes from a rigorously validated government source (see Table 16 and Figure 22).

Still, there is at least one important caveat regarding this dataset: the smallest rural settlements often do not have polling places; instead, their voters are likely to be registered at polling places either in nearby villages or other central locations, such as a school. This is understandable given the cost and logistics of providing polling places to the smallest and most rural communities. However, it results

Table 16 Polling units and registered voters in Kaduna Electric area (INEC 2015)

State	Number of Polling Units	Number of Registered Voters	Average Number of Registered Voters per PU
Kebbi	2,397	1,478,388	617
Kaduna	5,101	3,417,079	670
Sokoto	3,035	1,671,898	551
Zamfara	2,515	1,502,349	597
Total	**13,048**	**8,069,714**	**618**

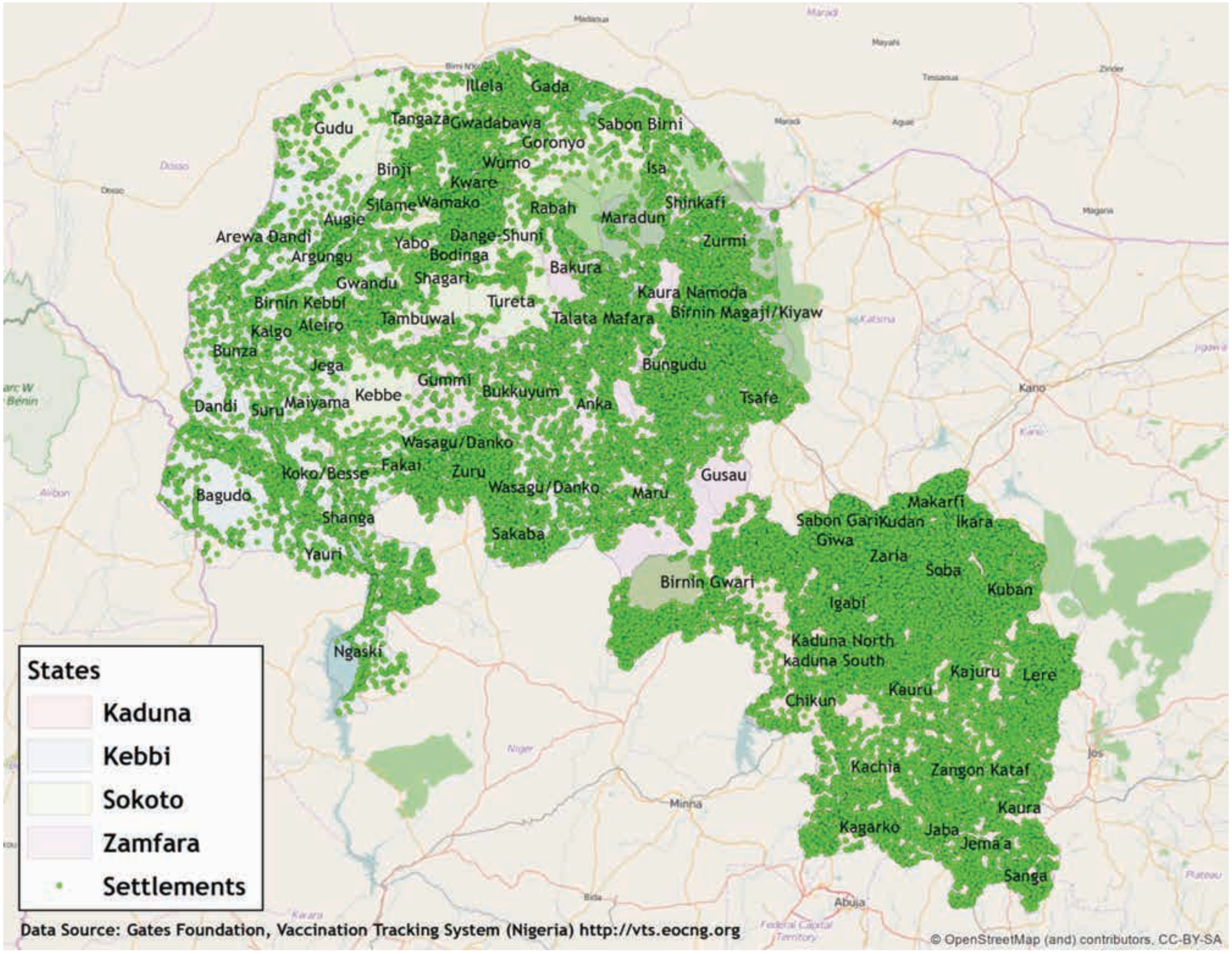
Figure 22 Locations of polling places for Kaduna Electric coverage area (INEC, 2015)



in an aggregation of the smallest settlements into nearby villages and towns, effectively preventing the smallest communities from being geo-located as distinct locations. The omission of the locations of smallest villages from the INEC dataset, and aggregation of this population into larger settlements, effectively "clusters" the population into larger rural agglomerations. This clustering of people reduces predicted cost of networked technologies and thus skews the model results toward grid and mini-grid recommendations, and away from solar home systems which tend to be more cost-effective for isolated households and communities.[2] For this reason, it is important to consider alternative data for populated places.

Another geo-located settlement dataset has been created for this project's target area (and soon to be extended to Nigeria as a whole) by the Bill & Melinda Gates Foundation, eHealth Africa and other partners. The data was collected as part of a Vaccination Tracking System (VTS) used to guide and validate polio-vaccination throughout the country.[3] This program combined GPS tracking and inspection of satellite imagery to create a dataset with locations for each settlement (including small hamlets) in each ward (see Figure 23). This resulted in a much more detailed and higher-resolution dataset than the INEC polling unit data, since the VTS/Gates Foundation dataset includes about 31,865 settlements in total for the four states,

Figure 23 **Gates Foundation settlement data for Kaduna Electric service area.**



more than double the number of points in the INEC data.

Figure 24 shows a direct comparison of the VTS / Gates Foundation dataset (green points) with the INEC data (red points) for a low-density area within Kaduna state.

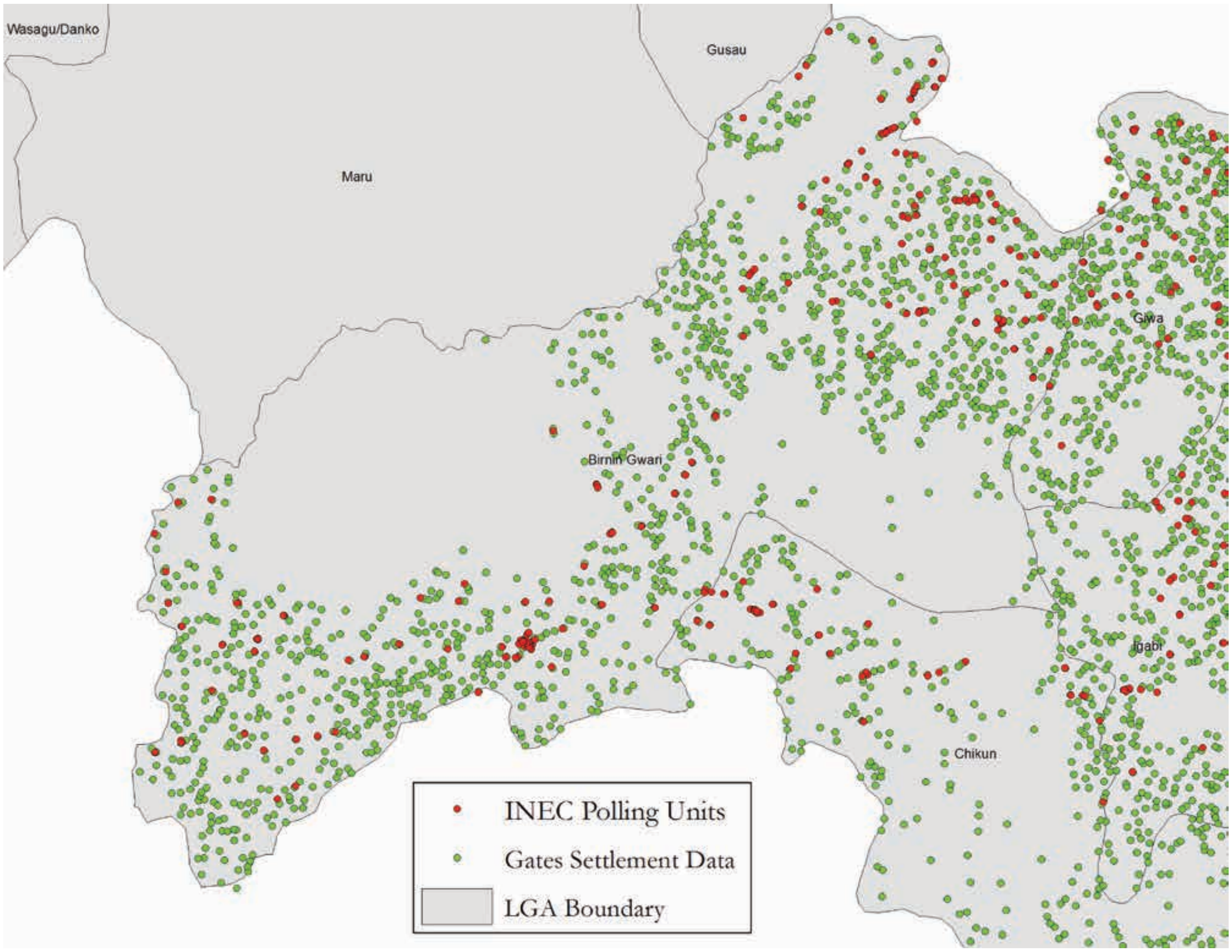
Figure 25 shows a similar comparison at a finer scale, presenting the VTS/Gates Foundation data alongside with the INEC data for polling units against a satellite image background. This comparison shows 5–10 times the number of settlements in the VTS/Gates Foundation data. The satellite background also helps to confirm that the VTS/Gates Foundation data includes true settlement locations.

Primarily because of its higher resolution, the SEL/EI team's planning work used the Gates Foundation data as its base layer for populated places. This is the most important way that the methodology used for the NEAP-2 analysis (for Kaduna Electric) will differ from the NEAP-1 analysis (for Kano Electric).

There was a few "data cleaning" steps for the VTS/Gates Foundation data:

- There are 1836 points in the VTS/Gates Foundation settlement data without population (out of 31,773 settlements, that is, ~5–6% of the settlement points, though not the same percentage of the population).

Figure 24 **Comparison of INEC 2015 and VTS/Gates Foundation data (Kaduna State).**



- Some of these were duplicates. When duplicates were found, SEL/EI selected the larger of the two population values for the duplicated point.
- Remaining points with zero population were included in the model runs, and these generally result in unelectrified points, since they have no residential demand (though those with education or health facility demand will be given an electrification recommendation from the model).

Other Geo-located Demand Points

An important aspect of the NEAP-2 project is electrification planning for non-residential demands. The Nigeria MDG Information System (NMIS) provides a source for this data for locations of education and health facilities for the Kaduna Electric service area, as show in Figure 26.

The number of education and health facilities, nearly 15,000 in total, are provided by state and for the Kaduna Electric service area as a whole in Table 17.

Figure 25 Satellite imagery shows greater accuracy of VTS/Gates data relative to INEC.

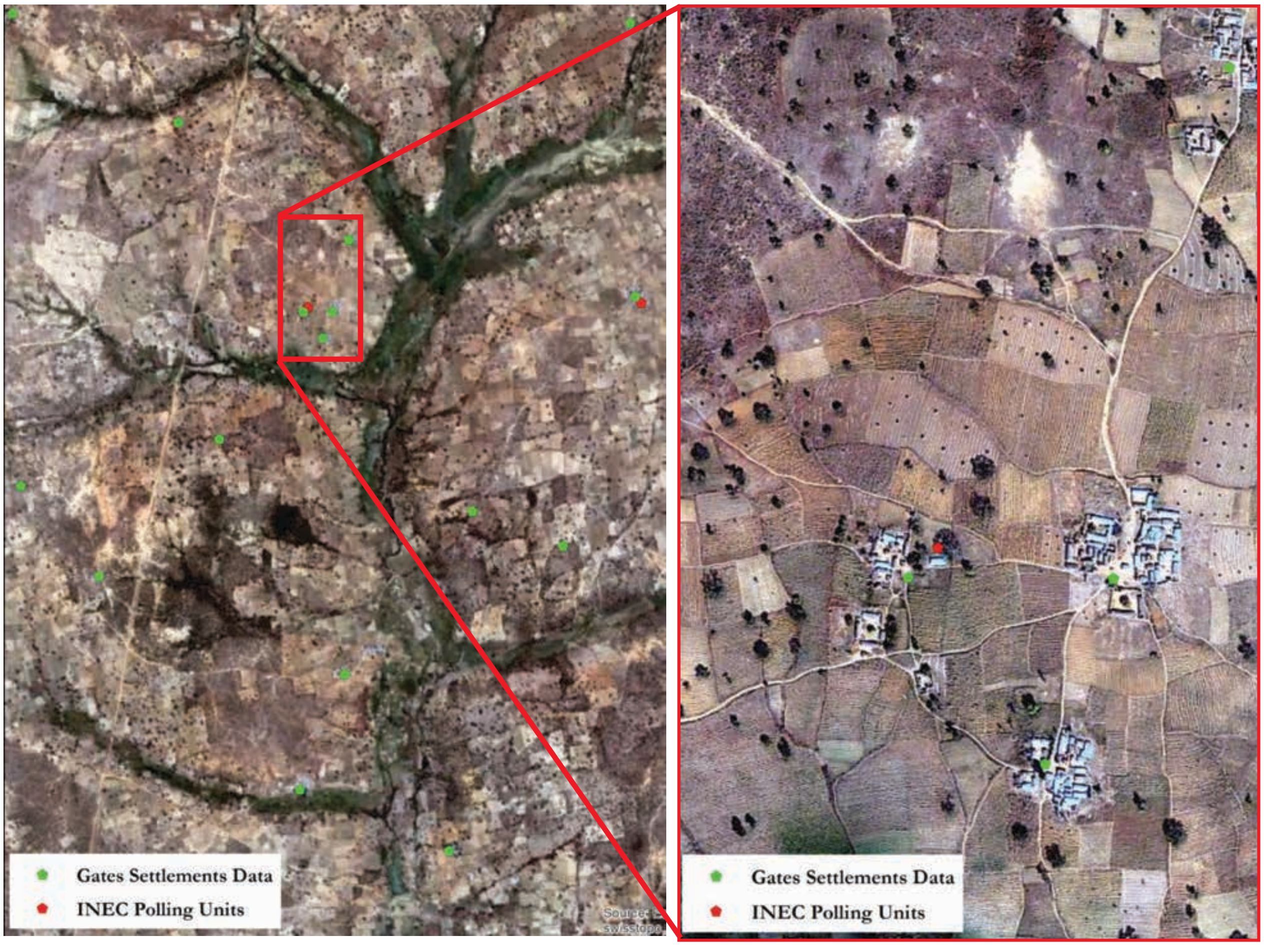


Figure 26 NMIS location data for schools and clinics (nmis.mdgs.gov.ng).

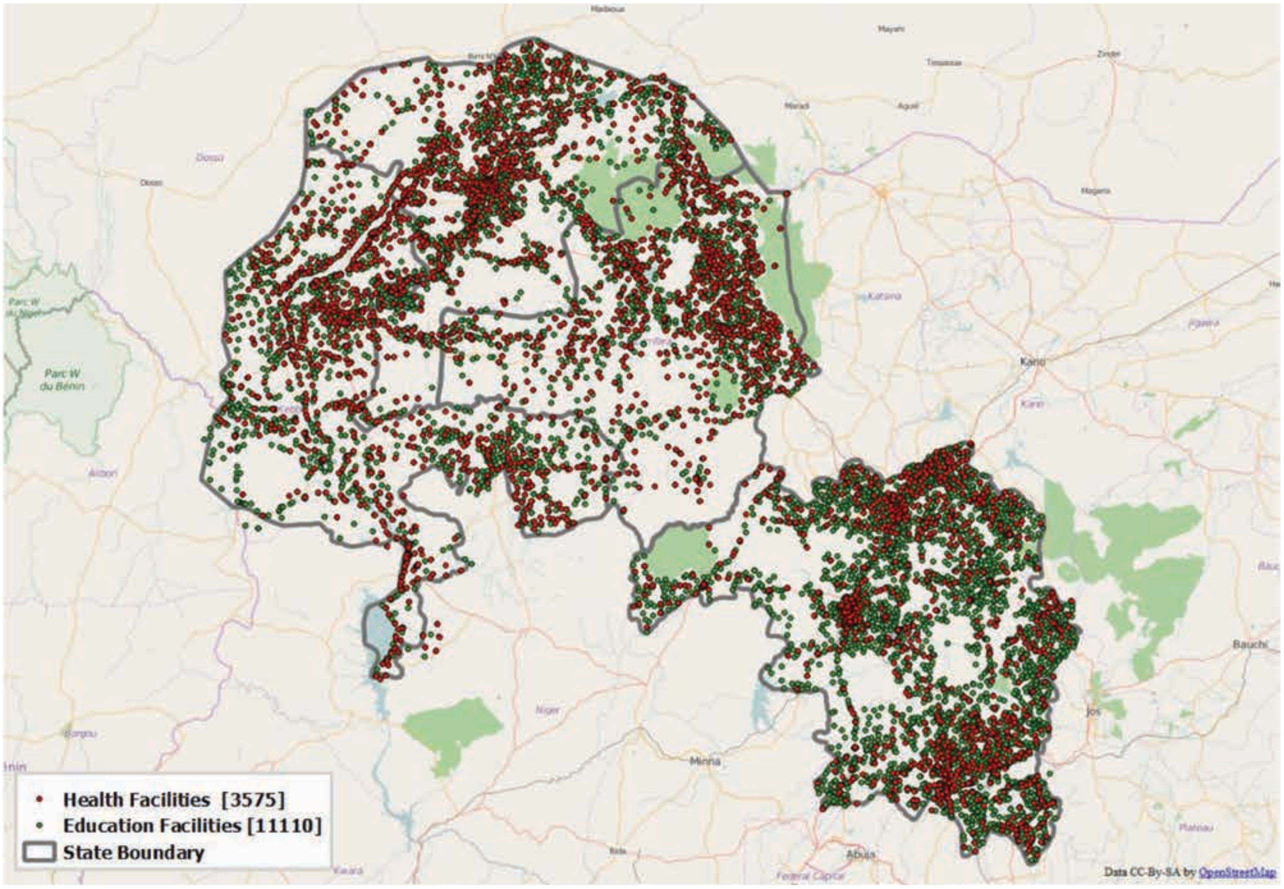


Table 17 Education and Health Facilities in the Kaduna Electric Service Area (NMIS)

	Facility Count		
	Education	**Health**	**Combined**
Kaduna	4,881	1,248	6,129
Kebbi	2,019	821	2,840
Sokoto	2,284	764	3,048
Zamfara	1,926	742	2,668
Total	**11,110**	**3,575**	**14,685**

ENDNOTES

1. These were listed in the proposal, and include: NIMA, City Population, Global Gazetteer, AfriPop, WorldPop and Landscan.
2. This issue with the limited resolution of INEC data required a fairly complicated supplementary effort to estimate a correction, a factor of two increase, in the medium voltage grid line lengths recommended by a similar modeling effort undertaken in 2015 for the Kano Electric Distribution Company (KEDCO) project area, also funded by the World Bank.
3. http://www.gatesfoundation.org/, http://www.ehealthafrica.org/, http://vts.eocng.org/

Appendix C: Grid Line Mapping and Related Training

Along with geolocated demand points, the next most important data type for electrification modeling is **geo-referenced data for electricity infrastructure, primarily the existing—and planned, if possible—medium-voltage (MV) distribution network and related equipment.** As of project launch the primary utility partner, Kaduna Electric, had limited GIS based data about the existing MV line. Discussions between Kaduna Electric and SEL/EI concluded that the best approach to fill this geo-referenced data gap would be a grid data gathering effort combining field mapping with smartphones with a web-based data management platform.

Two key criteria have guided data acquisition for this project. First is the accuracy criteria for geo-referenced information suitable for the sort of "planning grade" study covered by this TA: grid line and point demand maps must be sufficiently accurate to determine which locations have access and which do not, as well as the distance between locations. Given the small size of many communities in rural areas, a rough guideline is that these maps should be at a spatial resolution of perhaps 100 or 200 meters, or higher accuracy if possible, but not essential. In contrast, "design grade" geospatial information may require accuracy to the sub-meter scale, in order to properly position every transformer, pole, or other key piece of equipment. Since this TA focuses on broad cost and technical planning, but not design, high accuracy at sub-meter is not needed.

Second is the definition of "medium voltage" infrastructure: This typically includes only 11 kV and 33 kV distribution lines in Nigeria, and additionally substations and transformers that provide power to or from these distribution lines. It is important to note that both high voltage transmission lines (132 kV and above)[4] and low voltage (0.415 and 0.220 kV) distribution lines are not mapped for this access planning work and so are outside the scope of this TA. However, the utility could easily adapt and use the same set of mapping tools and techniques for which SEL/EI has provided training to map other features and infrastructure as well. The details of this data gathering are discussed in subsequent sub-sections.

Training for MV mapping with smartphones, laptops & open-source software

Prior to the MV line mapping training, SEL/EI team provided Kaduna Electric with guidance for purchase of GPS-enabled android smartphones and laptops suitable for mapping and data editing. The training plan was to train in two phases: first, train a "core" group of around 10 Kaduna Electric staff intensively so that they could the following week, and under SEL supervision, train a larger group of 24–30 staff (2 from each of 8 area offices). The rationale was to ensure that Kaduna Electric would be prepared to increase the size of the training team as needed without the need for additional training directly from the SEL/EI team. In early December 2015, the SEL/EI team provided a training following this two-phase approach in Kaduna, Nigeria, to approximately twenty-six utility staff. The training prepared the utility for field data gathering followed by editing of medium voltage line data. The core group training took place at the Kaduna Electric headquarters from Wednesday December 9th to Sunday December 13th, and the full training was taken at the same location from Monday December 14th to Friday December 18th.

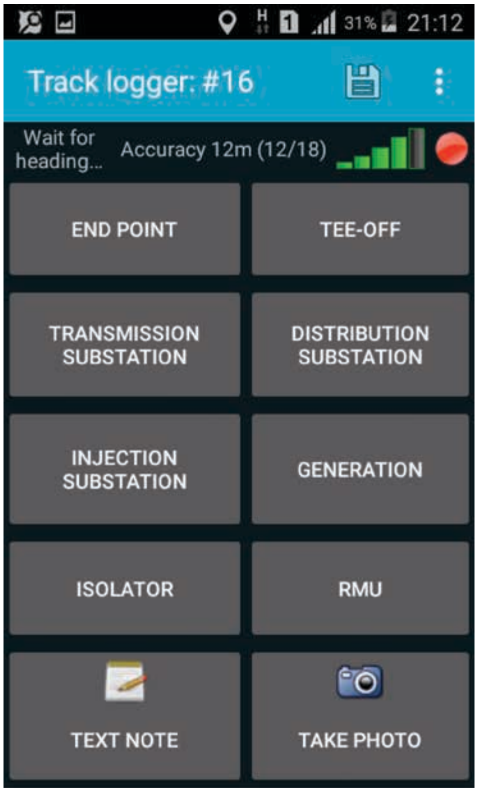
The basic modules that were covered during the training area are as follows:

1. Installation and Configuration of Android Apps
2. How to Use the OSMTracker App for MV Line Mapping
3. Walking Practice Using the OSMTracker App
4. Field Practice of MV Line Mapping in vehicles
5. JOSM Installation and Configuration
6. Review of Raw GPX Data Collected via OSMTracker in JOSM
7. Extra field Practice of MV Line Mapping in Vehicles
8. Advanced JOSM Editing and Validation of MV Line data
9. Upload/Download Data to/from <kaduna.gridmaps.org> server
10. Review of MV Line Mapping Process and Schedule of Future Mapping Effort

Week 1: Core Team Training – Wednesday December 9th to Sunday December 13th

SEL/EI began the core team training with a brief introduction by Edwin Adkins (SEL/EI Project Manager) of geo-spatial planning methodology and objective, as well as data collection requirements for this World Bank funded scope of work. This introduction helped Kaduna Electric arrange logistics for the training accordingly in terms of vehicles, equipment and personnel. Also, it was useful to better inform the Kaduna Electric management of what the overall project entailed.

Figure 27 Customized OSMTracker layout (L); Kaduna Electric staff in field training (R)



Then, SEL/EI trainer Naichen Zhao led training for the core group in how to install and configure the new phones that Kaduna Electric had purchased with OSMTracker app, as well as how to use different features, settings and layouts on the app that are needed for mapping the MV lines. The SEL/EI approach employs smartphones equipped with a modified version of OSMTracker app, with a visual layout customized for gathering the MV line and related equipment. This layout was customized, based on discussions with Kaduna Electric engineers, to include the specific equipment that Kaduna Electric found most important: distribution substations (transformers), injection substations, isolators, ring main units (RMU), generation sites, end points and tee-offs. (see Figure 27). This layout was shared with participants and installed on the smartphones.

The next two days were divided between OSMTracker practice (first walking, then in vehicles) followed by transfer and editing of collected data. Mapping practice during the early part of each day allowed trainees to become familiar with using the app in the field, including the sequences of screens, buttons and layouts as well as how to properly note attribute information such as names and ratings for feeder lines and transformers, or types for other equipment, such as switches.

The latter half of each day was spent working with Java OpenStreetMap Editor (JOSM), an open source geospatial data editing application that runs on laptop and desktop computers and facilitates the editing and cleaning of raw data collected by OSMTracker to create a clean, integrated and consistent grid line dataset. Editing raw field data with JOSM follows these steps:

- Transfer the files: Import raw GPX tracks (the output format of OSMTracker app) from the android smartphone to the computer running JOSM; archive / store the raw files on the phone and computer.
- Using JOSM, covert the raw GPX tracks to an editable data format
- Iteratively apply several editing actions:

Figure 28 **SEL/EI JOSM training and editing sessions (with support from KEDCO staff).**

    - Simplify and correct complicated or inaccurate MV line tracks to create clear lines
    - Confirm accuracy of the edited lines with knowledgeable engineers using background satellite imagery or map as reference
    - Correct or assign attribute information to lines and points (e.g. ratings, names)
    - Combine feeders and branches (tee-offs) that were tracked separately to integrate individual tracks into a connected, unified grid files.
- Validate and upload completed grid lines to a password-protected website (kaduna.gridmaps.org) which provides a comprehensive view of all data collected, allowing collaborative planning and assessment of MV line tracking process in field.

As with the OSMTracker app, a group of settings (or "presets") in JOSM were customized for ensure that the editing process assigned the specific attributes that Kaduna Electric wanted to record for each map feature. This customization occurred throughout the week, in discussion with Kaduna Electric staff.

Week 2: Full Team Training — Monday December 14th to Friday December 18th

Throughout the following week two additional engineers from each of the 8 area offices joined the group, for a total of 16 new trainees. The "core" team members took the lead in training, both by presenting to the group and by directly assisting the new trainees with support by SEL/EI team. This gave the "core" team experience in training and troubleshooting while allowing the SEL/EI team to observe, support and confirm the team's capacity to train others as well as to make a preliminary assessment of the pace of data gathering and JOSM editing, including setup of the software. Each pair of engineers from one regional office was supported by one member of the "core" group trained the previous week, usually the ICT staff member from the same area office, forming a small team of 3. The 16 new field engineers were trained to use OSMTracker and gained practical experience with MV line mapping. This MV line tracking practice provided a preliminary baseline for measuring the capacity of core Kaduna electric team to train others.

In last two days of full team training, SEL/EI split the team to give new trainees more practice on OSMTracker app for MV line mapping and provide the "core" group with additional training and advanced skills in JOSM editing.

SEL/EI concluded the full team training after each of core team member demonstrated the ability to train others how to edit, validate and upload a clean set of dataset to the webserver. This was then followed by a brief review of the entire process from installation and configuration of both the OSMTracker app and JOSM, and all the steps from loading MV line data in JOSM through submitting a clean and validated data, as well as how to geo-tag photos in JOSM.

Figure 29 SEL/EI training: smartphones in the field (L); JOSM in the classroom (R)

Estimated Timeline for MV Line Mapping

Logistics for field tracking—essentially the allocation of vehicles and staff—was the critical determinant of costs and time-labor commitment by Kaduna Electric for field mapping. Results of past field tracking experience in the Kano service area (under NEAP-1), as well SEL/EI experience in other countries, combined with some assumptions about the speed for mapping different line types (see Table 18), allowed the Kaduna Electric/SEL team to estimate the time required for the overall mapping effort (see Table 19). In both tables, the values in the blue cells show the best-guess estimate of the duration of total grid mapping, which is expected to be about 7 total weeks of work, with about 16 teams conducting mapping on alternate days (two teams from each Kaduna Electric office).

Table 18 Assumptions about the rate of MV line mapping

NB: changes in these assumptions strongly affect the total time budget for the overall mapping program			
Line type	**km per team-day (slow)**	**km per team-day (average)**	**km per team-day (fast)**
11 kV (urban)	5	12.5	20
33 kV (rural)	50	100	150

SEL/EI Validation Support

Figure 30 illustrates a means of approximate validation of the MV grid mapping effort. The map shows results from a national survey of social facilities conducted in 2012/13 then updated in 2014 (as part of the SEL/EI's NMIS project) in which *yellow points represent those health and education facilities that reported having a grid connection*. The map also shows green and red lines representing the MV grid lines recently mapped by Kaduna Electric. The image background shows "nightlights" data (light emitted from cities and other primarily anthropogenic light sources from the earth's surface at night and recorded by orbiting satellites). A visual comparison between these types of information shows that most of the facilities that reported having a grid connection (yellow points) appear very near to mapped MV grid (green or red lines), thus offering independent confirmation of the accuracy and near-completeness of the Kaduna Electric mapping effort. However, some areas, highlighted with orange ovals, show places where multiple facilities reported having a grid connection, yet no grid had at this point been mapped nearby by the utility. Though inexact, this validation method indicates mapping of 95% of the MV grid, while providing SEL/EI and Kaduna electric with ideas of what may be gaps in the mapping effort.

Follow-up efforts between the mapping managers at Kaduna Electric headquarters and field offices from which staff were conducting field mapping identified two reasons for these apparent gaps. In as many of half of these cases some additional

Table 19 Estimated Duration for MV line mapping for the Kaduna Electric system

Line type	Km	Slow Pace			Average Pace			Fast Pace		
		Team-days (one team)	**Total Days** (all teams, non-stop)	**Total Days** (all teams, alternate days)	**Team-days** (one team)	**Total Days** (all teams, non-stop)	**Total Days** (all teams, alternate days)	**Team-days** (one team)	**Total Days** (all teams, non-stop)	**Total Days** (all teams, alternate days)
11KV Lines	2,706	541	34	68	216	14	27	135	8	17
33KV Lines	8,269	165	10	21	83	5	10	55	3	7
Total (11 & 33 kV)	**10,975**	**707**	**44**	**88**	**299**	**19**	**37**	**190**	**11.9**	**24**
Work Days per Week			**5**	**5**		**5**	**5**		**5**	**5**
Total Work Weeks			**9**	**18**		**4**	**7**		**2**	**5**

Figure 30 Orange ovals show facilities that reported grid access (NMIS) but no grid was mapped (Kaduna Electric).

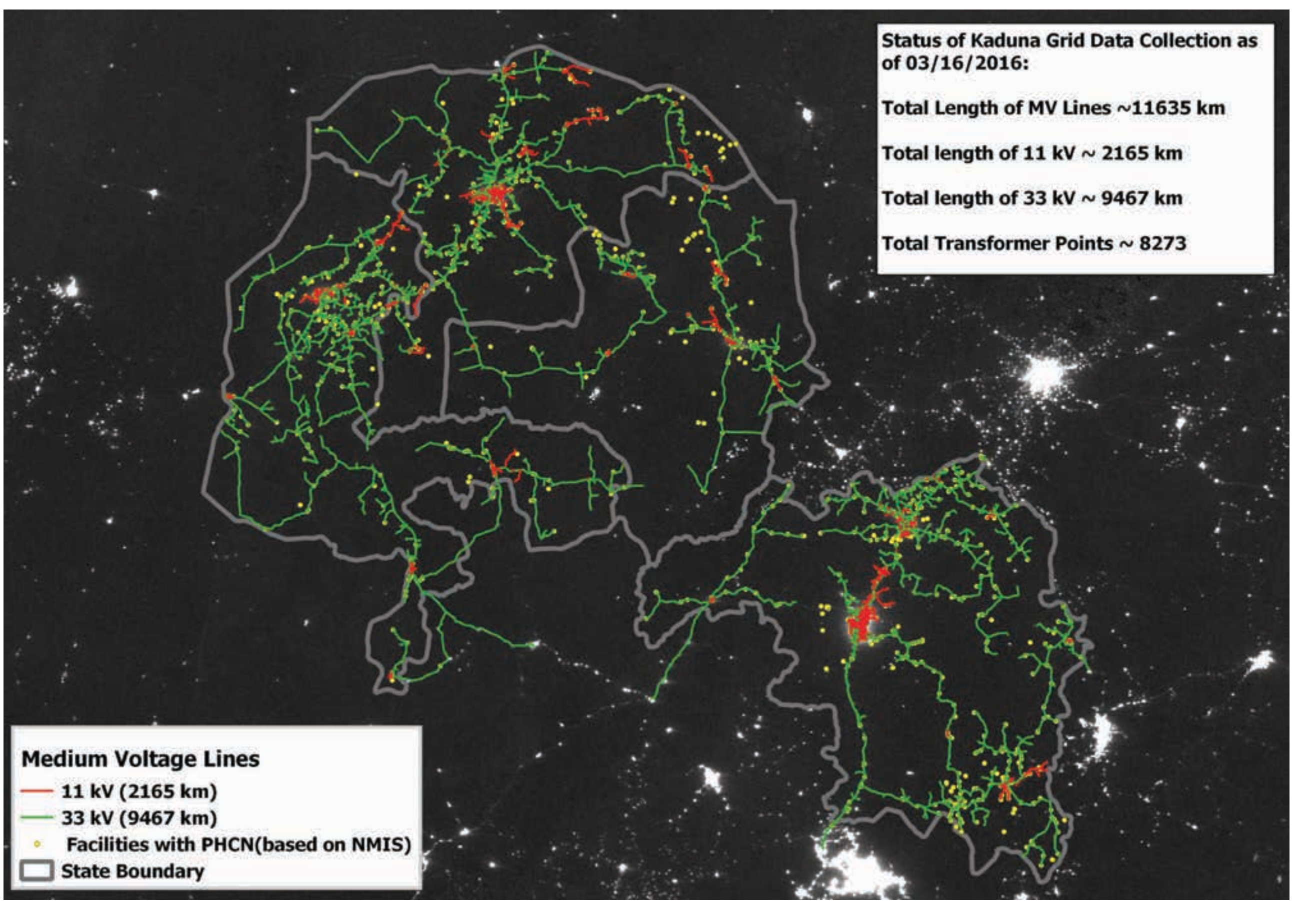
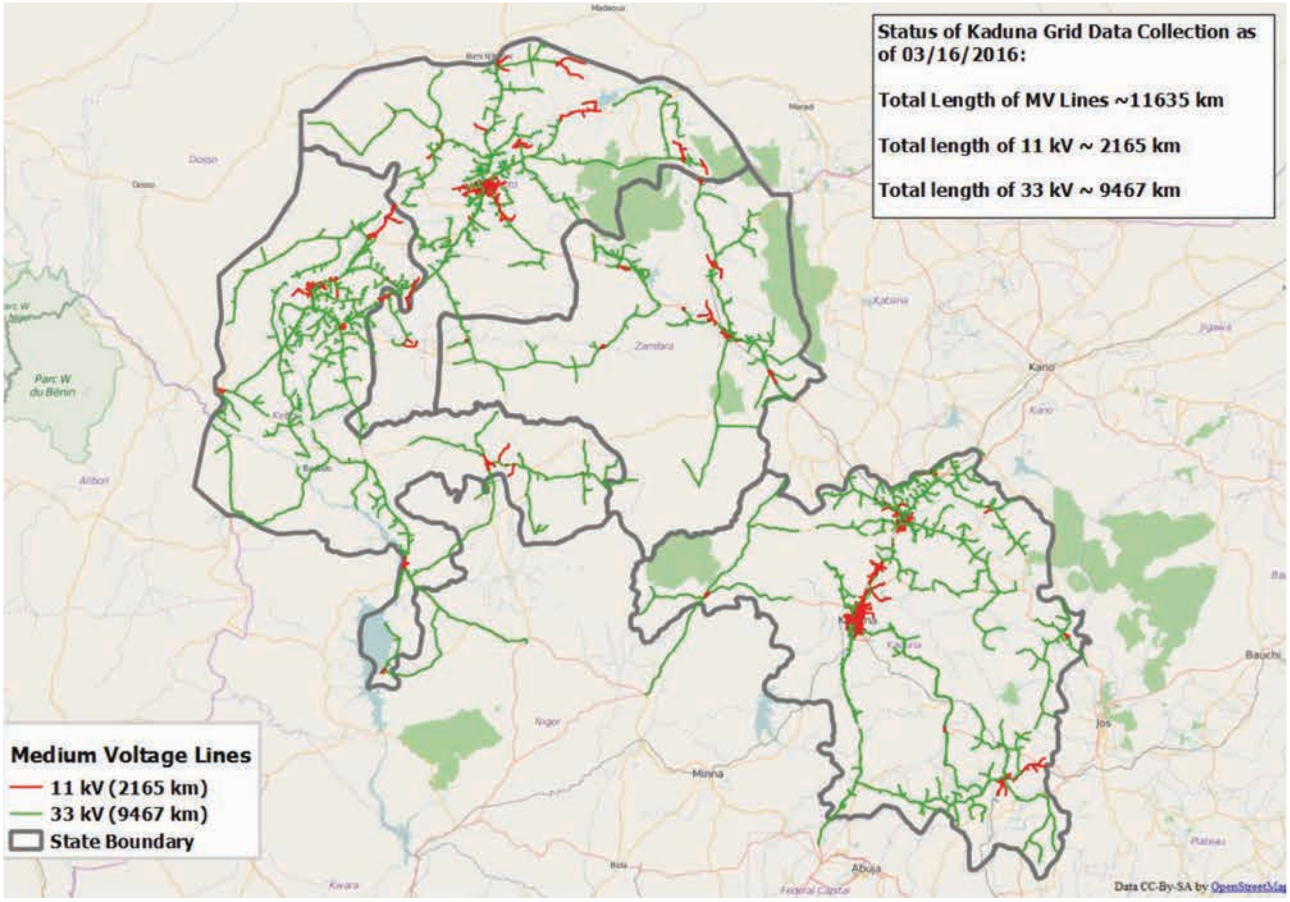


Figure 31 **11 kV and 33 kV lines mapped by Kaduna Electric (Mar. 16, 2016)**



field mapping or data editing remained to be done; in other cases, it appears that reports of social infrastructure connections to grid may either have been incorrect, or the lines may have been removed due to prolonged service interruptions.

Results of Kaduna Electric's grid mapping program

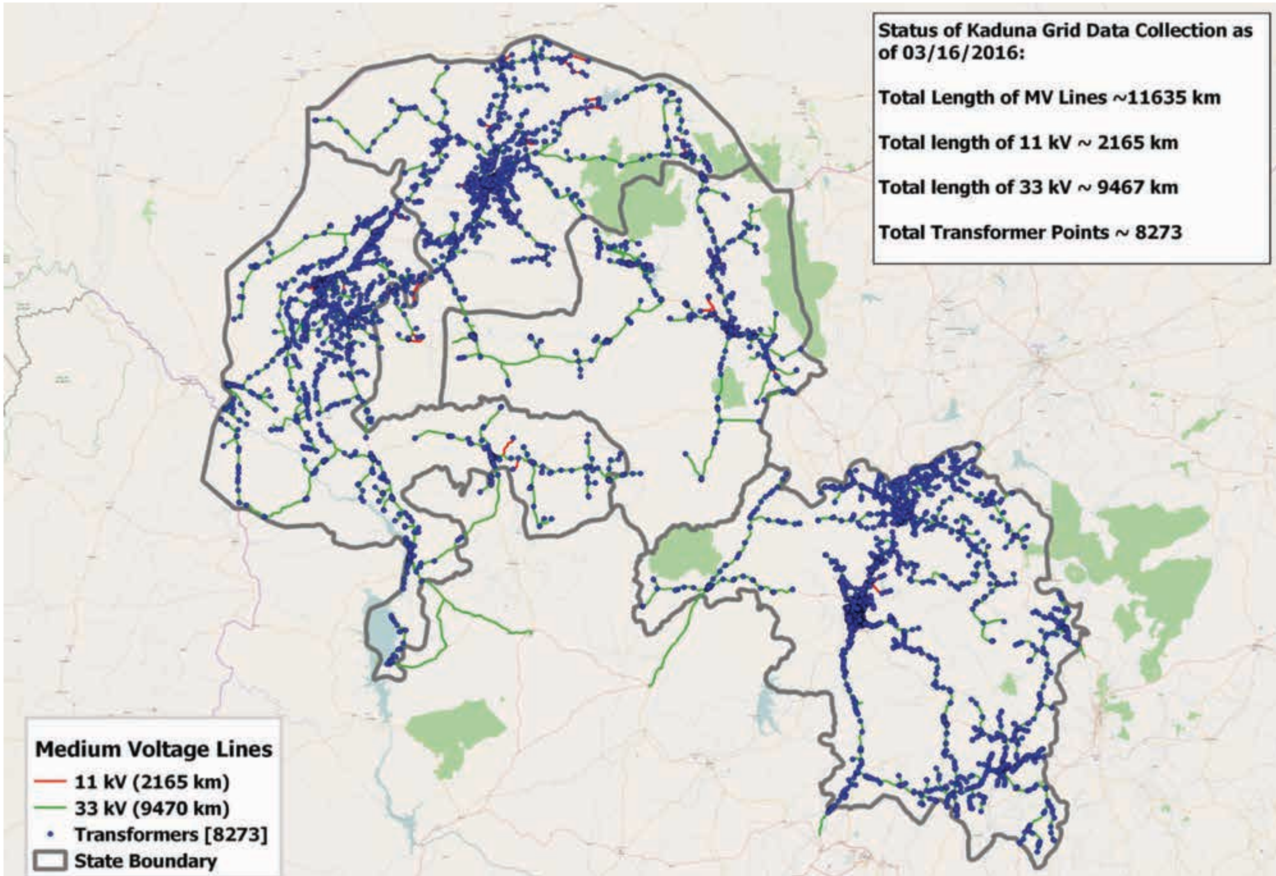
As of March 16, 2016, Kaduna Electric mapped a total of 11,635 km of MV lines (see Figure 31). The duration of mapping was very close to two calendar months, and with about 20 working days per month, this suggests that Kaduna Electric has achieved ~95% or more of its mapping in about 35–40 total work days for the utility as a whole.

This is in good agreement with our "average" mapping pace estimate (the blue columns in Table 19), which yielded an estimate of 37 total work days for the utility. Of these lines, over 2,100 km are predominantly urban 11 kV and nearly 9,500 km are predominantly rural 33 kV. In addition, the Kaduna Electric team has also mapped nearly 8,300 transformers (distribution substations) substations (see Figure 32).

Overall, the medium voltage grid system mapping was a successful and commendable effort by the Kaduna Electric utility and its field staff. Not only was the effort undertaken quickly and completed rapidly, but the results appear comprehensive and accurate.

Looking ahead, the utility recognizes the value of the map that has been created (for planning, operational, and other purposes) but also plans to extend this sort of mapping work, and other GIS-related

Figure 32 **Transformers mapped by Kaduna Electric (Mar. 16, 2016)**



tools and techniques, into other areas of the utility for improved management and planning.

ENDNOTES

1. Geo-located data for high voltage lines and generation sites, although not strictly the focus of this study, can be very useful in planning the system more broadly, to, for example, evaluate where higher voltage facilities may be placed to serve the MV grid.

Appendix D: Model Parameter Inputs

After demand points and MV grid line information, the third essential data category needed for grid and off-grid system modeling is an assortment of parameters for projecting populations forward in time, estimating demands for a variety of points, specifying the technical details of systems to meet these needs, and assigning a cost to each technical option. The NetworkPlanner modeling framework uses over 70 different parameters related to population and economic growth; financial variables like interest rates; electricity demand; initial and recurring costs as well as technical specifications for a wide assortment of grid and off-grid electricity system technologies; and other variables as they arise.

Table 20 Full list of NetworkPlanner Cost and Technical Parameters

Category	Parameter Omits unused / null values	Parameter (July 2016)	Source 1 Kaduna Electric 2 Market Research 3 World Bank Data 4 default value / int'l comparison Others are noted explicitly
demand (household)	household unit demand per household per year	Range, by location, (600–1800 kWhy/yr)	3, WB poverty data; night lights (Urb/Rur)
demand (household)	target household penetration rate	1	3, ToR / World Bank
demand (peak)	peak demand as fraction of nodal demand occurring during peak hours (rural)	0.4	4
demand (peak)	peak demand as fraction of nodal demand occurring during peak hours (urban)	0.4	4
demand (peak)	peak electrical hours of operation per year	1460	4
Demographics	mean household size (rural)	6.8	3
Demographics	mean household size (urban)	6.5	3
Demographics	mean inter-household distance	15 m urban, 30 m rural	1
Demographics	population count	by location	VTS/ Gates Foundation
Demographics	population growth rate per year [a]	0.0121 (rural), 0.0467 (urban)	3
Demographics	urban population threshold	by location	Night lights
Distribution	low voltage line cost per meter	$11.5	1
Distribution	low voltage line equipment cost per connection	Urban $295, Rural $316	1
Distribution	low voltage line equipment operations and maintenance cost as fraction of equipment cost	0.01	1
Distribution	low voltage line lifetime	50	1
Distribution	low voltage line operations and maintenance cost per year as fraction of line cost	0.01	1
Finance	interest rate per year	0.07	4
Finance	time horizon	2~15 yr pop. growth ~30 yr recur. costs	ToR 4
system (grid)	available system capacities (transformer)	range (50 kVA min)	1

(continued on next page)

Table 20 **Full list of NetworkPlanner Cost and Technical Parameters *(continued)***

Category	Parameter Omits unused / null values	Parameter (July 2016)	**Source** 1 Kaduna Electric 2 Market Research 3 World Bank Data 4 default value / int'l comparison Others are noted explicitly
system (grid)	distribution loss	15%	1
system (grid)	electricity cost per kilowatt-hour	$0.075;	1
system (grid)	installation cost per connection	$0 (incl. in LV equip)	1
system (grid)	medium voltage line cost per meter	$12.9 urban, $14.3 rural	1
system (grid)	medium voltage line lifetime	50	1
system (grid)	medium voltage line operations and maintenance cost per year as fraction of line cost	0.01	1
system (grid)	transformer cost per grid system kilowatt	$35 urban, $40 rural	1
system (grid)	transformer lifetime	15	1
system (grid)	transformer operations and maintenance cost per year as fraction of transformer cost	0.03	1
system (mini-grid)	available system capacities (diesel generator)	Range (60 kVA min)	1
system (mini-grid)	diesel fuel cost per liter	$0.67	1
system (mini-grid)	diesel fuel liters consumed per kilowatt-hour	0.5	4
system (mini-grid)	diesel generator cost per diesel system kilowatt	$150	4
system (mini-grid)	diesel generator hours of operation per year (minimum)	2190	1
system (mini-grid)	diesel generator installation cost as fraction of generator cost	0.15	1
system (mini-grid)	diesel generator lifetime	5	4
system (mini-grid)	diesel generator operations and maintenance cost per year as fraction of generator cost	0.1	1
system (mini-grid)	distribution loss	0.08	1
system (off-grid / SHS)	available system capacities (diesel generator)	range (60 kVA min)	1
system (off-grid / SHS)	available system capacities (photovoltaic panel)	1.5, 1.0, 0.4, 0.15, 0.075, 0.05	4
system (off-grid / SHS)	diesel generator hours of operation per year (minimum)	2190	1
system (off-grid / SHS)	peak sun hours per year	2007.5	2
system (off-grid / SHS)	photovoltaic balance cost as fraction of panel cost	2	4
system (off-grid / SHS)	photovoltaic balance lifetime	10	4
system (off-grid / SHS)	photovoltaic battery cost per kilowatt-hour	150	2
system (off-grid / SHS)	photovoltaic battery kilowatt-hours per photovoltaic component kilowatt	8	4

(continued on next page)

Table 20 Full list of NetworkPlanner Cost and Technical Parameters *(continued)*

Category	Parameter Omits unused / null values	Parameter (July 2016)	Source 1 Kaduna Electric 2 Market Research 3 World Bank Data 4 default value / int'l comparison Others are noted explicitly
system (off-grid / SHS)	photovoltaic battery lifetime	4	1
system (off-grid / SHS)	photovoltaic component efficiency loss	0.35	4
system (off-grid / SHS)	photovoltaic component operations and maintenance cost per year as fraction of component cost	0.05	4
system (off-grid / SHS)	photovoltaic panel cost per photovoltaic component kilowatt	800	2
system (off-grid / SHS)	photovoltaic panel lifetime	20	4

Note:
[a] Population growth modeling used values provided by NBS/CBN/NCC Social-Economic Survey, 2010, modified to fit two timelines: a timeline of ~15 years to project population from 2015 to 2030, and 30 years for recurring costs (a widely accepted duration for amortization of loans and for major infrastructure investments (grid lines, generation equipment, etc.).

This section addresses a few broad categories of parameters and their sources.

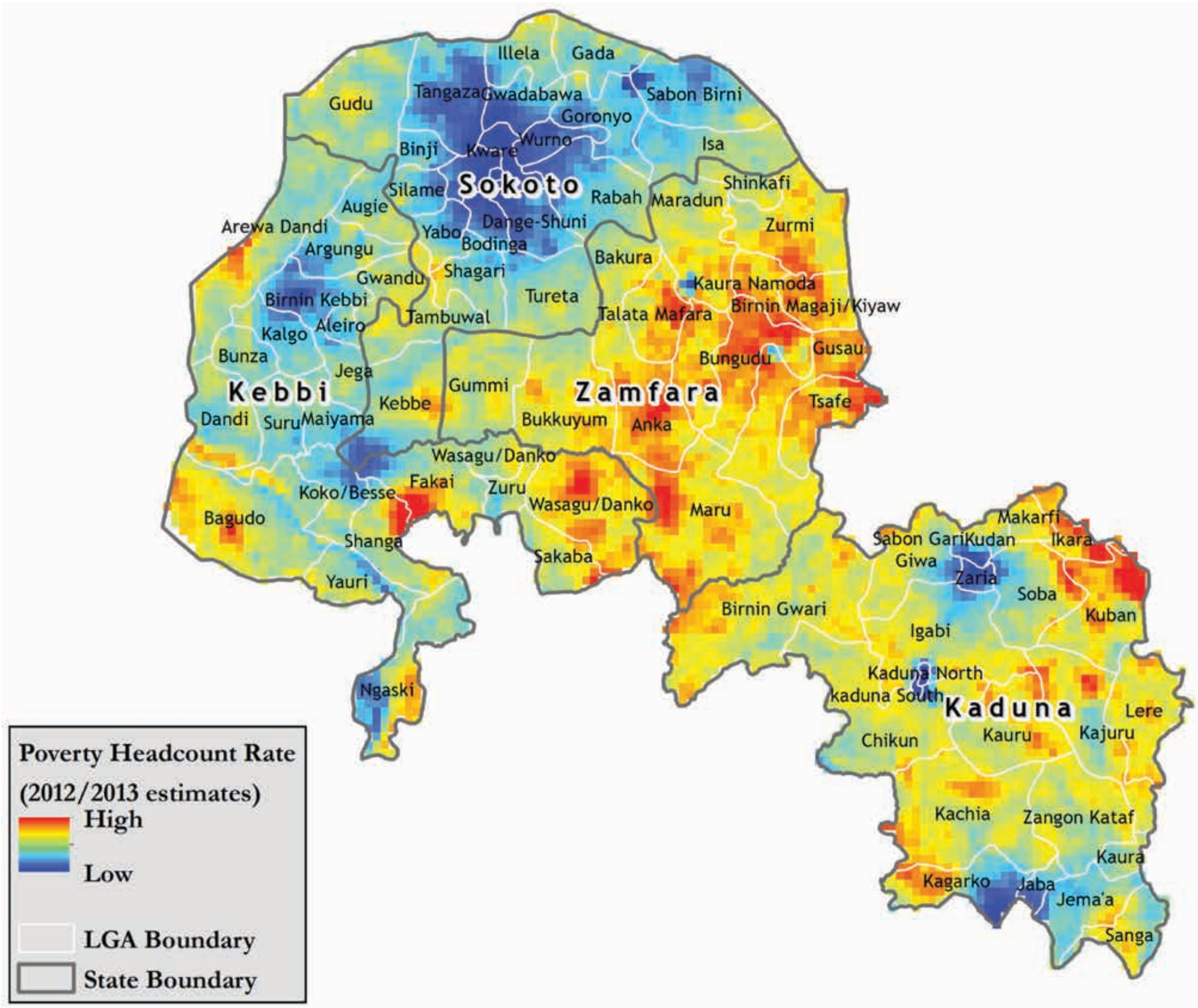
Electrification technical and cost parameters

Electrification modeling relies upon several parameters related to initial and recurring costs for all relevant generation, distribution, connection and metering technologies. This includes costs of all distribution equipment, such as transformers and electricity connections to homes, as well as all equipment for off-grid systems, such as costs of solar photovoltaic panels, batteries, and diesel generators. For all generation technologies, we will gather data on recurring costs, such as fuel, maintenance and battery replacements. The SEL/EI team began gathering this information from Kaduna Electric during the inception visit, and refined and validated it during our training visit with high-level utility planners. In case of data gaps, parameters can be drawn from NEAP-1 TA project results, international experience, or market research.

Electricity Demand and Socio-Economic Data

SEL/EI used the same general approach to electricity demand estimation for the Kaduna Electric service area as was performed for KEDCO under NEAP-1. The lowest consuming households are assumed to around 600kWh/year (the utility's "life-line" service level of 50kWh per month). This basic demand data was then combined with daily electricity expenditure information from LSMS survey results for the Kaduna Electric service states. Energy expenditures related to services such as lighting, mobile phone, media (TV, radio, etc.)—but excluding cooking—were aggregated for poor vs. non-poor respondents. While, for the Kano service area, the ratio of the expenditures for poor and non-poor categories were estimated to be at a factor of 2, Kaduna Electric planners specified the upper limit of the consumption range to be a factor of three larger, or around 1,800 kWh annually, in their 4-state coverage area. With this range of minimum 600 and maximum 1,800 kWh/yr established, electricity demand can be estimated for each point settlement based on that point's estimated poverty rate by calculating number of households—poor vs. non-poor—in each settlement, then computing a weighted household demand. For example, using the above household electricity demand range: a polling unit composed of 100% poor households would have an average demand of 600 kWh/year (the lowest extreme), while a polling unit composed of 100% non-poor households would have a demand of 1,800 kWh/year. However, as shown by the preceding figures, each area has a mix of poor and non-poor

Figure 33 **Poverty rates for Kaduna Electric service area (Oxford University / World Bank)**



households. Thus, each polling unit falls somewhere within this range.

Poverty and wealth mapping information can be used in this process to add geo-spatial specificity to these household demand estimates. From the past collaboration with the World Bank, SEL/EI has already had poverty data prepared by researchers from Oxford University. In NEAP-1 TA, SEL/EI conducted analysis for KEDCO to obtain geo-spatially detailed indicators of average electricity demand based on poverty rates. Similarly, Figure 33 shows the spatial distribution of poverty rates in Kaduna Electric coverage areas.

Other Input Data

Population Growth Rates

Population growth rates were obtained from National Bureau of Statistics Social-Economic Survey on Nigeria, 2010

Electric grid access rates and Residential Electricity Demands

Estimates of the current population's access to the electricity grid were based on a detailed examination of the LSMS survey results for the Kaduna Electric service states. A review of LSMS data with-

Table 21 Electrification Rate data (LSMS, 2012)

	PHCN Connected / Total HH	Urban PHCN Connected / Urban Total HH	Rural PHCN Connected / Rural Total HH
Kaduna	52.0%	92.9%	36.5%
Kebbi	39.4%	100.0%	32.6%
Sokoto	58.0%	100.0%	44.3%
Zamfara	17.6%	45.0%	9.9%
Total	**41.6%**	**83.3%**	**30.5%**

out any additional analysis results in a grid access rate of 41.6%, with 83.3% connected in urban areas, and 30.5% in rural areas (see Table 21).

However, as described previously (see Preparing the Input Dataset, sub-section Estimate of Current Grid Access) a SEL/EI analysis utilizing geospatial data—with recently mapped MV grid line, and the VTS/Gates Foundation settlement data, neither of which were available to the LSMS surveying program—results in a somewhat different value of 49% grid access throughout the Kaduna Electric coverage area (a difference of 7–8%). A summary of the steps is as follows:

- Define whether a settlement is "within range" of the grid
- For those settlements within grid range:
  - Define the fraction of the population that has a grid connection
  - Define the fraction of the *un*-connected population that is poor vs. non-poor
  - Apply the minimum consumption rate (600 kWh/yr) to the poor fraction, and the maximum consumption rate to the non-poor households.

The result is a poverty-weighted average household electricity demand for each point.

The steps for obtaining the SEL/EI estimate are described in detail below:

1. A geo-spatial query compared the demand points with the MV grid line to check if a given point was "within range of grid connection." For both the the VTS/Gates Foundation settlement points and social infrastructure points (the education and health facility points obtained from NMIS), this criterion was a distance of 1.0 km in urban areas and 1.5 km in rural areas from the grid or a transformer.
2. For settlement points, it was not assumed that 100% were connected. Instead, SEL/EI applied the rate of households already connected rate, from LSMS, of 90% for urban areas and 79% for rural settlements within range of grid. Urban and rural areas were defined by nightlights data. This calculation determined the population "already connected", which subtracted from the total population in the VTS/Gates data left the "input" population that was used for the modeling.

Total input pop = Total pop — already connected pop

3. The poverty rate from the Oxford / World Bank study (see Figure 33) was applied to all settlements to calculate the *poor population* and *non-poor population* in each:

Poor pop = Total pop × Poverty Rate
Non poor pop = Total pop × (1 — Poverty Rate)

4. It was assumed the fraction of the population already connected to the grid was the least poor in every community; conversely, those without connections were assumed to be the poorer residents. Mathematically:
   a. If: *Non poor pop — already connected pop ≥ Total input pop*
   this means all the input population are non-poor, so
   Input non poor pop = Total input pop
   b. If: 0 < *Non poor pop — already connected pop < Total input pop*
   this means part of the total input pop is poor, so
   Input non poor pop = Non Poor pop — already connected pop

c. If: *Non poor pop — already connected pop* ≤ 0, this means all the input pop is poor, so *Input non poor pop* = 0

5. Define *Input non-poor population*:

$$\text{Input non poor pop} = \text{Total input pop} - \text{Input poor pop}$$

6. Household size is derived from LSMS survey data, for urban and rural in each state.
7. Define *annual household electricity demand* in each polling unit:

$$\text{Input Poor household} = \text{input poor pop} / \text{householdsize}$$

$$\text{Input non poor household} = \text{Input non poor pop} / \text{householdsize}$$

8. Compute the weighted average household demand, assuming:
   a. poor household uses 600 kWh electricity per year,
   b. non-poor household uses 1800 kWh per year

Annual houehold electricity demand

$$= \frac{\text{Input non poor household} \times 1800 + \text{Input poor household} \times 600}{\text{Input non poor household} + \text{Input poor household}}$$

Renewable Resource Data

This project's TOR also describes the need to address renewable energy resources as an element of system planning. While some renewable energy sources, particularly solar photovoltaic, can be cost-effectively scaled down to very small systems and implemented at the level of the locality and even household, others, such as hydro, wind and geothermal, must typically be evaluated in a manner that is highly location-specific, and often at much larger scales, to be cost-effective. This would require additional, sustained and site-specific data gathering and engineering assessments that are beyond the scope of this project. Also renewable sources with substantial temporal variability and supply uncertainty are typically best managed by tying them to the grid, where their supply can be more effectively balanced by other dispatchable power sources. For these reasons, data on resources such as hydropower, wind and geothermal is, if available, typically integrated into grid parameters like "bus-bar" costs. For this analysis, the primary off-grid renewable option considered in the model has been solar, and the key input for this energy source is the hours of sunlight per year.

Appendix E: Training in Electrification Cost Modeling for Kaduna Electric

Soon after the completion of medium voltage grid mapping in late March, 2016, there was a period of roughly two weeks for checking the collected data for completeness, followed by planning for the next stage in project, focused on modeling and planning. To start this next stage, the SEL/EI team conducted a second two-week training in Abuja, Nigeria, from April 18–29, 2016 for Kaduna Electric. This second training was provided to high-level, managerial staff of the utility and covered technical and cost modeling for expansion of electricity access using grid and off-grid technologies, as well as analysis, reporting and visualization of results using desktop software (Excel, Quantum GIS).

Participants

The training was intentionally focused toward a small group of high-level participants with both the knowledge to supply costs for grid extension technologies and also with the decision-making roles within the utility to influence planning and strategy. A total of nine Kaduna Electric staff members joined the training, including the Chief Engineer of Technical Services (Engr. Bello Musa), Yasir Abdussalam from the Information Technology department (the key Kaduna Electric contact points throughout the NEAP-2 project, as well as other staff from Power System Planning, Metering, Asset Management, Strategy, and information technology. The training was offered by Edwin Adkins, Shaky Sherpa and Naichen Zhao, of SEL/EI. The training was also joined briefly by Kyran O'Sullivan, Muhammad Wakil, and Ogochukwu Joy Medani, all representatives of the Abuja World Bank offices, and Rahul Kitchlu and Chiara Rogate, from the Washington, D.C. World Bank office. The SEL/EI director, Prof. Vijay Modi, joined on the final day of the training event.

Content: Topics and Modules

The content covered by the training included three general topics: i) overview and preparatory steps for model input data, ii) modelling with NetworkPlanner, including parameter validation; and iii) analysis and visualization of model outputs using Excel and Quantum GIS (QGIS).

This material was broken into the following ten one-day modules:

1. Introduction and Agenda
2. Data: Overview, Processing, Methods
3. Introduction to QGIS
4. Preparation of the Data for Demand Points
5. Local "Override" of Global Values, Pt. 1: Poverty Map Data and Urban/Rural Extents
6. Local "Override" of Global Values. Pt. 2: Distance from Grid and Household Demand
7. Modeling with NetworkPlanner: Part 1: Parameters
8. Modeling with NetworkPlanner: Part 2: Model Runs

Figure 34 **Trainees with the SEL/EI team, April, 2016, Abuja, Nigeria.**

9. Data Visualization of NetworkPlanner Output in QGIS
10. Validation: VTS/Gates Foundation Data and Satellite Imagery

Validation of parameters

Throughout the training, all input parameters for the model were discussed directly with Kaduna Electric staff responsible for areas of corporate strategy, power system planning, technical services, energy metering asset management (for operations and maintenance) and information technology. The parameters that were the focus of the most attention and have the strongest impact on model results were:

- **Household demand:** the Kaduna Electric team agreed that the minimum of the demand range should be set at 600 kWh/year per household, and the maximum value in the range should be 1,800 kWh/household per year (as used for prior estimates).
- **Mean inter-household distance:** This variable was explored in detail, including discussion of field experience with electrification of households in urban and rural areas, as well as a review of satellite imagery. The conclusion was to keep the parameter inputs of 15 m distance between households in urban areas, and 30 m in rural areas, on average.
- **Factors related to estimating the number of connections to the existing grid:** The group as a whole discussed the number of Kaduna Electric "customers" (connections with accounts) as well as "consumers" (connections that either lacked accounts, had formal connections or did not pay).

Appendix F: Review of VTF/ Gates Foundation Data

The VTS/Gates Foundation dataset for the Kaduna Electric coverage area is, overall, an excellent data source. The SEL/EI team believes that it is, by a wide margin, the best geo-located data resource for the target area of this study, and probably for the country as a whole, if the same approach and data quality hold for other areas. Nonetheless, it is important to describe in an analysis like this what specifically the dataset provides, and what may be the limits in its use for the specific purpose of electrification planning, particularly when the target areas are rural, sparsely populated villages and homes, which are among the most difficult places in the world to map with high precision and accuracy.

Based on past experience with other datasets (INEC data for Nigeria, survey and census data in other countries) the SEL/EI team typically looks for the most comprehensive coverage possible of small, rural villages. This is the data that allows effective planning for distinguishing where grid vs. off-grid systems are cost-effective. In this context, it is important to note that while electrification planning is primarily concerned with connecting *structures*, a vaccination program such as that funded by the Gates Foundation, is primirily concerned with mapping *population.* This is important, since—as the Gates team explains—some locations are mapped in the practical sense that vaccination teams may not visit every single cluster of homes, provided that the population residing in those specific structures can be reached for vaccination by visiting a somewhat more concentrated area. For this reason, a key concern of the SEL/EI data review is to evaluate the likely impact of extremely small clusters of homes that may have been "skipped" in the mapping (in that they may not have a geo-located lat/lon point in the dataset) even if they were "covered" by the vaccination program (since the population was vaccinated nearby).

Although a thorough vetting of the VTS/Gates Foundation dataset is beyond the scope of this project, a brief review of the data against freely available satellite imagery was sufficient to make the following basic conclusions:

- It was confirmed that the VTS/Gates Foundation data had extremely good "coverage" of the Kaduna Electric area, in that virtually all villages or small household clusters visible in the satellite imagery had corresponding lat/lon points in the dataset; it was extremely rare that even very small villages had no point.
- In the rare cases that a small village had no corresponding point, it was virtually always located near a geo-located village that was itself less than 1.5 km away (i.e. within the radius of a low voltage line extension by the utility).
- While attempts to count homesteads or "compounds" are admittedly unreliable, the effort to do this for test areas shows that a broad estimate of 30 m inter-household distance (the value estimated by Kaduna Electric staff) is a reasonable length, on average.

Each of these conclusions is detailed briefly below.

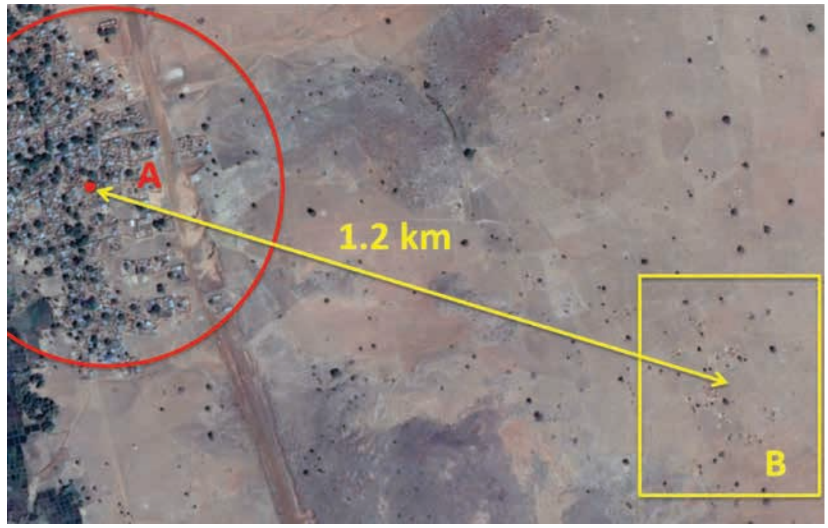
Non-geolocated villages are rare, and typically close to a geo-located point

Figure 35 shows an example, found after examining about 20–30 locations, of an area where the satellite image included a dispersed group of household compounds (B) that was not included in the VTS/ Gates Foundation geo-located points. Note that the distance between the two areas is between 1 and 1.5 km, which is within range of a low voltage connection, according to Kaduna Electric engineers. This is also seen in Figure 36. *Depending upon the density of households in an area such non-geolocated areas, it may not be cost-effective to electrify with grid, hence the inclusion of 1%, 2.5% and 5% off-grid program outlines in the analysis* (see Off-Grid Electricity Access Program, p. 46).

Satellite imagery supports 30 m / HH as inter-household distance

Two examples from review of VTS/Gates Foundation points for both dense and sparsely settled rural areas can be seen in Figure 37 and Figure 38. These images show efforts to identify specific settlement structures, label them with points, and quantify the distances between them, in order to obtain an inter-household distance. It is important to note at the outset that this approach—identification of households from satellite imagery in Northern Nigeria—has been tried with multiple teams of engineers and planners from both the Kano and Kaduna Electric utilities, and despite direct familiarity with the landscape, cultural settlement patterns, and other local factors, these efforts confirm that it is, at best, highly approximate. It is virtually impossible to identify single homes from satellite

Figure 35 **Non-geolocated village (B) near geolocated point (A) (rural Kebbi State)**



imagery, particularly in highly clustered rural villages, where earthen homes join together in a manner that makes all structures irresolvable. For very sparsely settled areas, what appear to be dwelling "compounds" can be identified fairly consistently by imagery, but it remains very difficult to resolve specific households here, as well, since dwellings are very difficult to distinguish from non-dwelling structures (such as kitchens, food storage, or animal shelters).

Nonetheless, the SEL/EI team has reviewed the imagery in an effort to validate the Kaduna Electric

Figure 36 **Non-geolocated points are typically within 1 km of a geo-located village**

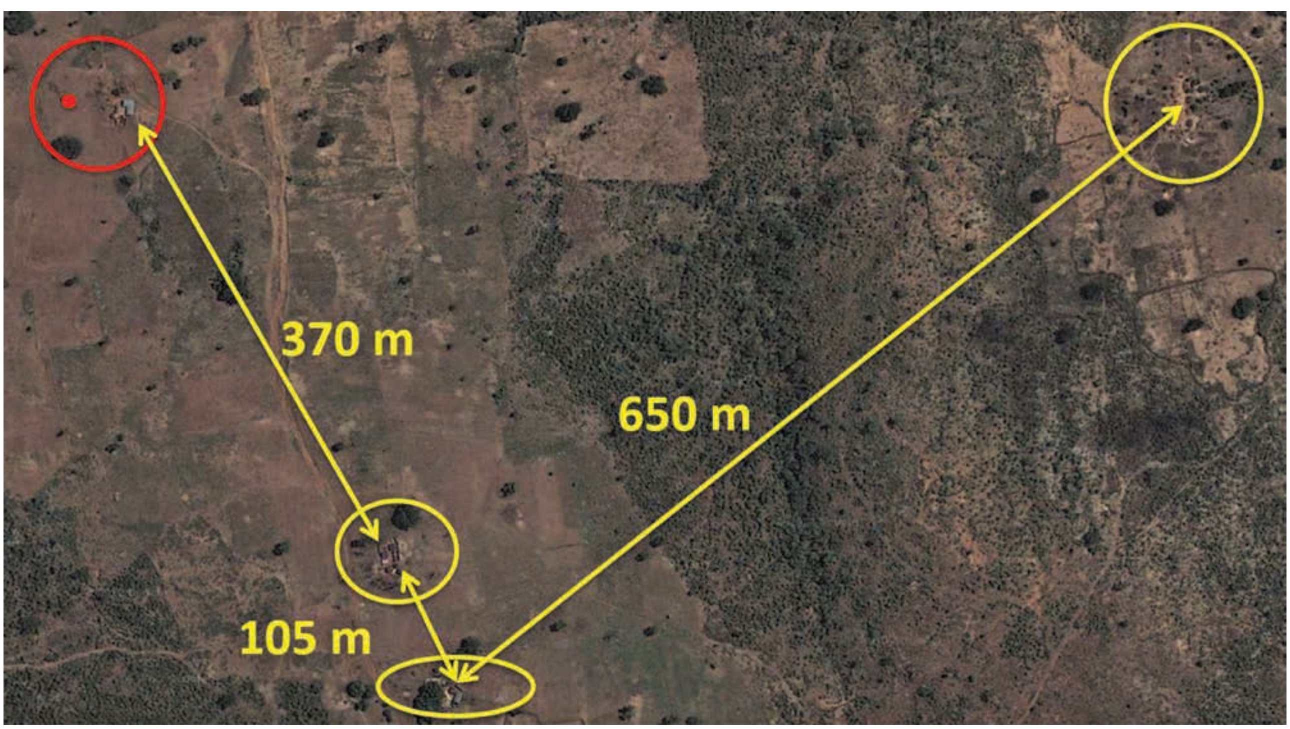


Figure 37 **Ten compounds in a dense rural area (251 meters total; ~28 m/compound; ~14 m/HH)**

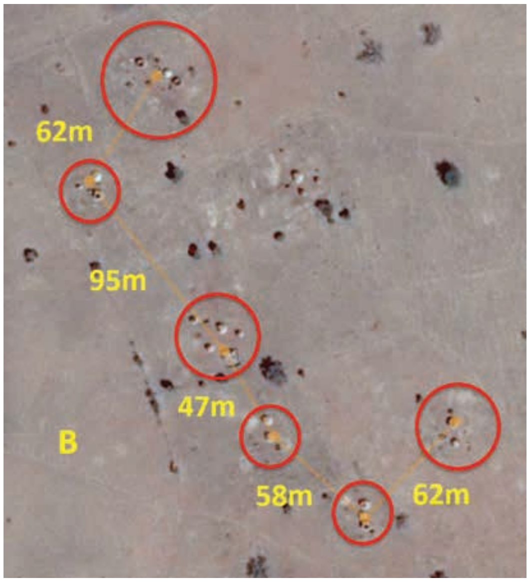
staff's estimate of 30 m inter-household distance in rural areas, and found it to be a realistic, if inexact, estimate.

The first example, Figure 37, shows a densely settled rural village, with 10 "compounds" approximately identified and geo-located from imagery. The total distance between these points, the sum of line segments between points, is 251 meters, which divided among the compounds, gives an average inter-compound distance of about 28 meters. If one considers that a compound is unlikely to contain only one household—families tend to cluster in multiple household areas—then the average inter-household distance is likely to be perhaps 14–5 meters.

The next example, Figure 38, shows 6 dwelling "compounds" in a very sparsely populated area. The total line distance among these compounds is approximately 324 meters, or around 64 meters per compound. Again, assuming two households per compound yields an average of about 32 meters per household.

Comparing these two values—and recalling that they are both rural areas—suggests that an average of 30 meters per household is reasonable, perhaps even too large, on average, given that the majority of rural residents most likely live in more densely packed pattern evident in Figure 37 rather than the sparsely settled pattern show in Figure 38. Moreover, the quantitative result of the review is obvi-

Figure 38 Six compounds in a sparse rural area (324 meters total; ~65 m/compound; ~32 m/HH)



ously highly dependent upon the assumptions that: a) compounds can be reasonably effectively resolved visually in imagery, and b) that a typical compound has two households, on average. Both are difficult to defend without substantial ground-truth efforts, combined with surveys, that are beyond the scope of this project. However, the VTS/Gates program has undertaken both—extensive reviews of satellite imagery and "micro-census" surveying—to validate its own data.

Given this situation, the two best data sources available to the SEL/EI team are the VTS/Gates Foundation point data (for settlement locations and populations), and the Kaduna Electric staff (who provide inter-household distance estimates of 15 m/HH in urban areas, and 30 m/HH in rural areas), and it is difficult to improve upon these with the resources at hand.

PART 2

INVESTMENT PROSPECTUS FOR THE ELECTRIFICATION OF THE KADUNA SERVICE AREA

Advisory Service Document

Consultant Summary Report

Contents

64 Abbreviations and definitions

65 Executive Summary
65 Introduction
66 Least-cost geospatial electrification rollout programme
68 Programme implementation – Readiness
69 Mobilizing physical programme implementation
69 Financing the universal access rollout programme
70 Phasing strategy for implementation of the electrification programme (2016–2023)
71 Grid rollout implementation (2018–2023) – Two scenarios
73 Investment financing prospectus – Grid rollout (2018–2023)
75 Investment financing gap (2018–2023)
76 Financing mechanisms and on-lending terms for public funds support
76 Technical assistance
77 Off-grid programme
78 Notes

81 Chapter 1: Background – Kaduna service zone and Kaduna Electric
81 1.1 The market and regulatory framework
82 1.2 Geospatial least-cost plan for universal electrification
86 Notes

89 Chapter 2: Indicative electrification programme
90 2.1 Conservative grid electrification scenario
92 2.1.1 *Capital costs – grid electrification conservative scenario*
92 2.1.2 *Increment of demand on the main grid from the conservative electrification program*
92 2.2 Best-practice electrification programme
93 2.2.1 *Capital costs – grid electrification best-practice scenario*
94 2.2.2 *Increment of demand on the main grid from the best-practice electrification program*
94 2.3 Capacity strengthening
96 Notes

97 Chapter 3: The role of the policy maker and regulator
97 3.1 The current institutional framework
97 3.2 A National Policy for Universal Access
99 Notes

101 Chapter 4: Financing of the Access Program
101 4.1 Capacity of Kaduna Electric to finance investments
103 4.2 Financing gap for the electrification programme (2018–2023)
105 4.3 Investment needs in generation and transmission
106 Notes

109 Chapter 5: Current tariff regime and the electrification program
109 5.1 The current tariff regime
110 5.2 Equity concerns and strategic rollout of the electrification programme
110 5.3 Potential cross-subsidy implications of the access rollout
111 Notes

113 Chapter 6: Off-grid electrification
114 6.1 Enabling factors for the development of an off-grid programme
116 6.2 The current regulatory framework for isolated grids
116 6.3 DISCO-led off-grid electrification and targeted support
116 6.4 Non-DISCO-led off-grid electrification
117 6.5 The Future Role of REA and REBs
118 Notes

119 Annexes
119 1 Summary of Kaduna Electric rapid readiness assessment
119 1.1 *Summary of readiness assessment*
125 2 Customer income, expenditure and affordability
125 2.1 *Income and expenditure distribution*
125 2.2 *Geographic distribution*
128 3 Transitional electrification options
128 3.1 *Choices*
128 3.2 *Electrification to target poverty*
128 3.3 *Off-grid electrification strategies*
131 4 Independent electricity distribution networks
132 5 Examples of international experience
132 5.1 *Brazil*
133 *5.1.1 Key lessons learned*
133 *5.1.2 Information sources*
133 5.2 *Chile*
133 *5.2.1 Key lessons learned*
133 *5.2.2 Information sources*
134 5.3 *India*
134 *5.3.1 Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) scheme*
135 *5.3.2 Key lessons learned*
135 *5.3.3 Information sources*
135 5.4 *Off-grid developments: Bangladesh and Ethiopia*

Figures

85 **Figure 1** Map showing least-cost access provision by location (left), and the prioritized grid expansion plan based on average cost per household (right), 2015–2030
86 **Figure 2** Map showing that 99% of schools (left) and clinics (right) planned are best suited for grid connection (2015–2030)
91 **Figure 3** Conservative grid electrification programme for Kaduna Electric
93 **Figure 4** Best practice grid electrification programme for Kaduna Electric

111 **Figure 5** Impact of cross-subsidy requirements on tariffs
120 **Figure A1** Post-privatization m arket structure
121 **Figure A2** Kaduna Electric payment of NBET invoices (Apr 2015–Apr 2016)
126 **Figure A3** Estimated distribution of relevant energy expenditure
127 **Figure A4** Poverty rate (% of poor households) for the Kaduna service area
129 **Figure A5** Multi-tier matrix for access to household electricity supply
130 **Figure A6** Decision tree for non-Kaduna Electric grid electrification

Tables

67 **Table 1** Electricity access in 2015 and grid extension programme for the KEDCO service area, 2015–2030
68 **Table 2** Technical summary for the LV intensification and MV extension components of the universal access programme for the Kaduna service area, 2015–2030
71 **Table 3** Electrification phasing for the Kaduna service zone
72 **Table 4** Preparatory Phase – Key Actions
73 **Table 5** Electricity access rollout programme (2018–2030)
74 **Table 6** Grid rollout capital investment cost (2018-2030)
75 **Table 7** Impact on electricity demand
75 **Table 8** Investment financing requirements for grid electrification ($ million)
77 **Table 9** Technical assistance (TA) programme (present – 2023) – US$ million
83 **Table 10** Electricity access in 2015 and grid extension programme for the Kaduna service area, 2015–2030
84 **Table 11** Technical summary for the LV intensification and MV extension components of the universal access programme for the Kaduna service area, 2015–2030
91 **Table 12** Electricity access rollout programme (2018–2030)
92 **Table 13** Conservative grid electrification programme
92 **Table 14** Capital cost of the Kaduna grid electrification programme (conservative)
93 **Table 15** Increased grid load associated with the conservative roll-out program
93 **Table 16** Best practice grid electrification programme
94 **Table 17** Capital cost of the Kaduna Electric grid electrification programme
94 **Table 18** Increased grid load associated with the best practice roll-out
95 **Table 19** Technical assistance (TA) programme (present– 2023) – US$ million
101 **Table 20** Kaduna Electric's past and forecast financial position
102 **Table 21** Summary of Kaduna's non-access investment requirements (US$ million)
104 **Table 22** Capital investment requirements – grid electrification (US$ mn.)
109 **Table 23** Kaduna Electric selected tariffs (February 2016 after tariff revision)
114 **Table 24** Cost per household and for full program, for pre-electrification off-grid access
125 **Table A1** Current expenditure on energy
126 **Table A2** Expenditure in NGN/month

Abbreviations and definitions

ATCC	Aggregate technical, commercial and collection losses
BPE	Bureau of Public Enterprise
DISCO	Distribution company
ECA	Economic Consulting Associates
EPSRA	Electric Power Sector Reform Act
FGN	Federal Government of Nigeria
IFI	International Financing Institution
KEDCO	Kano Electricity Distribution Company
LGA	Local Government Area
MYTO	Multi-year tariff order
NAPTIN	National Power Training Institute of Nigeria
NBET	Nigerian Bulk Electricity Trading Company
NEAP	Nigeria Electricity Access Program
NEPA	Nigerian Electric Power Authority (former integrated electricity utility)
NEPP	National Electric Power Policy (2001)
NERC	Nigeria Electricity Regulatory Commission
NESI	Nigerian Electricity Supply Industry
NGN	Nigerian Naira
NIAF	Nigeria Infrastructure Advisory Facility
NIPP	National Integrated Power Project
NW	North West
Off-grid	Electricity provided other than through the main DISCO network (i.e., isolated grids, SPDs (see below) and distributed power such as solar home systems and pico lighting)
PHCN	Power Holding Company of Nigeria (successor to NEPA)
PRG	Partial Risk Guarantee
RAB	Regulatory Asset Base
REA	Rural Electrification Agency (Federal level)
REB	Rural Electrification Board (State level)
SHS	Solar home systems
SPD	Small Power Distribution company
TCN	Transmission Company of Nigeria
WACC	Weighted Average Cost of Capital

Key data

Exchange rate, September 2015: US$ 1 = Naira 200. Calculations were made in 2015 and starting in January 2016 the exchange rate experienced major fluctuations (as of June 2016 the official exchange rate dropped to US$ 1 = Naira 280 and the unofficial rate is lower).
Price datum: mid-2015 (Costs are based on the prices and exchange rate of mid-2015. It is assumed that subsequent movements in the exchange rate will eventually feed through into local prices and costs and purchasing power parity will prevail.)
Financial year for Discos: 1 June to 31 May

Executive Summary

This Investment Prospectus was developed in close collaboration with the Kaduna Electricity Distribution Company (Kaduna Electric) and is based on the geospatial least-cost electrification plan produced by the Earth Institute of Columbia University.

The Prospectus provides a multi-year action plan for the achievement of universal access by 2030 in the Kaduna Electric service area, combined with an assessment of the projected investment needs, financing gaps, and possible sources of funding for the implementation of the first five years of the electrification rollout.

The recommendations contained in the report reflect and respond to the operating context and the challenging sector environment of Kaduna Electric, while integrating the knowledge emerged from best practices in international experience.[1] The Prospectus identifies the key weak links, and interrelated issues, in respect of the major gaps and ambiguities in the policy, institutional, and financing frameworks that pose significant barriers to achieving universal access by 2030 at least-cost. Investments alone will not be sufficient, and these make or break challenges for scaling up access—especially those outside Kaduna Electric's control—require priority attention and resolution.

The Prospectus is divided in six Chapters. The report provides first an overview of the Kaduna Electric service area and the findings of the geospatial analysis (Chapter 1), it then presents the access rollout plan up to 2030, detailed scenarios for the first five years of implementation, and an overview of capacity strengthening needs (Chapter 2). The key role of sector institutions and policies is highlighted (Chapter 3) before providing an assessment of the electrification plan's investment requirements and related financing gap (Chapter 4). The last two sections are devoted to equity considerations (Chapter 5) and the potential offered by off-grid solutions for the timely scale-up of electricity access (Chapter 6).

This Summary presents an overview of the main findings and recommendations emerged from the analysis.

Introduction

The Kaduna Electric service zone comprises the four states of Kaduna, Kebbi, Sokoto and Zamfara in the North West Nigeria, with a combined population of about 28.4 million[2] and an estimated 4.2 million households. Today, access to electricity grid in the Kaduna service zone is approximately 49% of the population. Schools, clinics, and a large number of businesses also have limited access, not only in rural areas (only ~20% of schools and clinics currently has access to electricity services). By 2030, the population in the Kaduna service zone is projected to be almost 38.9 million or about 5.8 million households. Under business-as-usual, the share of population without access will *grow, not diminish.*

The Kaduna Electric's Business Plan attached to the Performance Agreement under the overall Concession Agreement submitted at privatization (2014), and entered into force in January 2015, envisages capital expenditures for a small number of "new customer" connections (about 191,260 in a five-year period). However, these in effect are already reflected in the 49% access statistic mentioned above; as they mostly represent the installing of meters in the sub-population of existing consumers without meters presently.[3] The analysis underpinning this Report is guided by the national targets identified in the Federal Government of Nigeria (FGN)'s National Electric Power Policy (2001). Specifically, the Kaduna Electric's electrification plan for achieving universal access by 2030, is underpinned by the following building blocks:

- **Geospatial least-cost electrification rollout program plan (2015–2030)** to achieve universal access by 2030. This high level (MV, LV, final beneficiary connections) geospatial plan also delineates broadly the boundaries in space and over time of areas for staging a well-designed and coordinated off-grid rollout across the entire Kaduna service zone for pre-electrification; particularly in areas where grid extensions are not projected to materialize through the mid-term (2025). Also identified are investments for major equipment categories, including MV extensions, LV rollout, final customer connections where grid delivery is appropriate.

- **Implementation Readiness** – A rapid appraisal was undertaken at the start of the study to broadly gauge critical readiness factors that pose material limitations for scaling up affordable and reliable electricity access, efficiently and sustainably, and in a timely manner. Some are relatively easy to address by targeted capacity strengthening (especially technical, planning, logistics of mobilisation and program management of a hugely scaled up access rollout program by Kaduna Electric). Some others are inter-related systemic factors endemic to the sector's power market operating environment that are beyond any single sector agents' control. These are severely limiting Kaduna Electric's financial condition and its space to undertake even routine capital expenditures critically needed to upgrade the existing network and operations. In addition, there are "show stoppers" that emanate in one manner or another, from ambiguities and key gaps in the enabling policy and regulatory framework today. *Any meaningfully significant start of implementation of an electrification programme for achieving universal access can only begin subject to the Federal Government of Nigeria's (in collaboration with the Ministry of Power and NERC) addressing of the key enabling show stoppers identified in this report.*
- **Investment Financing Prospectus (2018–2023)** – The investment financing requirements for achieving universal access are substantial and financing must be sustained over the duration of the program and beyond to 2030, and ensuring its "bankability" is the pivotal challenge. No country that has achieved universal access, or advanced substantially in access provision, has done so without significant levels of public funding support for investment sustained over the program duration; irrespective of whether the distribution sector was privatised or a national utility. The Prospectus highlights for the specific case of Kaduna Electric the extent of the projected financing gap in magnitude, and the potential sources of funds—besides private equity—that would have to be intermediated by the Government for the Kaduna Prospectus.
- **Technical assistance and capacity strengthening for key sector institutions and agents** are identified in terms of areas of focus directly linked to and essential for the successful implementation of the programme; although detailed scoping can only be undertaken once the interlinked set of key policy and regulatory ambiguities and gaps are effectively addressed.

Least-cost geospatial electrification rollout programme

A high level least-cost geospatial plan for scale up of electricity access in Kaduna Electric's entire service area was prepared by the Earth Institute of Columbia University. The analysis and results provide a geospatial and quantitative frame for the design and detailing of a well-coordinated and harmonized implementation program for off-grid electrification over a fifteen-year timeframe (2015–2030), alongside the grid rollout, which is the focus of this report.

Columbia University undertook a digital mapping of the spatial demographic settlement patterns of households across the entire service area. In addition, Kaduna Electric engineers and field staff were trained by the Columbia geospatial specialists to undertake the digital mapping of the existing network infrastructure (MV lines). This involved digital data capture and processing to prepare the spatial representation data layer to support the least-cost analysis of network rollout.

The Columbia University Network Planner Platform is supported by several digitised data layers (demographic, socio-economic, affordability, existing MV infrastructure). The modelling algorithm rapidly assesses the relevant technical, economic and financial trade-offs underlying the delivery modalities and technology options available—grid connections by LV intensification, MV lines extension, off grid Solar Home Systems and isolated mini-grids—to identify the least-cost option for access provision.

The geospatial analysis indicates that over the long term (2030), grid extension is the least-cost electrification option for virtually the entire population (~99%) within the Kaduna Electric service area.

Table 1 Electricity access in 2015 and grid extension programme for the KEDCO service area, 2015–2030

Electricity Access Status (2015)			Grid Extension Program (2015–2030)				
Type of Access	Population (Households)	Percent	Components of grid program (type of grid access planned)	Population (Households)	Percent	Total CAPEX (M USD)	CAPEX per HH (USD)
Grid access	14,100,000	49%	**A) Customers:** Kaduna has ~400K customers (2015); almost all need meters ($275/HH)	2,600,000	9%	$105[a]	$275
				(400,000)			
	(2,100,000)		**B) Consumers:** ~1.5 m HHs (2015 est.) consume power but do not pay Kaduna; all need meters & improved connections (~$400 per HH)	11,500,000	40%	$685[b]	$400
				(1,700,000)			
No grid access	14,500,000	69%	**C) LV Intensification:** By 2030, ~1.6 M HHs near the grid will need LV line, meter, connection (~$670 per HH)	10,600,000	27%	$1,060	$670
				(1,600,000)			
	(2.200,000)		**D) MV grid extension:** By 2030 ~2.1 M more distant HHs from transformer will need MV and LV line, connection, meter (~$920 per HH)	14,300,000	37%	$1,950	$920
				(2,100,000)			
Total	**28,500,000**	**100%**	**Total**	**38,900,000**	**100%**	**$3,800**	**$650**
	(4,300,000)			**(5,800,000)**			

Source: Earth Institute, 2016.
[a] Not included as part of the electrification access programme.
[b] As above.

Table 1 above summarizes the components and costs for a ~US$3 billion[4] (including metering and upgrades to existing consumers) grid extension program that will reach about 3.7 million households, resulting in nearly universal grid coverage, by 2030:

a. **Customers**: Kaduna Electric has approximately 400,000 residential customers who are billed.
b. **Consumers**: About 1.7 million households are served with electricity but are not registered as customers, they all require meters.

   Though not formally "electrification", customers without a meter and consumers together are the lowest hanging fruit for a DISCO as they require a one-time very low capital investment to install appropriate metering and integrate them into the customer billing and revenue collection systems; thereby boosting otherwise lost revenues from energy purchased but unbilled. From a commercial and business perspective this represents a high yield and quick payback investment opportunity.
c. **LV Intensification**: By 2030, 27% of projected homes will be situated in locations that are currently close to an existing transformer. They require possibly a simple LV extension, but otherwise just service drops and meters. Customers, consumers and LV connections together target a total of 1.6 million homes, which represents about 63% of the universal access programme
d. **MV Grid Extension**: About 2.1 million households are located beyond the range of a transformer and their connection would require extension of MV lines and LV reticulation. This segment corresponds to 37% of the access rollout and is the single largest component of the electrification programme, both in numbers of households to be served and total costs.

Table 2 above highlights physical program specific parameters—kilometre of MV and LV lines, and incremental demand from the new connections—specific for each of the four states in the Kaduna service zone.

Table 2 Technical summary for the LV intensification and MV extension components of the universal access programme for the Kaduna service area, 2015–2030

	Number household grid connections proposed ('000)		Grid length proposed (km)				New generation needed (MW) for residential connections	
			MV grid extension			LV intensification	MV grid extension	LV intensification
State	MV grid extension	LV intensification	MV	LV	MV/HH (km per 1,000 HH)	LV		
Kaduna	578	652	14,300	16,800	24.7	15,500	230	260
Kebbi	408	334	6,200	12,100	15.2	9,300	160	130
Sokoto	575	414	4,500	16,800	7.8	11,200	270	200
Zamfara	568	188	8,100	16,900	14.3	4,800	210	70
Sub-total	**2,129**	**1,588**	**33,100**	**62,600**	**15.5**	**40,800**	**870**	**660**
Total	**3,717**		**136,500**				**1,530**	

Source: Earth Institute, 2016.

Physical Program – The program would require about 36,000 km of additional MV line, approximately tripling the length of the Kaduna Electric's existing MV distribution network (currently 11,000–12,000 km in total). The vast majority of the MV line (90% or more) is planned for the grid extension phase, which accounts for the substantial cost difference between electrification of households by grid "intensification" versus grid "extension". Each state is recommended for about 1 million new connections, plus or minus 25%, depending on the state. The physical program is greater in Kaduna state, with around 1.2 million new connections, reflecting its higher population but the programme is fairly evenly spread over the four states, while about 750,000 will be needed in Zamfara.

The physical program is greater in Kaduna state, reflecting its higher population but the programme is fairly evenly spread over the four states.

Incremental demand – The grid extension program will result in a substantial increase in generation supply requirements for the Kaduna service zone. The program would add 3.7 million new residential customers to the Kaduna Electric grid, with incremental demand of about 1,500 MW,[5] of which about ~870 MW would be due to MV grid expansion, while the other ~650 MW 191,260, that is, almost 60% of new electricity demand will result from MV extension.

Programme implementation – Readiness

Kaduna Electric (indeed, most the other DISCOs as well) is still attempting to correct years of underinvestment and poor management of the industry. A Rapid Readiness Assessment was undertaken at the outset to gauge the key hurdles and challenges to the company's ability—managerially, technically, and financially—to mobilize for another priority, of the magnitude and scope called for by the universal access program; even though scaling up access is within the broader mandate of the terms of its Concession Agreement entered into with the Federal Government of Nigeria (FGN) and the Bureau of Public Enterprises (BPE).[6]

The Readiness Assessment focused on the key factors and drivers that pose a material and significantly inhibiting impact on Kaduna Electric's technical, operating and financial performance in the immediate to near term; and looking beyond, to the Company's ability and incentives as a private utility to initiate implementation of an access scale up program of the scope, and scale identified by the Geospatial least-cost rollout plan. Broadly, the key challenges to initiate and accelerate the program implementation broadly stem from two institutional framework dimensions:

i. those within Kaduna Electric, that are relatively easily and quickly addressable, and

ii. those critically impacting Kaduna Electric but largely out of its control as they are driven by the external environment in the sector within the utility must function, including in particular: (a) regulatory framework and process for retail tariff review and setting; and, (b) systemic modus operandi of the bulk power supply market adequacy, cost structure, and transactional payments settling environment presently.

Mobilizing physical programme implementation

Kaduna Electric has limited experience to date of extending electricity grids on any scale. Most if not all of the "new connections" reported and/or depicted in its capital expenditure plan filed with NERC, are in essence a few new meter installations mostly.[7] Further, Kaduna Electric presently has limited human, material and technical resources for undertaking a major programme of connecting customers through intensification and grid extension.

Kaduna Electric staff and management acknowledge that purely from a technical and engineering standpoint, to a large extent the electrification work will need to be and can be contracted out to the private sector (both grid and off-grid). However, Kaduna Electric will need targeted capacity building to enable it to supervise and manage a major electrification programme. Fortunately, the private sector in North West Nigeria is sufficiently experienced in undertaking electrification works, though not on the scale necessary to achieve the electrification rollout required for Kaduna Electric.

Upstream training and capacity strengthening can help address this limitation in implementation capacity to the physical program rollout; both within Kaduna Electric as well as trading of more private contractors typically provide in-house training for linesmen, fitters, jointers, etc.

In particular, the Industrial Training Fund (ITF) is used for training engineers and technicians mostly in the private sector. In the electricity sector, the National Power Training Institute of Nigeria (NAPTIN) operates a training facility in Kaduna city that provides training for the electricity companies in NW Nigeria. This facility is equipped with modern equipment. While it does not currently provide training in the skills needed for the expansion of the distribution network (linesmen, fitters, jointers, etc.) it has the space and facilities to do so.

Financing the universal access rollout programme

The investment requirements of the least-cost access scale up program are substantial. For the grid component, capital expenditure of about $3 billion over 15 years is estimated, at an annual average of $200 million per year over the program implementation period. Undertaking implementation of such a program will require mobilisation of significant levels of financing flows into Kaduna Electric, sustained year-in-and-out over its implementation horizon; and at terms that do not undermine Kaduna Electric's commercial and financial position.

Under the present policy and regulatory framework and review process in-place, financing the universal access implementation program is not a bankable proposition. To wit, the Readiness Assessment clearly indicates:

- The multi-year tariff order ***(MYTO) approved in February 2016 covering the next 5–10 years, does not make allowance for large scale electrification investment.*** This will need to be satisfactorily remedied before the electrification programme can be launched. Indeed, there are no explicitly mandated access targets over the medium term and beyond. Furthermore, under the current MYTO 2015 regime, tariff revenues are in-sufficient to even cover 100 per cent of all operating expenses with rapidly accumulating deficits.[8]
- The bulk power market that Kaduna Electric purchases supply from, is still marked by conditions of power supply inadequacy (even planned allocations), considerable unpredictability, and a rising unit cost of bulk power generation, most of the time working in the direction of pushing retail tariff adjustments upwards. Under such circumstances, the lagged six monthly tariff review process of NERC, to remedy such "unanticipated changes" to assumptions in the baseline tariff calculations, results in adding to the cumulatively mounting adverse pressures on Kaduna Electric's financial conditions.

Everything considered, for the foreseeable future, very limited equity contributions can be expected forthcoming from Kaduna Electric owners towards financing some portion of the capex for the universal access program implementation. And as highlighted above, financing capex for the access scale up program via retail tariffs is not a workable proposition.

Indeed, relevant experience from other nations—that have effectively implemented electrification programmes for achieving universal access—unambiguously indicates that *no country has achieved universal electricity access—irrespective whether the distribution sector is privatised or in public hands—without some form of public funds (subsidy) to finance a substantial portion of the capital investment requirements of the access rollout (MV, LV and service connections),* at least in the early stages of program implementation when revenues from other sources are inadequate.

Indeed, this distinguishing feature of the enabling policy framework marks a dividing line separating those countries that have effectively navigated a universal access rollout and others that are stalled or move in starts and stops. This represents a lynchpin (and make-or-break) policy issue that the FGN/Ministry of Power would need to address in any new/updated National Energy Policy for Universal Electricity Access. The policy context for achieving universal access, goes well beyond addressing "rural electrification".

More specifically, a necessary pre-requisite for any meaningful and sustainable start of an electrification programme, is for FGN to adopt a specific policy, encompassing much more than a statement of vision, and access targets. Inter alia, the "National Universal Access Policy" should address clearly the full range of enabling policy measures and drivers necessary to facilitate the DISCOs in scaling up electricity access in a systematic and comprehensive manner for provision of adequate, affordable and reliable access to all residents. The national access policy should also clarify the key roles, mandates and accountabilities of the sector institutions (including State and Local Authorities) and stakeholders, whose engagement is essential in some manner for achieving the Universal Access Program's time-specified targets.

Such a policy would need to transparently put forth and articulate the principles and key supporting mechanisms for ensuring affordability, especially for the poor (connection charges[9] and tariffs); at the same time ensuring commercial viability of Kaduna Electric. To the extent that NERC regulated tariffs—guided by FGN policy on access—combined with other revenue sources potentially available to a utility[10] do not allow recovery of 100 per cent of the capital expenditures (capex) of the access scale program (investment in MV, LV and final service drops and connections, meters); the universal access policy would need to identify the means and mechanisms for providing public funds to bridge the shortfall (investment financing gap associated with the access rollout implementation each year). Such funding would need to be ex-ante, administered transparently and backed by independent regulatory review, oversight, monitoring and compliance process of the physical program implementation, and by an independent and competent trust agent to administer the funds flows and reporting requirements.

Phasing strategy for implementation of the electrification programme (2016–2023)

In light of the Readiness Assessment considerations highlighted above, this section recommends a time-phased implementation (2016–2030), as shown in Table 3:

- *Phase 1 (present-2017 end) — Laying essential groundwork*
- *Phase 2 (2018–2023) — Building momentum and acceleration in scale of implementation (grid and off-grid)*
- *Phase 3 (2024–2030) — Full throttle grid electrification rollout*

Phase I allows for time essential to prepare for program launch (both on-grid and off-grid), which would require the timely undertaking of specific actions, as shown in Table 4, to set in place a policy and regulatory enabling environment and to acquire the capacity and materials needed for the programme implementation. Development partners could provide targeted support via technical assistance to strengthen the capacity ok key sector actors.

In particular, the preparatory phase should focus on three dimensions:

- ***FGN to prepare and enact National Universal Access Policy*** – to drive Nigeria's National Electrification Rollout Program for Universal Access as outlined above. The Policy will include access targets and supporting financing mechanisms.
- **NERC** – informed by the Universal Access Policy—to appropriately refine, expand and detail the MYTO framework and update its oversight, review and verification processes and mechanism to play its due role in support of the Universal Access Implementation Program.
- **Kaduna Electric** – to strengthen its organisational and functional capacities to implement the

Table 3 Electrification phasing for the Kaduna service zone

PHASE	Years	Activities
PHASE 1	2016–17	**Preparation** *Capacity-building* – directly linked to facilitate grid rollout consistent with achievement of annual connection targets. *Finalise national policy for enabling achievement of universal electricity access* – targets, public funding support, tariffs, and guidelines on service standards appropriate for range of off-grid access services (pre-electrification, as well as remote area); Regulatory framework: update tariff regulation and related oversight consistent with national access policy; to monitor achievement of DISCO targets for access per agreed annual rollout plan parameters. *Off-Grid program:* complete detailed design of key components of rollout; including institutional framework, service standards, certification, and annual targets to be achieved consistent with overall geospatial least-cost rollout plan (2015–2030) *Tier 1 and 2 beneficiary segments*[a] – market based supply and delivery chains for cash-and-carry pico-solar PV products and home systems that are quality certified. *Isolated mini grids* (Tier 3+) – identify business models that are commercially viable, and readily scalable, consistently with meeting off-grid program targets[b].
PHASE 2	2018–23	**Accelerate grid electrification carefully** *Grid:* Focus on intensification with some MV extensions. Build up experience. Substantial increase in grid access by 2023. *Off-grid*: launch pre-electrification program for Tier 1 and Tier 2 beneficiary segments. For Tier 3+ field test business models and schemes for isolated micro/mini-grid networks. For latter, focus priority on spatial locations projected to receive grid service after 2023; per geospatial least-cost plan.
PHASE 3	2024–30	**Full throttle grid electrification** *Grid*: Focus on extension of the MV grid; complete any remaining or emerging intensification. *Off- grid*: continue with pre- electrification where appropriate.

Note: the off-grid pre-electrification programme entails both communities that are not expected to receive access in the medium-term and those that are not expected to receive a grid connection by 2030.
[a] A Multi-Tier Framework for electricity access was developed by the World Bank Group under the Sustainable Energy for All (SE4All) engagement. The framework defines five different tiers of access for electricity supply corresponding to different electricity services is further discussed in Annex 4.
[b] Various donors are providing support for off-grid electrification in Kano zone and elsewhere including GIZ and DFID.

access scale up program particularly in relations to planning, design, procurement, construction management, contracting, materials management, quality and standards. In parallel, Kaduna Electric would continue to further reduce technical and commercial losses and strengthen its financial stance.

Grid rollout implementation (2018–2023) – Two scenarios

In light of the Readiness assessment findings and recommendations above, two scenarios are identified following completion of Phase I—laying the essential groundwork. They differ in the trajectory

Table 4 Preparatory Phase – Key Actions

Responsible agent	Action	Milestone
On-grid electrification		
FMP	Design and adoption of a National Access Policy	by end 2016/beginning of 2017
Kaduna Electric	Develop a plan for electrification showing indicatively when different areas will be electrified. This will allow them to be prioritised for off-grid electrification.	by end 2017
FMP/NERC/Kaduna Electric	Set electrification targets, targets developed in coordination with the NERC tariff review.	beginning early 2017
NERC/Kaduna Electric/ FMP	Update MYTO.	Begin early 2017 for implementation of new tariffs in 2018
Off-grid electrification		
NERC/GIZ	Finalise the revised regulation on Independent Electricity Distribution Networks.	early 2016
Kaduna Electric	Kaduna Electric management to decide role in relation to off-grid electrification – include in tariff submission to NERC in 2017.	early 2017

of the year-to-year implementation of the physical program on-grid; the number of connections implemented each year and speed and acceleration. They also differ in the underlying expectations on improvements in key constraining/inhibiting factors, especially: bulk power supply adequacy and variability; quality of enabling policy framework announced, and its provisions and mechanisms for public funding to bridge the capex financing gap; and a conducive and supportive regulatory framework for retails tariffs consistent with the universal access policy. Table 5 shows the annual implementation profile.

- ***conservative scenario*** – reflects a cautious trajectory due to the degree of progress in the sector environment, with slow enactment of key enabling actions and/or processes and funding mechanisms; power supply adequacy picture takes more time as well as Kaduna Electric's commitment and readiness to engage.
- ***best-practice scenario*** – reflects best practice experience in ramping up the physical rollout of implementation on a programmatic basis; that all key actors commit with top priority to putting their best efforts towards making this program achievable in Nigeria; especially FGN (policy), NERC (tariff framework) and Kaduna Electric.

- ***Conservative scenario*** – in the first two phases of the programme for Kaduna Electric, up to 2023, an investment financing requirement of US$ 400 million would be required for grid electrification. The on-grid electrification would begin cautiously with 30,000 new connections in 2018 rising to nearly 200,000 connections in 2023 and cumulatively over this period a total of nearly 550,000 new connections would have been made. The electrification rate would still be a relatively modest 53% at the end of 2023, compared with 49% today, but this would be the foundation for of a much more rapid electrification rate over the subsequent years with an annual electrification rate of up to 400,000 per year and ultimately bringing the electrification rate to 81% by 2030 and to 99% for social institutions such as schools and clinics.
- ***Best practice scenario*** – in the first two phases of the programme for Kaduna Electric, up to 2023, an investment financing requirement of nearly US$ 580 million would be required for grid electrification. The on-grid electrification would again begin relatively cautiously with 50,000 new connections in 2018 rising to 325,000 connections in 2023 and cumulatively over this period a total of 775,000 new connections would have been made. The electrification rate would still be nearly 57% at the end of 2023. Over the subsequent years the annual electrification rate would

Table 5 Electricity access rollout programme (2018–2030)[a]

Access Rollout 2018–2030								
2015 (baseline):	**Conservative scenario**				**Best practice scenario**			
	Grid connections: 2.1 mn.	**Grid access rate: 49%**	**Institutions connected: 1,583**	**Institutions access rate: 20%**	**Grid connections: 2.1 mn.**	**Grid access rate: 49%**	**Institutions connected: 1,583**	**Institutions access rate: 20%**
	New connections ('000)	**Progressive access rate (%)**	**New connections**	**Progressive access rate (%)**	**New connections (#)**	**Progressive access rate (%)**	**New connections**	**Progressive access rate (%)**
2018	30.0	47%	500	20%	50.0	48%	500	20%
2019	40.0	47%	750	25%	75.0	48%	800	26%
2020	50.0	47%	850	31%	75.0	49%	950	32%
2021	93.4	48%	1000	38%	105.9	50%	1050	39%
2022	136.8	50%	1350	47%	144.8	52%	1400	49%
2023	198.0	53%	1497	57%	324.6	57%	1547	60%
Total additions 2018–2023	548.2		5,947		775.3		6,247	
Total connections by 2023	2,621.2	53%	8,400	57%	2,848.3	57%	8,700	60%
Total connections added 2024–2030	2,052.0		6,084		2,950.0		5,784	
Total connections by 2030	4,673.2	81%	14,484	99%	5,798.3	99%	14,484	99%

[a] Note, the electrification rate declines between 2015 and 2018 because, despite some electrification in 2018, this has not kept pace with the growth in the number of households. The same is not true of social institutions where the total number of institutions is assumed to be fixed (instead the size of the schools and clinics grow as the population grows).

increase up to 500,000 connections per year ultimately bringing the electrification rate to 99% by 2030 2030 and to 99% for social institutions such as schools and clinics.

Investment financing prospectus – Grid rollout (2018–2023)

Table 5 summarizes for the two scenarios for the capital requirements of the physical programme. Cumulatively, the implementation of the conservative rollout is estimated to require US$ 2 billion by 2030, whereas US$ 3.1 billion are estimated for the best practice rollout. The year-to-year capital costs are also displayed, together with the investment need for the construction of LV and MV lines. As shown in the Table, the conservative scenario up to 2030 is relatively less focused on MV extension (US$ 920 million), and the investments are mostly directed to the construction of LV lines (over US$ 1 billion). In the best-practice scenario, investments in LV lines are coupled with more investments in MV extension (US$ 2 billion), which are pursued more aggressively in time (starting in 2020 instead of 2021) and size (2.1 million new connections versus 1 million in the conservative scenario), and the main reason underpinning greater achievements in access by 2030.

Table 7 presents the incremental impact on demand due to new connections by 2023, which is nearly 220 MW in the conservative scenario and 310 MW in the best-practice one. This should be manageable.

Table 6 Grid rollout capital investment cost (2018–2030)

Conservative scenario 2018–2030									
		LV Intensification			**LV Intensification**			**Total**	
	Grid access rate	**New grid connections ('000)"**	**$ per connection**	**Total cost ($ mn.)**	**New grid connections ('000)"**	**$ per connection**	**Total cost ($ mn.)**	**Average $/ connection (LV+MV)**	**Total LV+ MV/$ mn.**
2018	47%	30	670	20	0	n/a	0	670	20
2019	47%	40	670	27	0	n/a	0	670	27
2020	47%	50	670	34	0	n/a	0	670	34
2021	48%	63	670	42	30	852	26	728	68
2022	50%	97	670	65	40	857	34	725	99
2023	53%	148	670	99	50	866	43	720	142
Total prospectus: 2018–2023		428	670	287	120	860	103	711	390
Total: 2024–2030		1,172	670	785	880	928	817	781	1,602
Total program life: 2018–2030		1,600	670	1,072	1,000	920	920	766	1,992
Best-practice Scenario 2018–2030									
		LV Intensification			**LV Intensification**			**Total**	
	Grid access rate	**New grid connections ('000)"**	**$ per connection**	**Total cost ($ mn.)**	**New grid connections ('000)"**	**$ per connection**	**Total cost ($ mn.)**	**Average $/ connection (LV+MV)**	**Total LV+ MV/$ mn.**
2018	48%	50	670	34	0	0	0	670	34
2019	48%	75	670	50	0	0	0	670	50
2020	49%	75	670	50	0	0	0	670	50
2021	50%	76	670	51	30	858	26	723	77
2022	52%	105	670	70	40	864	35	724	105
2023	57%	145	670	97	180	881	159	787	255
Total prospectus: 2018–2023		525	670	352	250	875	219	736	571
Total: 2024–2030		1,075	670	720	1,875	966	1,812	858	2,532
Total program life: 2018–2030		1,600	670	1,072	2,125	956	2,031	833	3,103

Table 7 Impact on electricity demand

Year	Conservative		Best practice	
	Grid access rate	Demand impact (MW)	Grid access rate	Demand impact (MW)
2018	47%	12	48%	20
2019	47%	28	48%	50
2020	47%	48	49%	80
2021	48%	85	50%	122
2022	50%	140	52%	180
2023	53%	219	52%	310

Investment financing gap (2018–2023)

The investment financing requirements are indicated in Table 8 below for the two electrification scenarios. This provisionally assumes an equity contribution by Kaduna Electric's shareholders of 10% of the capital required[11]. This assumes that Kaduna Electric's shareholders are comfortable that the regulatory framework going forward will reward them sufficiently for the risks entailed in such investments and that the market reforms continue to show results in terms of improved availability of electricity at the wholesale level.

The DISCOs were privatised at the end of 2013 (Kaduna Electric at the end of 2014). The 2005 Electric Power Sector Reform Act prescribes the regulatory framework governing them, such that the companies should earn revenues that cover their costs and provide a reasonable market return on the capital invested. For the DISCOs, any investment they make in the expansion of electricity access would therefore need to be undertaken on a commercial basis.

The current owners of the DISCOs largely financed the acquisitions of the companies with loans securitised against the parent companies' assets, not against the DISCOs' own profits. Nigerian commercial banks are currently unwilling to finance the DISCOs' investments or to finance revenue shortfalls when securitised against the DISCOs' revenues on terms that are consistent with the MYTO allowed revenue formula. Borrowing by the DISCOs on commercial terms to finance investments that are needed simply to create a stable platform to supply their existing customers is therefore problematic[12],

Table 8 Investment financing requirements for grid electrification ($ million)

	Conservative	Best practice
Capital investment requirement (2018–2023)		
2018	20	34
2019	27	50
2020	34	50
2021	68	77
2022	99	105
2023	142	255
Total capital investment	**390**	**571**
Minus: Assumed Kaduna Electric equity (assumed 10%)	39	57
Connection charges	-	-
Plus technical assistance	11	16
Total financing gap	**362**	**529**

and major borrowing on commercial terms on any scale to expand the network is unlikely over the first phase of the electrification access programme. We tentatively assume for illustration purposes, that Kaduna Electric's shareholders may be willing to contribute 10% as an equity contribution (injections or retained profits)[13].

The resultant financing gap is assumed to be financed in some manner consistent with international best practices, highlighted above. Namely, the international experience with undertaking national electrification programmes has almost universally been largely financed through grants and concessionary loans[14] obtained by the Government from a variety of sources including Development Partners, Provincial Governments, Local Authorities, and on lent to the utility; on terms that ensure the commercial viability of the implementing agent, be it private or a public entity.

Financing mechanisms and on-lending terms for public funds support

Based on international electrification rollout experiences[15] we suggest the establishment of an Electrification Fund that will be used to provide financial support to the private DISCOs when expanding access. The Fund will on-lend to DISCOs publicly raised funding on terms that are commercially viable, whether in the forms of grants or concessional loans, and will also keep DISCOs accountable for the financing received by monitoring and auditing their progress. As shown by international experience, it would be the Government responsibility to (i) secure the funding and (ii) ensure its availability before the electrification rollout takes off.

Various arrangements have been adopted worldwide for this kind of institution, but all of them responded to four main principles: transparency, accountability, independence and ex-ante funding of the programme. The Fund management will act as a trust fund payment agent and will be subject to specific rules and guidelines, with the supervision of NERC, governing cash-flow management and in particular how the financial resources are to be dispersed, monitored and, in the case of loans, returned. Finally, if the Fund is to be housed at an already existing agency (e.g. NERC), firewalls will have to be raised between the two entity to ensure the independence of both.

Technical assistance

Technical assistance directed to key sector institution and agents is envisaged for the acquisition of the capacity required for the physical implementation of the access rollout and for the design and establishment of the enabling policy, legislations, and regulatory instruments that would set the stage for and ensure the successful execution of the electrification programme. Although some support should be directed toward the achievement of the key actions to be undertaken in the phase preliminary to the access rollout (described in Table 4), capacity strengthening will be needed on an ongoing basis during the implementation phase as the programme expands and accelerates.

A proposed technical assistance programme for capacity strengthening is described in below. The programme is indicative, as the detailed scoping and its quantification will ultimately be defined by the more specific actions that Kaduna Electric, the private sector and FGN will decide to undertake to close the gaps and solve the ambiguities related to the policy and regulatory framework and to the role of public finance within the programme.

Two main areas of assistance are identified:

- ***Programme design:*** FGN to prepare and enact National Universal Access Policy coordinating grid and off-grid solutions comprehensive of targets and timetables and ensuring the commercial viability of the programme for the DISCOs together with affordability of electricity services for consumers. The policy will identify the key roles and responsibilities of sector stakeholders, fill the gaps for the establishment of an enabling legislative and regulatory environment, including mechanisms to monitor progress and a system of rewards and penalties of performance toward the achievement of the access targets;
- ***Physical implementation***: Kaduna Electric to acquire the organizational capacities to implement the access scale up program (particularly in relations to planning, design, procurement, construction management, contracting, materials management, quality and standards) and supervise private sector contractors. The rollout will require large scale training of contractors to expand the work force and to bring private manufacturing up to standard, to be achieved for instance through the capacity expansion of the National Power Training Institute of Nigeria (NAPTIN)[16].

Table 9 Technical assistance (TA) programme (present – 2023) – US$ million

Beneficiary	Measures	Conservative	Best practice
Kaduna Electric	Planning (yearly program), tendering, management, supervision	2.5	3.0
	Strengthening of standard equipment specification, policies & procedures, procurement, mains records (location of plant)	1.0	1.0
	Customer Relationship Management	0.5	1.5
	Off-grid electrification assessment	0.5	0.5
	Sub-total	4.0	5.5
Ministry of Power	Planning, training for private contractors[a] other activities	5.3	8.0
Private manufacturers	Technical assistance to ensure manufacturing processes are up to standard	1.0	2.0
NERC	To be determined		
REA[c]	To be determined		
Monitoring & evaluation		0.2	0.2
Ministry of Finance	To be determined		
Total		11.0	16.2

[a] This could be provided through NAPTIN, the electricity training institute based just outside of Kano.
[b] Nigerian Electricity Regulatory Commission (NERC).
[c] Rural Electrification Agency.

Off-grid programme

Although connection to the grid is the least-cost solution in the long-run for most of the population, to ensure shared well-being and prosperity across the country, off-grid solutions should also be employed in coordination (in space and time) with and to complement grid developments.

More specifically, on the basis of the geospatial analysis, two categories of beneficiaries of off-grid solutions can be identified:

- ***Long-term off grid*** – small communities or households residing in remote and isolated[17] areas where the grid is not recommended as the least-cost option by 2030. This is a very small percentage of the total population and of schools and clinics (only about 2,500 households by 2030 or less than 1% of the overall access programme, including provision to social institutions).
- ***Pre-electrification*** – households residing in areas targeted for grid electrification in the latter part of the electrification programme which will thus be required to wait potentially for several years (5 to 10, if not longer) for electricity access.

This is potentially the largest component of the off-grid programme and, depending on the electricity access services provided, it could be characterized by two subcomponents:

i. ***Tier 1&2 access delivery*** – The *economic* potential of this off-grid sub-programme refers to the ~3 million households that are not expected to receive access to the grid during the first 5 years of the electrification programme (up to 2023) regardless of the conservative or best-practice trajectory implemented (see Table 5)[18].
ii. ***Tier 3+ access delivery*** – the *technical* potential for isolated mini- and micro-grids is identified in the latter segment of grid development (in space and time), requiring the extension of MV lines and affecting 2.1 million households (see also Table 5).[19]

These communities and households could be provided with sufficient power for essential electricity services such as household lighting, charging of mobile phones and other batteries and devices, and basic connectivity for schools and clinics to power computers, vaccine cold chain, and other services.

Given the country's richness in solar resources, the technologies identified to provide off-grid services are pico-solar, solar home systems or diesel or hybrid mini-grids, although a thorough geospatial resource mapping of the country, completing the exercise started by GIZ, could reveal more renewable energy opportunities. For the Kaduna service zone, the costs associated with these technologies identified by the Earth Institute are in the range of US$50–100 per household for pico-solar, US$300 on average for solar home systems, and between US$500 to US$1,2000 for mini-grids.[20]

The costs associated with an off-grid programme will eventually depend on its size (that is, on the number of beneficiaries, their needs, and the technologies deployed) and are potentially substantial. For instance, given per-household SHS costs, the needs of the long-term off-grid beneficiaries could be met for less than US$ 1 million. . As regards pre-electrification purposes, the full rollout of the Tier 1 &2 programme could require almost US$ 395 million alone (with an average combination of pico-solar and SHS solutions). Not strictly belonging to the off-grid access programme, but a potentially important segment of the off-grid market is constituted by the use of off-grid solutions for power back-up purposes. This market refers to households already provided with electricity access in 2015, or to be connected during the rollout plan, that could choose to rely on off-grid technologies for power back-up as long as the power supply provided by the grid is not reliable (high fluctuation of voltage, blackouts and load shedding). This could also constitute a significant component of the off-grid developments, as Nigeria is the second market for self-generators, far more expensive than efficient off-grid solutions would be.

Several factors constrain the growth of the solar market in Nigeria, particularly lack of access to finance for importers, distributors and consumers[21]. Hence, a financing plan—tailored to the current market structure—should be developed to support off-grid developments. The plan could envisage a combination of private sector and public sector-led endeavours:

- **Private sector-led off-grid –** the establishment of a credit line for off-grid electrification was very successfully introduced in countries such as Ethiopia and Bangladesh.[22] The financing mechanism can be designed to create a market-driven, private sector-led approach addressing some of the main issues preventing the off-grid market from taking off such as: access to finance at relatively lower cost of capital, improvements to the general lending environment, and identification of commercially viable delivery models. A line of credit could be opened to support DISCOs or small and medium sized private sector enterprises, and it could either become integral part of the Electrification Fund suggested for the on-grid rollout or established separately.
- **Public sector-led off-grid –** building on the National Renewable Energy and Energy Efficiency Policy adopted in 2015, stating that solar PV and SHSs will be used to power low to medium power applications such as communication stations, water pumping and refrigerator in public facilities in remote areas, the FGN could provide electricity access to all public institutions across the country.

The successful implementation of a large scale plan would also require tackling the other major obstacles to off-grid electrification. In particular, roles and responsibilities of sector institutions (e.g. Rural Electrification Agency) and stakeholders should be identified in the new market structure, leading to the establishment of an enabling policy and regulatory framework. This would include designing and enforcing quality standards and possible subsidy frameworks. The establishment of technical standards for off-grid technologies will also be key to protect protect investors' businesses after the arrival of the grid, after which off-grid solutions can become power supply back-ups and/or feed into the grid network. Finally, off-grid electrification will have to be undertaken in coordination with the actual spatial grid rollout of Kaduna Electric in the next five to seven years.

Endnotes

1. The Prospectus' findings and recommendations are specific to the operating situation of Kaduna Electric and in light of the broader sector-wide framework and operating environment context of Nigeria today. At the same time, the analysis and recommendations of the Prospectus are informed by the rich lessons and experiences of relevant best practices from national electrification programs from numerous countries world-wide, that have successfully navigated their respective electrification programmes to universal or well advanced access (Morocco, Indonesia, Vietnam,

Thailand, Tunisia, Kenya, among others). While in each instance the specific design features were home grown and tailored to their institutional environment and political economy, they all exhibit adherence to a set of core organizing principles and policy drivers that were necessary to enable their achievements.

2. Earth Institute, Nigeria Electricity Access Program (NEAP) Kaduna zone, Geospatial Implementation Plan for Grid and Off-Grid Rollout.
3. As per discussion with the utility. We understand that connections targets for access scale up (to the estimated 51 % without access in 2015) may be revisited as DISCOs requested a review and update of the Performance Agreement parameters originally entered into with BPE.
4. All costs throughout the text and tables of this document are in constant 2015 US dollars, unless otherwise noted.
5. Ensuring adequate electricity supply to all customers served by Kaduna Electric is urgent. As of 2015, average peak supply to Kaduna Electric was typically around 240 MW with occasional higher amounts up to 360 MW. This is well below the 1.6 GW that Kaduna Electric estimates to be its total current demand.
6. The access targets stated in the original Performance Agreements entered into with FGN/BPE have been essentially treated to this day, by all parties, as "pro forma place holders", to be revisited and revised appropriately; once the DISCO managements assumed control and gained some operating experience and obtained hand first knowledge of the ground realities facing the company.
7. See next section.
8. Kaduna Electric's accumulated deficit from privatization through 2015 is $80 million. These figures represent the unpaid share of costs of bulk power purchases over this period. Kaduna Electric like all other DISCOs faces this systemic under-recovery for their respective bulk power purchase costs. Regardless of the circumstances, sooner or later, FGN together with NERC would need to satisfactorily and speedily resolve and redress this situation. Carrying such amounts of "accounts payables" on the balance sheets does not bode well for any DISCO to raise even short terms working capital from financial markets.
9. As per NERC 2012 Regulation DISCOs are currently not allowed to impose connection charges, but the policy could be apt for revision at some stage of the access rollout.
10. For example: connection charges, utility equity, bill surcharge on non-poor customers within the Kaduna service zone.
11. At the time of drafting this Report, the shareholders, IFIs and development partners were not in a position to comment on their likely willingness to provide equity, debt or grants. The mix of financing provided here are therefore placeholder values.
12. World Bank estimates, February 2016.
13. The 10% equity contribution is consistent with international experience from countries such as Brazil, though it may be optimistic for Nigeria.
14. Examples described in the Report include Brazil where 90% of capital expenditures were financed from grants and concessionary loans and India where 100% is financed in this way.
15. Brazil, India and Chile, for instance.
16. NAPTIN was formerly part of the Power Holding Company of Nigeria (PHCN) but is currently owned by the Federal Government of Nigeria (FGN).
17. Defined by the geospatial report as areas where households average more than 100 metre distance from neighbouring households.
18. The successful experience of the WBG Lighting Africa and Lighting Global initiatives in Africa (see, for instance, the experiences of Kenya, Ethiopia and Tanzania) and Asia demonstrated that Tier 1 &2 products can be rapidly scaled-up, although not yet at the scale of ~3 million households (international experience suggest that ~30% of the size could be easily provided with access). World Bank Task Team Leaders estimates, 2016. For more information, visit: https://www.lightingafrica.org/.
19. No country has yet scaled-up an isolated mini- or micro-grid programme and the identification of viable business models is still a work in progress. However, international experience suggests that the market potential for this off-grid development is to date around 10% (i.e. 210,000 connections of the 2.1 million potential beneficiaries). World Bank Task Team Leaders estimates, 2016. The WBG Lighting Global started to operate in the Tier 3+ access delivery market.
20. The geospatial analysis identified the cost for a mini-grid with a service standard of 120 kWh/HH-year to be in the range of US$1,000–1,200 and for a 60 kWh/HH-year per customer service, between US$500 and US$700.
21. Other factors include: i) lack of an enabling policy and regulatory framework; (ii) lack of national

quality standards for PV products and competition from low quality products; (iii) low levels of awareness of solar products, their advantages and ways to distinguish good quality products; and (iv) low availability of products due to lack of distribution networks in rural areas. Lighting Nigeria, 2015.

22. Bangladesh SHSs program has been widely acknowledged as the most successful national off-grid electrification program in the world reaching 100,000 installations a month.

CHAPTER 1

Background – Kaduna service zone and Kaduna Electric

Kaduna Electric is responsible for the distribution and supply of electricity to users in the four states of Kaduna, Kebbi, Sokoto and Zamfara in the North West of Nigeria.

The four states served by Kaduna Electric have a combined population of 28.4 million. Kaduna is Nigeria's third most populous of Nigeria's 36 states[1] after Kano and Lagos. All the four states have a relatively high population density. Today, grid electricity in the Kaduna service zone is available to approximately 49% of the population. By 2030 the population of the four states is expected to reach nearly 40 million, which will add a further 1.5 million households to the zone for a total of 5.8 million households. Under business-as-usual, the share of the population without access will grow, not diminish.

North West Nigeria has a high concentration of poverty. The *Updated Poverty Map of Nigeria* prepared by Oxford University for the World Bank[2] indicates that Kaduna state is 22nd out of 36 states in terms of poverty but Sokoto, Kebbi and Zamfara are among the bottom ten, having 85%, 86% and 92% incidence of poverty respectively[3] compared with a national average of 53%. There is also a correlation between poverty and low electrification rates.

1.1 The market and regulatory framework

Kaduna Electric was privatised, one year after the other nine of Nigeria's DISCOs, at the end of 2014[4]. The Nigerian Electricity Supply Industry (NESI) had experienced years of under-investment and poor management in all parts of the electricity supply chain from fuel supply through to distribution and customer supply. This resulted in chronic power shortages across the whole country and privatisation was an attempt to remedy these problems. The new DISCOs' management inherited a number of major issues including massive Aggregate Technical, Commercial and Collection (ATC&C) losses estimated after the completion of the privatization process at around 50%[5], very poor customer record keeping and billing systems, poor network maintenance and overloading of lines and transformers, and very low levels of supply reliability. The problems are well documented[6].

Although the 2010 Power Sector Reform Roadmap has achieved important goals, such as the completion of the privatization process for the generation and the distribution segments, the establishment of the Nigerian Electricity Regulatory Commission (NERC) and the Nigerian Bulk Electricity Trader (NBET), the speed of the ATC&C loss reduction programme that had been anticipated at the time of privatisation[7] has not been achieved and by the end of 2016 DISCOs will have accumulated almost US$3 billion[8] owed to the rest of the value chain.

Kaduna Electric inherited ATC&C losses of 47.6%, the majority of which are due to collection losses (27.5%)[9]. The utility has now been in private ownership for just a year and management are attempting to come to grips with the problems of enumerating customers, collecting revenues and computerising basic accounting and management systems. The utility has accumulated deficits of US$79.5 million. However, in 2015 Kaduna Electric was able to pay less on average 24% of NBET invoices. Although the Performance Agreements came into effect in January 2015, cost-reflective tariffs were adopted but subsequently abandoned until February 2016, and the utility had not made any investments in improved efficiency at the time of collecting data in June 2016.

With the implementation of the new MYTO 2015 in February 2016, tariffs were brought back to cost-reflective levels, however, to reduce the impact on end-consumers they were set at under-recovery for the first few years then allowing for over-recovery for the achievement of cost-recovery levels over a ten-year period. The size of under-recovery has been estimated at almost US$700 million for 2016 or 16% of expected total revenue for the whole sector. Kaduna Electric is expected to achieve cost-recovery levels until the beginning of 2017[10] and will hence keep accumulating deficits on account payables until then.

The regulatory framework for tariffs covering the next 5–10 years, does not make allowance for large scale electrification investment and this will need to be remedied before the electrification programme can be launched. Under MYTO 2015 tariff revenues are also in-sufficient (fixed charges were also removed and public administration arrears were deducted from the account of collection losses[11]) to cover 100% of operating expenses.

During the last round of tariff revision, the DISCOs complained that insufficient capex had been allowed in the MYTO 2015 calculations to allow them to meet the Minimum Performance Targets contained in the Performance Agreements. However, NERC did not approve an increase in this allowance. In MYTO 2015 the capex allowance was actually decreased for some DISCOs; NERC argued that this was because the DISCOs had not made use of the capex allowance that they had previously been allocated. The DISCOs had not made investments because in an environment where tariffs were non-cost-reflective, they were unable to raise capital to fund capital expenditure, implement their business plans and invest in metering and loss reduction activities.

A reduction in its capital allowance was not the case for Kaduna Electric, given that it was privatized later than the other DISCOs, although it may experience an equivalent capex reduction in the future. The DISCOs are allowed to file for upward revisions if and when they can demonstrate that the expenditure is necessary and are able to prove that they have sufficient funding sources for planned capital expenditure.

Wholesale generation and transmission is also inadequate to supply electricity to meet the demand implied by a rapid roll-out of electrification. The company is currently allocated with 8% of total generated power, but in 2015 received only 240 MW on average due to transmission constraints and at the beginning of 2016 power supply was further decreased because of sabotage of gas pipelines by militants. Power supply is therefore characterized by inadequacy and unpredictability, adding further pressure on Kaduna Electric's planning capacity and financial conditions (tariffs are currently adjusted to changes in the baseline with a 6-month time lag).

The utility, together with all the other DISCOs, is still attempting to correct years of under-investment and poor management of the industry by focusing on stabilising its business and generating cash flow for the establishment of a solid financial and electrical foundation for moving forward. It is therefore not immediately in a position, financially or managerially, to prioritise a major electrification programme. Even if the Business Plan submitted at privatization (and entered into force in January 2015), listed as part of Kaduna Electric's Minimum Performance Targets the connection of 191,260 customers in a five-year period, the target involved mostly meter deployment to existing consumers more than access provision[12].

Kaduna Electric also has limited experience of extending electricity grids on any scale, and it has limited human, materials and technical resources for undertaking a major electrification programme. However, these are not "systemic" challenges, and could quickly be addressed.

1.2 Geospatial least-cost plan for universal electrification

A geospatial analysis conducted by the Earth Institute under a separate contract with the World Bank disclosed that 2.1 million households in the four states are supplied from Kaduna Electric's grid, representing an electrification rate of around 49%. This is at the top end of estimates of the current overall national grid electrification rate that is thought to be around 35%–40%[13].

The geospatial analysis provided a detailed assessment of the optimal technologies to electrify the population of the Kaduna service zone and the investment cost to achieve 100% electrification by 2030. The plan identified the optimal electrification strategy for the year 2030 with the electrification of all households either through connection to Kaduna Electric's grid or through off-grid solutions for remote population and isolated households or as interim solutions before grid arrival. The results of the geospatial analysis for the grid extension program, including highlights of the physical programme spe-

Table 10 Electricity access in 2015 and grid extension programme for the Kaduna service area, 2015–2030

Electricity access status (2015)			Grid extension program (2015–2030)*				
Type of access	Population (Households)	Percent	Components of grid program (Type of grid access planned)	Population[a] (Households)	Percent	Total CAPEX (M USD)	CAPEX per HH (USD)
Grid access	14,100,000	49%	**A) Customers:** Kaduna has ~400K customers (2015); almost all need meters ($275/HH)(2015); 63% need meters ($160/HH)	2,600,000 (400,000)	9%	$105[b]	$275
	(2,100,000)		**B) Consumers:** ~1.5 m HHs (2015 est.) consume power but do not pay Kaduna; all need meters & improved connections (~$400 per HH)	11,500,000 (1,700,000)	40%	$685[c]	$400
No grid access	14,500,000	69%	**C) LV intensification:** By 2030, ~1.6 M HHs near the grid will need LV line, meter, connection (~$670 per HH)	10,600,000 (1,600,000)	27%	$1,060	$670
	(2.200,000)		**D) MV grid extension:** By 2030 ~2.1 M more distant HHs from transformer will need MV and LV line, connection, meter (~$920 per HH)	14,300,000 (2,100,000)	37%	$1,950	$920
Total	**28,500,000**	**100%**	**Total**	**38,900,000**	**100%**	**$3,800**	**$650**

Source: Earth Institute, 2015.

[a] It is assumed that population growth from 2015–2030 among those who currently have grid access (components A and B) will lead to net formation of new households that will need new connections requiring LV intensification (component C), MV grid extension (component D).

[b] Not included as part of the electrification access programme.

*As above.

cific to each state belonging to the Kaduna service zone are summarized in Table 10 and Table 11 below.

The geospatial planning study found that:

- Kaduna Electric has approximately 400,000 customers who are billed (Component A: customers).
- About 1.7 million households are served with electricity but are not registered as customers, they all require meters. (Component B: consumers).
- Though not formally "electrification", customers without a meter and consumers together are the lowest hanging fruit for a DISCO as they require a one-time very low capital investment to install appropriate metering and integrate them into the customer billing and revenue collection systems; thereby boosting otherwise lost revenues from energy purchased but unbilled. From a commercial and business perspective this represents a high yield and quick payback investment opportunity.
- Combining the customers with the consumers, 2.1 million households are currently supplied from Kaduna Electric's grid, whether paying for electricity or not (representing an electrification rate of around 49%).
- Between now and 2030 some 1.6 million households that are close to the existing grid could be connected without extending the MV network. These would represent 27% of households in 2030. At an estimated cost of US$690 per connection, the total cost of this investment would be just over US$1 billion. The majority of this intensification will target Kaduna state, the most urbanized state within the Kaduna service area.
- Another 2.1 million households, or 37% of all households in 2030, could be connected economically by extending the MV network at an average cost of US$920 per connection inclusive of MV and LV costs. The total cost of this investment would be slightly below US$2 billion. This

Table 11 Technical summary for the LV intensification and MV extension components of the universal access programme for the Kaduna service area, 2015–2030

	Number Household Grid Connections Proposed ('000)		Grid Length Proposed (km)				New Generation Needed (MW) for Residential Connections	
			MV Grid extension			LV Intensification	MV Grid Extension	LV Intensification
State	**MV Grid Extension**	**LV Intensification**	**MV**	**LV**	**MV/HH (km per 1,000 HH)**	**LV**		
Kaduna	578	652	14,300	16,800	24.7	15,500	230	260
Kebbi	408	334	6,200	12,100	15.2	9,300	160	130
Sokoto	575	414	4,500	16,800	7.8	11,200	270	200
Zamfara	568	188	8,100	16,900	14.3	4,800	210	70
Sub-total	**2,129**	**1,588**	**33,100**	**62,600**	**15.5**	**40,800**	**870**	**660**
Total	**3,717**		**136,500**				**1,530**	

Source: Earth Institute, 2015.

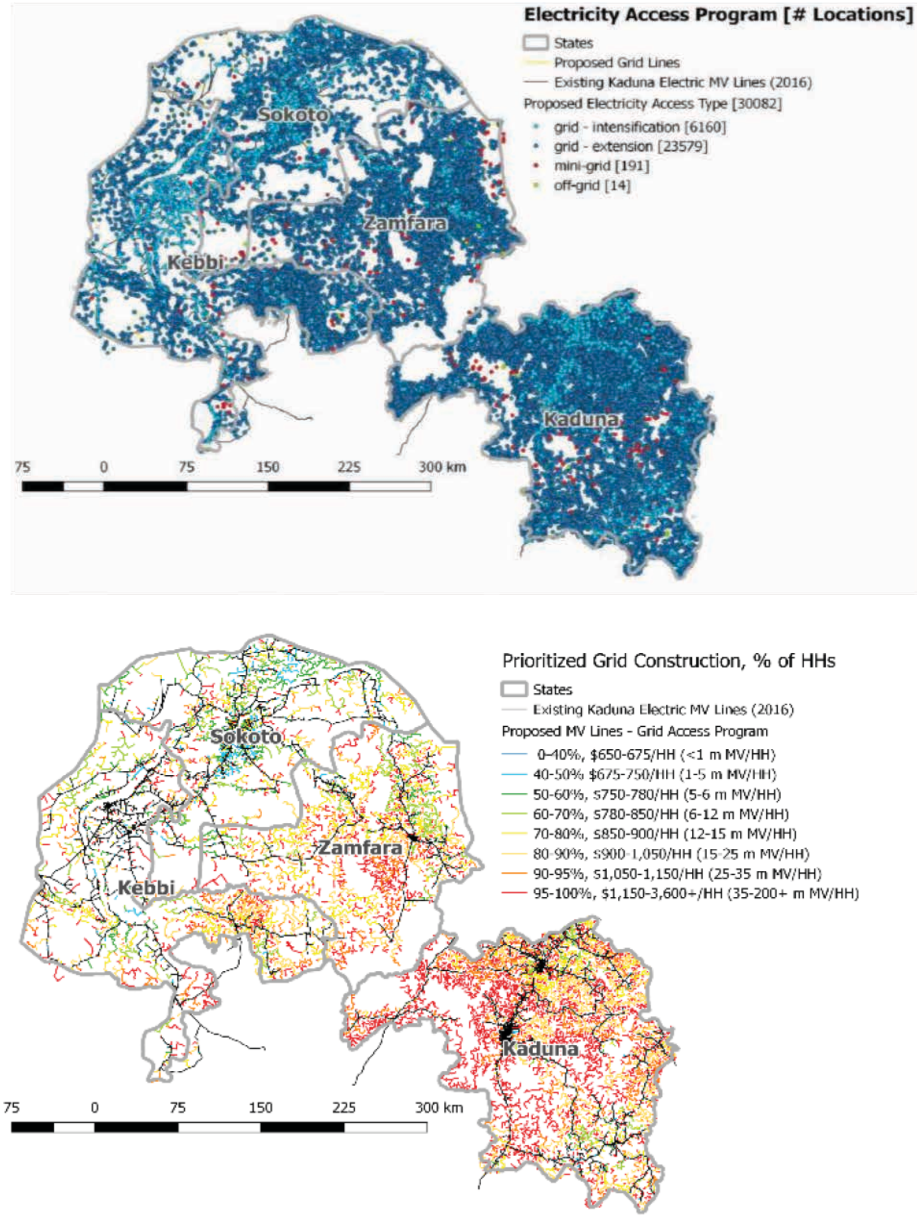
part of the electrification programme has been further subdivided by the Earth Institute into five phases, with increasing distance and cost. The program would require about 36,000 km of additional MV line, approximately tripling the length of the Kaduna Electric's existing MV distribution network and the investments are relatively evenly spread over the four states in the Kaduna service zone.

- For less than 1% of households in the Kaduna service zone off-grid solutions would be the least-cost option by 2030, together with households and communities which are targeted for grid connection in the latter part (beyond the medium-term) of the MV grid extension plan for which pre-electrification arrangements should be developed.
- The access rollout will add 3.7 million new residential customers with an incremental demand of about 1.5 GW, around 650 MW of which is attributable to intensification, while the other 870 MW would result from MV grid expansion. It is assumed by the Earth Institute that each new Kaduna Electric residential customer will add, on average, around 400 W of peak demand to the system.

The geospatial planning study conducted by the Earth Institute showed that there is a binary ***economic*** choice of electrification technology in the Kaduna service zone. This choice is between grid electrification on the one hand and distributed (mini-grid an off-grid) solar on the other. Because the majority of households lie within a short distance of the grid, for the majority of households (nearly 100%) the optimum electrification strategy *by 2030* was found to be connection to the main grid, as illustrated in Figure 1 below. The geospatial analysis also found that intensification (44,000 of the 140,000 km of new grid lines) represents around 30% of the physical assets (by length) required by the electrification programme, with the potential of providing access to 27% of the projected population by 2030, excluding those already connected, and to 63% when including customers and consumers already connected for the Kaduna service area. Connections through MV extension will provide access to about 37% of the population by 2030, constituting the single biggest component of the access programme.

The geospatial analysis indicates that only about 20% of public institutions (20% of schools and 24% of health facilities) are currently connected, although 70% of the most important ones, such as hospitals, already have grid connections to the existing network. The least-cost plan also indicates that by the end of the grid-electrification programme, about 99% of the existing institutions will be connected (Figure 2 below). Grid intensification is expected to increase access to by ~35% from current

Figure 1 Map showing least-cost access provision by location (top), and the prioritized grid expansion plan based on average cost per household (bottom), 2015–2030



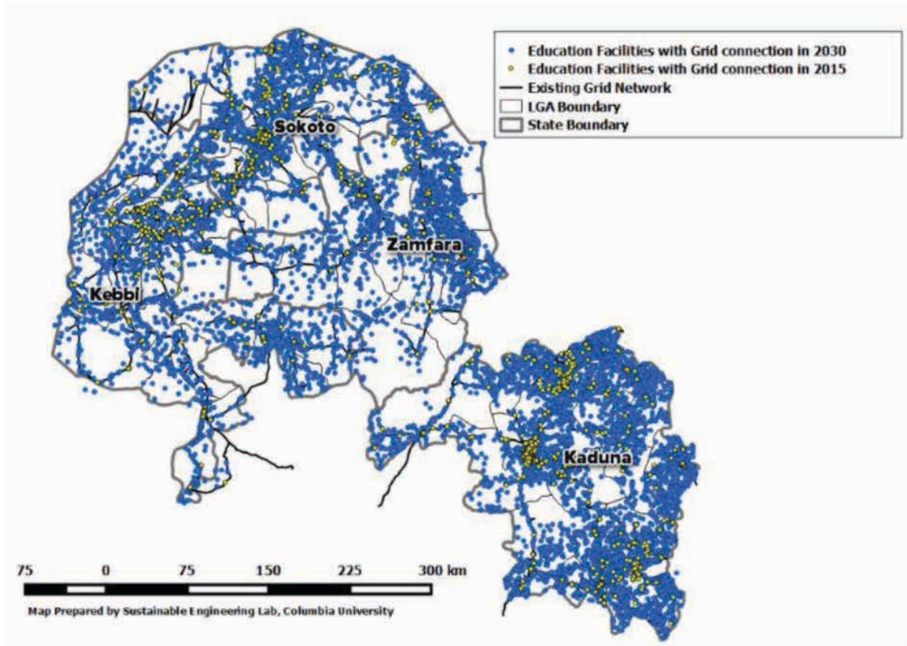
Source: Earth Institute, 2016[a]

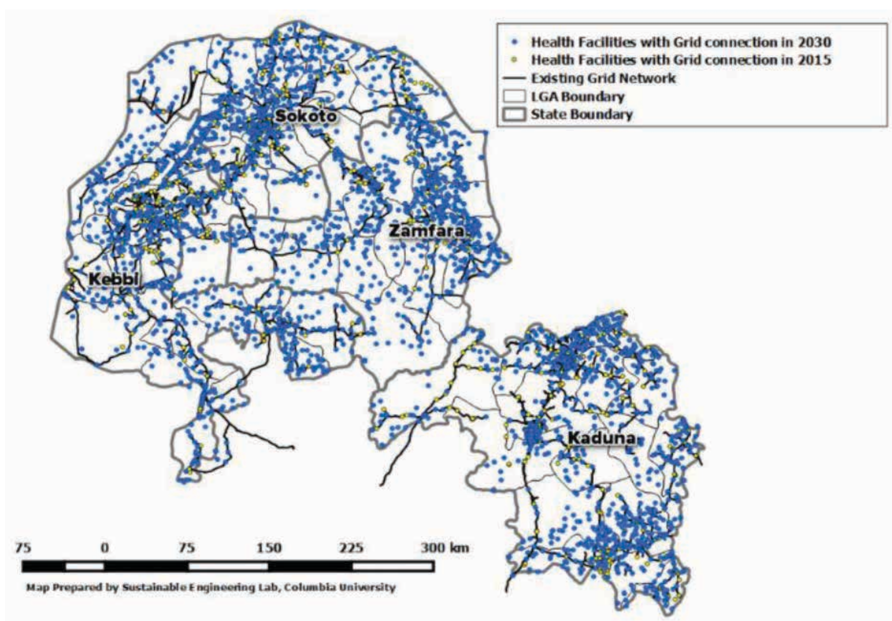
[a] Nigeria Electricity Access Program (NEAP) Final Report, Geospatial Least-Cost Implementation Plan for Grid and Off-Grid Rollout (2015–2030), August 2016.

levels (~20%), whereas MV extension would connect an extra 40/45%%.

Although connection to the grid is the least-cost solution in the long-run for most of the population, for those communities that are geographically remote, isolated) and/or scattered clusters, off-grid solutions (mini-grids, SHS and small-scale solar lighting/charging products) are the most cost-efficient.

Figure 2 Map showing that 99% of schools (top) and clinics (bottom) planned are best suited for grid connection (2015–2030)





Source: Earth Institute, 2016[a]

[a] Nigeria Electricity Access Program (NEAP) Final Report, Geospatial Least-Cost Implementation Plan for Grid and Off-Grid Rollout (2015–2030), August 2016.

The geospatial analysis revealed that less than 1% of the projected 2030 population will be best suited for off-grid solutions, together with about 1% of the existing schools and clinics.

The largest component of the off-grid electrification program potentially consists of households and communities[14] which are targeted for grid connections in the latter part (beyond the medium-term) of the 15-year MV grid extension plan and thus will be required to wait potentially for several years (5–10, if not longer) for electricity access. This could be a large group of beneficiaries, although, the size, target areas, cost and timing of a pre-electrification program will eventually also depend upon the actual implementation and sequencing of the rollout plan. The electrification possibilities for such pre-electrification areas are described in Annex 3.3.

Grid-coordinated pre-electrification plans will have to be developed as transitional measures since the grid is still the least-cost solution in the long-run, while at the same time designed to protect investors' businesses after the arrival of the grid. These pre-electrification transitional off-grid solutions could then become power supply back-ups and/or feed into the grid network.

A plan for off-grid will have to be separately developed and will have to identify the role of sector institutions, enabling policies and regulations, solar market developments and service delivery ability and modalities of interested and qualified providers. The off-grid plan will also identify Tier 1 and 2 electricity needs (see Annex 3.2), costs, commercially viable investment opportunities, and financing prospectuses to attract and syndicate funding from the private sector, donors, and government institutions (see also Chapter 6).

Endnotes

1. 2006 Census, population.gov.ng.
2. World Bank, *Updated Poverty Map of Nigeria*, Gething and Molini, June 2015.
3. This is a multidimensional definition of poverty adopted by the University. A person is identified as multidimensionally poor if they are deprived in at least one third of the weighted indicators including child mortality, education, access to infrastructure services, house size and assets.
4. The 11th DISCO was privatised but subsequently the private owner claimed force majeure and withdrew and it was taken back into government ownership.
5. The estimates of AT&C losses provided to bidders at the time of privatisation was much lower than the estimates revealed to the companies when they took over and gained full access to the DISCOs' records (around 50%).
6. See, for example: www.nigeriaelectricityprivatisation.com.
7. During the privatization process, bids were won on the basis of the ATC&C loss reduction targets.
8. World Bank estimates, May 2016.
9. The baseline of losses integrated into the new MYTO 2015 (implemented by NERC in February 2016) reports 27.5% of collection losses, 17.9% non-technical and 12.1% of technical losses. Note that the aggregate ATC&C losses of 47.6% is not additive.
10. World Bank estimates based on the MYTO model, March 2016.
11. For Kaduna Electric arrears from the public administration account for about 9 percentage points of total ATC&C losses.
12. As per discussions with the utility.
13. The figures of 35–40% for grid electrification is taken from a draft Nigerian Electrification Action Plan prepared by the World Bank (September 2015). The overall electrification rate, including own-generation, was thought to be around 48% in 2011. The latter figure of 48% is from World Bank Energy Data Table indicators 2012 report. The figure of 35–40% was derived from figures prepared by NERC and the Bureau of Public Enterprise and extrapolated to 2015.
14. The total number of households or communities targeted for pre-electrification will depend upon several factors that cannot be known at the time of this study, including the pace of grid expansion year-to-year, and the total funds available for these additional electricity systems.

CHAPTER 2

Indicative electrification programme

The geospatial plan concentrated on the optimal strategy for the year 2030 but in the sections below we show two scenarios—a **conservative** and **best practice** one—for the potential programme of connections over the period leading up to 2030. The conservative scenario assumes that greater time is need to allow improvements in the power market and the regulatory framework to take place, and that therefore it will not be possible to achieve universal electrification by 2030. The best-practice scenario is consistent with the 2030 optimum identified in the geospatial plan.

Although expanded electrification is currently not Kaduna Electric's priority, with the right regulatory, commercial and incentive framework, expanded electrification access should be an attractive option for the company to grow its business and expand its customer basis. For this reason, the electrification program is assumed to commence in 2018, allowing for a window to design the enabling policies and regulations for access rollout. The utility could use this time to concentrate on reducing losses and creating proper customer databases and billing systems and both the utility and the private sector could develop the capacity required by an electrification program. Kaduna Electric has already shown strong commitment to improve its revenue collection capacity through customer enumeration with the development of an in-house adaptation of the Earth Institute geospatial mapping system that identifies and enumerates consumers directly to the distribution system assets using a mobile phone application and GIS coordinates. This preparatory time could also be used to complete the software application trial and build the capacity to translate it into a large-scale effort.

Particularly key during the **preparatory time** up to 2018 will be the adoption of a National Universal Access Policy (see also Section 3.1). The strategic document will have to define the roles and responsibilities of sector institutions and include targets for annual connections coupled with monitoring instruments and funding mechanisms, including from public sources. In fact, no country has achieved universal electricity access without some form of public subsidy to finance the capital investment requirements (MV, LV and service connections), irrespective of whether the distribution sector was privatised or in public hands (see Chapter 4 for the financing of the capital costs of electrification programme).

The regulatory framework and tariff design will have to be tailored to the achievement of the goals set in the access policy. In particular, NERC will have to appropriately refine, expand and detail the MYTO framework in support of the access programme and update its oversight, review and verification processes and mechanisms. Furthermore, guidelines and regulations, including service standards, appropriate for the coordination of grid and off-grid efforts and for the development of an off-grid market, encompassing several service solutions (mini-grids, SHSs and pico-solar, but also interim and long-term solutions), will have to be designed.

The electrification targets for Kaduna Electric and the DISCOs will have to be designed by FMP in coordination with the Office of the Vice President through the Advisory Power Team—currently responsible for advancing the power sector reform—in coordination with NERC and the DISCOs, taking account of funding sources, grants available, and the impact on end-user tariffs. The targets will be firm for the initial periods, typically five-year periods to coincide with the multi-year tariff formulae, and indicative beyond that.

In addition, the preparatory phase should be used by Kaduna Electric to strengthen its organizational and functional capacities to implement the access scale up program particularly in relations to planning, design, procurement, construction management, contracting, materials management, quality and standards. In parallel to the access roll-out, Kaduna Electric would also have to continue to further reduce technical and commercial losses and strengthen its financial stance.

The two scenarios presented differ in the trajectory of the year-to-year implementation of the physical on-grid programme in terms of number of connections implemented per year, speed and acceleration. They also differ in the underlying expectations on improvements in key constraining/inhibiting factors, in particular: bulk supply adequacy, quality of enabling policy framework, support from the regulatory framework for retail tariffs consistent with the universal access policy, and provisions and mechanisms for public funding to bridge the capital expenditure financing gap (discussed in Chapter 4). The best-practice scenario requires a significantly greater commitment from all parties to a programme of full electrification by the target date of 2030 and for these reasons would require more technical assistance to enable the programme to be accelerated (discussed in Section 2.3).

Table 12 below shows the year-to-year implementation profile and the corresponding access achieved by the two trajectories. In both scenarios, the electrification programme is expected to connect 99% of social institutions, such as schools and clinics.

In the **conservative scenario** the on-grid electrification would begin cautiously with 30,000 new connections in 2018 rising to nearly 200,000 connections in 2023 and cumulatively over this period a total of nearly 550,000 new connections would have been made. The electrification rate would still be a relatively modest 53% at the end of 2023, compared with 49% in 2015, but this would be the foundation for of a much more rapid electrification rate over the subsequent years with an annual electrification rate of up to 500,000 per year and ultimately bringing the electrification rate to 81% by 2030. In the first two phases of the programme (up to 2023), an investment financing requirement of US$400 million would be necessary for grid electrification and the estimated increase in demand is of 220 MW.

In the **best-practice scenario** the on-grid electrification would again begin relatively cautiously with 50,000 new connections in 2018 rising to 325,000 connections in 2023 and cumulatively over this period a total of nearly 775,000 new connections would have been made. The electrification rate would still be nearly 57% at the end of 2023. Over the subsequent years the annual electrification rate of up to 500,000 per year and ultimately bringing the electrification rate to 99% by 2030 (100% for social and administrative institutions). In the first two phases of the programme for Kaduna Electric (again, up to 2023), an investment financing requirement of just over US$580million would be necessary for grid electrification and the estimated increase in demand is 310 MW.

From a physical implementation perspective, the two scenario differ as the conservative one is relatively less focused on MV extension (US$ 820 million) for the remaining duration of the programme (up to 2030), with US$ 785 million of investments directed to the construction of LV lines. In the best-practice scenario, investments in LV lines are coupled with more investments in MV extension (US$ 1.8 billion), which are pursued more aggressively in time (starting in 2020 instead of 2021) and size (2.5 billion new connections versus 1.6 billion in the conservative scenario), and the main reason underpinning bigger achievements in access by 2030, particularly as the MV extension is the biggest component of the electrification programme for the Kaduna Electric service area.

An **off-grid electrification** part of the programme would include pre-electrification communities that would otherwise wait several years for grid access. These areas are targeted for grid connections in the latter part (beyond the medium-term) of the 15-year MV grid extension plan and would otherwise be required to wait potentially for several years (5–10 years) for electricity access. Specific electrification technologies would be evaluated and selected—from options such as solar home systems and diesel or hybrid mini-grids—during a more detailed program design. A second group of off-grid electrification would provide non-grid solutions to areas where grid is not the recommended least-cost option within the period covered by the electrification programme. Finally, off-grid technologies could provide efficient power back-up solutions. The off-grid program is separately described in in Chapter 6.

2.1 Conservative grid electrification scenario

The conservative electrification trajectory for Kaduna Electric is depicted in Figure 3 below, with the electrification rate starting at 49% in 2015 and reaching 81% by 2030.

Specifically, there are an estimated 2.1 million households in the Kaduna Electric service zone

Table 12 Electricity access rollout programme (2018–2030)[a]

Access Rollout 2018–2030								
2015 (baseline):	**Conservative scenario**				**Best practice scenario**			
	Grid connections: 2.1 mn.	**Grid access rate: 49%**	**Institutions connected: 1,583**	**Institutions access rate: 20%**	**Grid connections: 2.1 mn.**	**Grid access rate: 49%**	**Institutions connected: 1,583**	**Institutions access rate: 20%**
	New connections ('000)	**Progressive access rate (%)**	**New connections**	**Progressive access rate (%)**	**New connections (#)**	**Progressive access rate (%)**	**New connections**	**Progressive access rate (%)**
2018	30.0	47%	500	20%	50.0	48%	500	20%
2019	40.0	47%	750	25%	75.0	48%	800	26%
2020	50.0	47%	850	31%	75.0	49%	950	32%
2021	93.4	48%	1000	38%	105.9	50%	1050	39%
2022	136.8	50%	1350	47%	144.8	52%	1400	49%
2023	198.0	53%	1497	57%	324.6	57%	1547	60%
Total additions 2018–2023	548.2		5,947		775.3		6,247	
Total connections by 2023	2,621.2	53%	8,400	57%	2,848.3	57%	8,700	60%
Total connections added 2024–2030	2,052.0		6,084		2,950.0		5,784	
Total connections by 2030	4,673.2	81%	14,484	99%	5,798.3	99%	14,484	99%

[a] Note, the electrification rate declines between 2015 and 2018 because, despite some electrification in 2018, this has not kept pace with the growth in the number of households. The same is not true of social institutions where the total number of institutions is assumed to be fixed (instead the size of the schools and clinics grow as the population grows).

with an electricity connection (though not all are registered and billed). At the early stages of the electrification program, the grid electrification rate dips somewhat (from 49% to 47%) reflecting Kaduna Electric 's focus on building its business (from customer enumeration and service to system automation) and the number of connections fails to keep pace with population growth.

The access scale-up program in the Kaduna Electric service zone is assumed to begin in 2018 with some relatively small-scale intensification programme (close to the existing grid) that begins to build Kaduna Electric's capacity and that of the private supply chains and contractors to undertake electrification. As also shown by Table 13, this lasts for a period of three years by which time an additional 120,000 new intensification connections are

Figure 3 Conservative grid electrification programme for Kaduna Electric

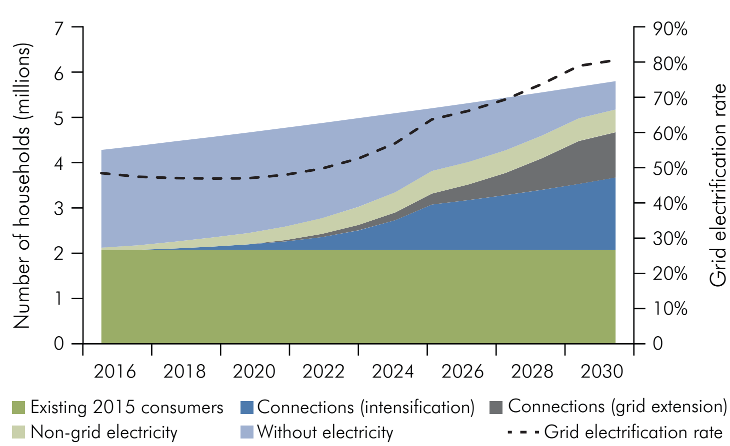


Table 13 Conservative grid electrification programme

	HH units	2015	2018	2023	2030
Existing 2015 Kaduna Electric household consumers	mn.	2.07	2.07	2.07	2.07
New intensification connections	mn.	0.00	0.03	0.43	1.60
New connections w/MV extensions[a]	mn.	0.00	0.00	0.12	1.00
Total Kaduna grid connections	mn.	2.07	2.10	2.62	4.67
Grid electrification rate (HHs)		49%	31%	53%	81%
Total households in the Kaduna zone	mn.	4.19	4.47	4.98	5.80

[a] As the MV grid extends outwards, households will be closer to the grid but they are still included in the 'MV extension' category.

assumed to have been added by the end of 2020. The programme then begins to move into a more serious gear, with a target of 1 million intensification connections by 2025 and 1.6 million by 2030.

The MV grid extension programme begins in 2021 in this programme with the same broad approach of building capacity over the first three years and then ramping up the rate of electrification to reach one million connections by 2030. Contrary to what envisaged in the geospatial plan, in the conservative scenario Kaduna Electric will not connect all 2.1 million potential connections involving MV extensions by 2030, but the electrification rate reaches only 81% by 2030, with the remaining section of the population for which grid connection is the least-cost solution to be electrified after 2030.

2.1.1 Capital costs – grid electrification conservative scenario

The capital cost associated with the Kaduna Electric grid electrification programme is estimated at US$2 billion. As indicated in Table 14 below, the electrification program starts with an investment cost for the first five years (2018–2023) of US$390 million whereas the subsequent 7-year time slice shows a gradual ramping up of the program, with US$1.6 billion in the period 2024–2030.

Although the investment needs for the first five years of the electrification program are relatively modest, they have not been anticipated in Kaduna Electric's tariff (MYTO) approved in February 2016 and they represent a substantial increase on the capital expenditure anticipated by NERC in its guidance to the DISCOs[1]. Some of this capital expenditure might be concessional financed, as discussed in Chapter 4, but there will be nevertheless a need for some capital expenditure to be financed by Kaduna Electric and this implies the need for a revision to MYTO before the electrification program is launched in the Kaduna Electric service zone.

The financing of the conservative electrification program and related financing gap are discussed in Chapter 4.

2.1.2 Increment of demand on the main grid from the conservative electrification program

Household electricity demand is calculated by the Earth Institute in the geospatial planning study at 400 Watts for all households. The aggregate peak demand associated with the electrification programme described above is shown in Table 15 below and is calculated using these household demand parameters[2].

2.2 Best-practice electrification programme

The best-practice electrification trajectory for Kaduna Electric is depicted in Figure 4 below. The sce-

Table 14 Capital cost of the Kaduna grid electrification programme (conservative)

	Units	2018–23	2024–30	2018–2030
New intensification connections	US$ mn.	287	785	1,072
New connections with MV extension	US$ mn.	103	817	920
Total	US$ mn.	390	1,602	1,992

Table 15 Increased grid load associated with the conservative roll-out program

	Units	2018	2023	2030
Energy demand (sales) from new connections[a]	GWh	40	729	3,458
Maximum demand from new connections	MW	12	219	1,040

[a] *Excluding technical losses. The energy needed from the wholesale market will be higher after taking account of network losses.*

Table 16 Best practice grid electrification programme

	HH units	2015	2018	2019	2020	2021	2022	2023	2030
Existing 2015 Kaduna Electric household consumers	mn.	2.07	2.07					2.07	2.07
New intensification connections	mn.	0.00	0.05					0.53	1.60
New connections w/MV extensions[a]	mn.	0.00	0.00					0.25	2.12
Total Kaduna grid connections	mn.	2.07	2.12					2.85	5.80
Grid electrification rate (HHs)		49%	47%					57%	99%
Total households in the Kaduna zone	mn.	4.19	4.47					4.98	5.80

nario also starts with an electrification rate of 49% in 2015, but assumes that Nigeria achieves the full electrification plan laid out in the geospatial analysis with over 99% electrification by 2030.

The best-practice scenario shown in Figure 4 also starts with an estimated 2.1 million households in the Kaduna service zone with an electricity connection (including unregistered and unbilled connections).

The electrification program in the Kaduna service zone is also assumed to begin in 2018 with an intensification programme that begins to build Kaduna Electric's capacity and that of the private supply chains and contractors to undertake electrification. As shown in Table 16, however, by 2023 it is assumed that Kaduna Electric connects 570,000 new households, both with intensification and grid extension, to its electricity grid bringing the grid electrification rate to 57% (compared with 53% in the conservative scenario). Thereafter, in the period 2024 to 2030, a further 2.5 million households would be connected through the program achieving 99% of grid access as envisaged in the Geospatial electrification plan.

2.2.1 Capital costs – grid electrification best-practice scenario

The capital cost associated with the Kaduna Electric best practice electrification programme is estimated at US$3.1 billion. As shown in Table 17 below, similarly to the conservative scenario, the program estimates a relatively slow build-up of investment cost for the first period, with of US$571 million in 2018–2023. The subsequent 7-year time slice shows a gradual ramping up of the programme, with US$2.5 billion in the period 2024–30.

Since the cost of an electrification program has not been anticipated in MYTO, the implementation of the best practice scenario would also require a re-examination by NERC of the tariffs to finance

Figure 4 Best practice grid electrification programme for Kaduna Electric

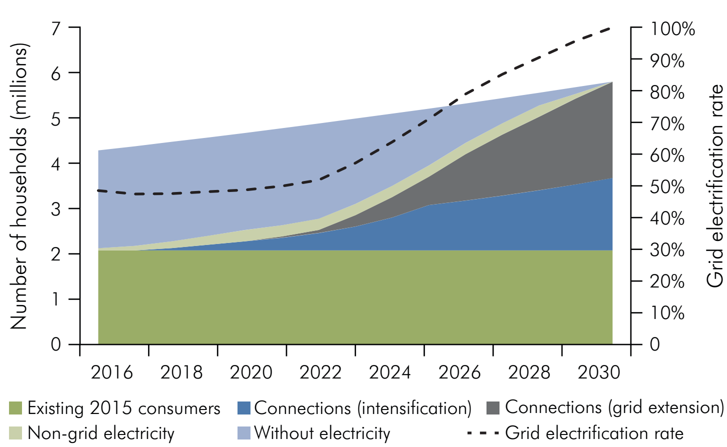


Table 17 Capital cost of the Kaduna Electric grid electrification programme

	Units	2018–23	2024–30	2018–2030
New intensification connections	US$ mn.	352	720	1,072
New connections with MV extension	US$ mn.	219	1,812	2,031
Total	US$ mn.	571	2,532	3,103

capital expenditure, even in the event of available grants and concessionary financing.

The financing of the best practice electrification program and related financing gap are discussed in Chapter 4.

2.2.2 Increment of demand on the main grid from the best-practice electrification program

Electricity demand in this scenario is calculated in the same way as the conservative scenario, as described above. The demand is summarised in Table 18 below.

2.3 Capacity strengthening

Technical assistance directed to key sector institution and agents is envisaged for the acquisition of the capacity required for the physical implementation of the access rollout and for the design and establishment of the enabling policy, legislations, and regulatory instruments that would set the stage for and ensure the successful execution of the electrification programme. Although some support should be directed toward the achievement of the key actions to be undertaken in the phase preliminary to the access rollout (described in Table 13), capacity strengthening will be needed on an ongoing basis during the implementation phase as the programme expands and accelerates.

A proposed technical assistance programme for capacity strengthening is described in Table 19 below. The programme is indicative, as the detailed scoping and its quantification will ultimately be defined by the more specific actions that Kaduna Electric, the private sector and the FGN will decide to undertake to close the gaps and solve the ambiguities related to the policy and regulatory framework and to the role of public finance within the programme.

Kaduna Electric has already demonstrated willingness, commitment and ability to rapidly implement major changes. For example, within the first eight months of operation, it underwent a major business and operational reorganization.[3] It has developed a comprehensive suite of policy documents, including: Corporate Strategy, Metering Standards & Installation Procedure and Supply Chain Management Guidelines. Furthermore, using the Earth Institute GIS network mapping study as a basis, Kaduna Electric will be able to build a database of mains records and customer connections, using the techniques already being developed within the company. An allowance for further data capture and cleansing is included in Table 19 below. Experience shows that a generous allowance should be made for this activity data capture and cleansing to ensure ultimate accuracy.

However, the utility has currently limited experience in extending electricity grids on any scale, and it has limited human, material and technical resources for undertaking a major programme of connecting customers through intensification or grid extension, whether implemented with a conservative or best practice trajectory. In fact, Kaduna Electric accepts that to a large extent the electrification work will need to be contracted out to the private sector (both grid and off-grid). The utility will there-

Table 18 Increased grid load associated with the best practice roll-out

	Units	2018	2023	2030
Energy demand (sales) from new connections[a]	GWh	67	1,031	4,954
Maximum demand from new connections	MW	20	310	1,490

[a] Excluding technical losses. The energy needed from the wholesale market will be higher after taking account of network losses.

Table 19 Technical assistance (TA) programme (present– 2023) – US$ million

Beneficiary	Measures	Conservative	Best-practice
Kaduna Electric	Planning (yearly program), tendering, management, supervision	2.5	3.0
	Strengthening of standard equipment specification, policies & procedures, procurement, mains records (location of plant)	0.5	0.5
	Customer Relationship Management	1.0	2.0
	Off-grid electrification assessment	0.5	0.5
	Sub-total	4.0	5.5
Ministry of Power	Planning, training for private contractors[a] other activities	5.3	8.0
Private manufacturers	Technical assistance to ensure manufacturing processes are up to standard	1.0	2.0
NERC[b]	To be detailed		
REA[c]	To be detailed		
Monitoring & evaluation		0.2	0.2
Ministry of Finance	To be detailed		
Total		11.0	16.2

[a] This could be provided through NAPTIN, the electricity training institute based just outside of Kano.
[b] The Nigeria Electricity Regulatory Commission is the regulator.
[c] Rural Electrification Agency.

fore need capacity building to supervise and manage a major electrification programme. As shown in Table 19, most of the technical assistance proposed for Kaduna Electric would be directed towards supporting the utility's planning capacity. Overall, the best-practice scenario will require more technical assistance (from US$11 million in the conservative scenario to US$16 million) to enable the access programme to be accelerated, with greater resources allocated to manage the programme and to improve more quickly Kaduna Electric's in-house capacity to plan, operate and manage an expanded network.

The private sector in North West Nigeria is experienced in undertaking electrification works[4], though not on the scale necessary to achieve the electrification roll-out required for Kaduna Electric and the work force will need to be expanded. Training and capacity strengthening can help address this limitation capacity to the physical programme rollout. The Industrial Training Fund is currently used for training engineers and technicians for the private sector. In the electricity sector, a wide range of training and services are currently provided by the National Power Training Institute of Nigeria (NAPTIN)[5] under contract to the electricity companies and the Institute could be expanded to provide the training necessary to enable the rollout of the electrification programme (linesmen, fitters, jointers, etc.)[6]. The facility might also provide training suited to the development of isolated grids and solar home systems. The best-practice scenario sees a 50% increase (from US$5.3 million in the conservative scenario to US$8 million) in the technical assistance needed to fast-track the training of linesmen, fitters and jointers through the Ministry of Power (NAPTIN) and the doubling of the technical assistance (from US$1 to US$2 million) needed to bring private manufacturing processes up to standard for a large-scale programme.

Finally, power sector institutions may also need some technical assistance for the development of nation-wide access policy, coordinating grid and off-grid solutions—with targets and timetables on par with international best practices and supported by a legislative and regulatory enabling environment ensuring the financial viability of the programme for the DISCOs and affordability of electricity services for consumers. The training of private contractors through the Ministry of Power is envisaged as the area mostly in need of capacity strengthening (with US$5.3 million in the conservative scenario and US$8 million in the best practice one). Although the support for the monitoring and evaluation of the program is currently quite small (US$200,000), this would be important and to be detailed hand in hand with the access policy.

On the off-grid side, capacity strengthening will be needed to develop the rules and regulations governing the off-grid market and to define roles of responsibilities of sector stakeholders, including private and public actors. Since the role of Rural Electrification Agency needs to be re-defined in the new sector structure, tailored technical assistance will have to be detailed accordingly. The distribution companies may also have an interest in participating in the off-grid rollout (see also Chapter 6).

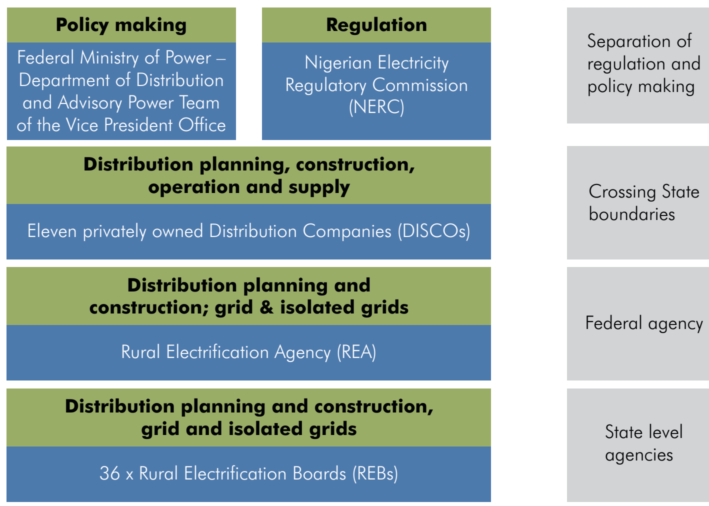
Endnotes

1. Only US$120 million over the five-year period, or US$24 million per year.
2. The household demand is understood to be the coincident, after-diversity maximum demand (i.e., the contribution to the aggregate peak demand of Kaduna Electric). We assume this takes account of network losses (i.e., is measured at the bulk supply point entering the Kaduna Electric grid). If the demand parameters are non-coincident or before diversity, the aggregate demand would be lower.
3. See Annex I for more information.
4. Private contractors typically provide in-house training for linesmen, fitters, jointers, etc.
5. NAPTIN was formerly part of the Power Holding Company of Nigeria (PHCN) but is currently owned by the Federal Government of Nigeria (FGN).
6. A facility already exists in Kaduna city and although equipped with modern equipment, it does not currently provide training in the skills needed for the expansion of the distribution network, though it has facilities to allow it to do so.

CHAPTER 3

The role of the policy maker and regulator

The following Section 3.1 describes the current institutional framework insofar as it relates to electrification access. Section 3.2 then discusses the need for an access policy and electrification targets to be adopted by FMP, the role of NERC in allowing the recovery of costs in electrification incurred by the DISCOs, in incentivising the electrification programme, and in making provisions for cross-subsidisation.



3.1 The current institutional framework

The current institutional framework for policy making, regulation, delivery and financing in the electricity distribution sector is depicted in the chart on the right.

The Federal Ministry of Power (FMP), in coordination with the Advisory Power Team of the Office of the Vice President (currently responsible for advancing the power sector reform), is the policy making arm of the Federal Government. NERC is the regulator and determines tariffs and allowed revenues for the DISCOs based on principles laid out in the primary law. NERC also ensures that Federal Government policy is appropriately implemented.

The Rural Electrification Agency (REA) and the Rural Electrification Boards (REBs) have, in the past, both had the primary function of supporting the former Federal-owned and vertically integrated electricity company[1] to develop electricity grids in rural areas and to then connect them to the national grid to be owned and operated by the electricity company.

When the electricity supply chain was Government-owned, the roles of REA and the REBs in helping develop distribution networks were clear but post-privatisation they need to be revised and properly designed and harmonized with the remit and mandate of DISCOs throughout their service areas.

3.2 A National Policy for Universal Access

The 2001 National Electric Power Policy (NEPP) is still the operational policy issued by the FGN. The policy explicitly specified a target for electrification to increase to 75% by 2020 towards the achievement of universal access by 2030[2]. However, these targets were established when the electricity sector was fully state-owned and before privatisation plans were introduced in 2005 with the Electric Power Sector Reform Act and were not actively pursued.

The NEPP electrification targets were designed to help prioritise actions by the Federal and State Governments, donors, REA and REBs and to help identify funding needs, but they were not actively pursued. They are not firm targets with financial penalties or rewards for the DISCOs nor a monitoring and oversight system was ever set in place.

In 2010, the Federal Government of Nigeria initiated a bold power sector reform program encompassing the entire value chain with the launching of the Power Sector Reform Roadmap. The Roadmap operationalized the 2001 National Electric Power Policy and the 2005 Electric Power Sector Reform (EPSR) Act. The Road Map, subtitled "A Customer Driven Sector-Wide Plan to Achieve Stable Power Supply", stemmed from the acknowledgment of consumers' frustration for unreliable and/or absence of electricity services. While achieving many of the goals set in the Roadmap, including the completion of the privatization process[3], the reform didn't detail targets and timetables for electricity access enhancement, nor the role of the FGN in a mostly privatized setting.

A necessary pre-requisite for any meaningful and sustainable start of an electrification programme, is for FGN to adopt a National Universal Access Policy, encompassing much more than a statement of vision. The revision of the 2001 NEPP should be tailored to the sector structure presently in place and include specific access targets accompanied by enabling policies. As demonstrated by international best practice experiences, no country has achieved universal access without a strong government commitment, vision and policy, whether in a privatized power sector setting or in a state-owned one[4].

The National Universal Access Policy should address clearly the full range of enabling policy measures and drivers necessary to facilitate the DISCOs in scaling up electricity access in a systematic and comprehensive manner for provision of adequate, affordable and reliable access to all residents. The Policy should also define the roles, mandates and accountabilities of sector institutions (including at the local levels) and stakeholders, and include targets for grid annual connections and off-grid developments coupled with monitoring instruments and funding mechanisms, including from public sources. The regulatory framework and tariff design will have to be tailored to the achievement of the goals set in the access policy; and guidelines and regulations, including service standards, appropriate for the coordination of grid and off-grid efforts and for the development of an off-grid market, encompassing several service solutions (mini-grids, SHSs and pico-solar, and interim and long-term provisions), will have to be designed.

The Policy and the electrification targets for Kaduna Electric and the other DISCOs will have to be determined by the Federal Ministry of Power (FMP) with the Office of the Vice President through the Advisory Power Team—currently responsible for advancing the power sector reform—in coordination with NERC and the DISCOs, taking account of funding sources, grants available, and the impact on end-user tariffs. The targets will be firm for the initial periods, typically five-year periods to coincide with the multi-year tariff formulae, and indicative beyond that.

Access targets will have to be designed and concretely pursued. The targets are necessary because there is currently no licence obligation to connect customers on demand and because, for affordability reasons, there is a need for cross subsidies between customer groups. Cross-subsidisation means that the DISCOs will be incentivised to maximise sales to the non-subsidised customers and to minimise the connection of subsidised customers.

The targets will have to have a concrete function in helping to identify investment expectations in the multi-year tariff orders (issued by NERC) and to provide incentives (penalties and rewards) for DISCOs for failing or succeeding in achieving the targets—again to be monitored and implemented by NERC.

The electrification investments and the targets will need to be established based on discussions between FMP, NERC and the DISCOs. The MYTO should be revised reflect the cost of investments in electrification and the DISCOs should be held to account in achieving the electrification targets implied by the investment programme. NERC should also appropriately update its oversight, review and verification processes and mechanisms to play its due role in support of the electrification programme.

To the extent that NERC regulated tariffs, combined with other revenue resources potentially available to the utilities (e.g. equity) do not allow for a complete recovery of the capital expenditure required by the access scale-up programme, the Policy would also need to identify the means and mechanisms for providing public funds to bridge the financing gap. In fact, no country has successfully achieved universal or well-advanced degree of electricity access without a strong financial commitment from the Government, even in a privatized setting (see also Chapter 4).

The discussion between FMP, NERC and the DISCO will then centre around the utilities' business plans, financial projections and financing needs (for investment in all aspects of their business—not only for electrification) and grants and concessionary funding available to the DISCOs and the implications, positive or negative, for end-user tariffs. More specifically, NERC will have to oversee the balance between DISCOs financial viability on the one hand, and of affordability on the other.

Endnotes

1. Until 2005 this was the Nigerian Electric Power Authority (NEPA) and between 2005 and 2013 it was the Power Holding Company of Nigeria (PHCN).
2. The 2006, Rural Electrification Strategy and Implementation Plan, developed by econ ONE for the Bureau of Public Enterprise mentions a policy of universal access to electricity by 2040. We have not obtained a copy of the original NEPP.
3. Under the reform program, PHCN was unbundled and privatized into eleven distribution and six generation companies (40 percent of shares are owned by the FGN), and the Gas Aggregator Company of Nigeria (GACN) and a bulk power trading company (Nigeria Bulk Electricity Trading Company, NBET) were established to facilitate private investments in power generation. A management contractor was brought in for the Transmission Company of Nigeria (TCN) and an independent regulator (Nigerian Electricity Regulatory Commission, NERC) was established. By early 2015, in accordance with the newly established market-based rules, the majority of the PHCN successor companies had signed power trading contracts with NBET and NERC had adopted and revised the 'Multi-Year Tariff Order' (MYTO) to cost-reflective levels.
4. Best practices include the ones of Vietnam, Thailand, Lao PDR, Kenya Rwanda, Tunisia and Morocco. For more information, see also Independent Evaluation Group (2015), "World Bank Group Support to Electricity Access, FY2000–2014. An Independent Evaluation", Washington D.C.

CHAPTER 4

Financing of the Access Program

4.1 Capacity of Kaduna Electric to finance investments

Kaduna Electric was privatised at the end of 2014 and has been in operation for one full financial year in 2015. A set of audited accounts for 2015 was not available at the time of this report[1] and the absence of published accounts or financial data is itself an indication of poor financial health.

The most recent and available estimated of Kaduna Electric's historical accounts, and projections of its future financial performance were submitted by the utility (at the request of NERC) for the definition for MYTO 2015. Some of the highlights are provided in Table 20 below. The estimates incorporate the loss reduction targets that Kaduna Electric committed to in the Performance Agreement and Business Plan submitted at the time of privatization[2], which entered into force in January 2015 when cost-reflective tariffs where first adopted (but abandoned in April 2015)[3].

The projections show improvements in Kaduna Electric's future financial performance. The Table shows a rapid growth in electricity sold, in part because of a slashing of technical and commercial losses from 28% in 2015 to about 3% in 2021. The improvement is also due to an expected increase in electricity available from the national grid and a resulting increase in electricity sales to customers with an underlying growth rate of 10% per annum. At the same time, the company is expected (by NERC) to reduce its collection losses from nearly 28% (27.5%) in 2015 to under 2% (1.6%) by 2020. These improvements are designed to allow the average tariffs to fall from NGN 43.3 (US$0.2 cents) per kWh in 2015 by nearly one half to around NGN 23.5 (US$0.11 cents) per kWh in 2020.

Table 20 Kaduna Electric's past and forecast financial position

	2014	2015	2016	2017	2018	2019	2020	2021
Electricity purchased wholesale (GWh)	3,142	2,414	3,091	4,132	5,213	6,110	6,644	7,374
Losses (technical and commercial – % of purchased)	18.1%	27.8%	18.4%	11.8%	7.6%	5.0%	3.2%	3.2%
Sales (GWh billed)	2,573	1,742	2,522	3,643	4,815	5,807	6,431	7,137
Growth in sales (%)	7%	–32%	45%	44%	32%	21%	11%	11%
Average tariff (NGN/kWh)	33.79	43.29	35.35	28.35	25.87	24.21	23.50	23.51
Revenues (billed – NGN million)	86,935	75,423	89,134	103,277	124,553	140,603	151,112	167,757
Collection losses (%)	37.4%	27.5%	16.6%	9.4%	5.2%	2.9%	1.6%	1.6%
Revenues collected (NGN million)	54,455	54,705	74,370	93,577	118,025	136,492	148,647	165,020
Bulk electricity costs (NGN million)	39,058	38,765	54,028	71,582	94,399	110,936	121,241	135,986
Operating costs incl. depreciation (NGN million)	10,991	11,883	12,309	13,182	14,109	15,095	16,145	17,259
Earnings before interest and tax (EBIT) (NGN million)	4,406	4,058	8,033	8,813	9,517	10,460	11,261	11,775
Return on regulated asset base (RAB)	10.8%	7.5%	14.1%	14.7%	15.2%	16.1%	16.8%	17.1%
Allowed return on RAB	11.0%	11.0%	11.0%	11.0%	11.0%	11.0%	11.0%	11.0%

Source: Kaduna Electric's submission to NERC for MYTO 2015 (December 2015).

However, the fulfilling of the financial projections is hindered some of the underpinnings of Kaduna Electric's Business Plan and by developments in the power sector after the completion of the privatization process, including recent power supply issues due to militant pipeline attacks.

In fact, the ATC&C loss reduction targets submitted at privatization (upon which bids were won and now integrated into MYTO 2015) and the corresponding investment programme approved by NERC of US$302.6 million over a five-year period (shown in Table 21 below) were designed to be consistent with the capital expenditure allowance contained in the MYTO model at the time of privatization (2014) and not on a bottom-up assessment of the utility's needs. Furthermore, although ATC&C losses were assessed and validated after privatization[4], and incorporated into the last round of MYTO revision, a throughout and bottom-up assessment of the utility's investment needs hasn't been conducted yet (nor it has for the other utilities).

Although during the last round of tariff revisions DISCOs complained that insufficient capex had been allowed in the MYTO calculations to allow the DISCOs to meet the Minimum Performance Targets contained in the Performance Agreements, NERC did not approve an increase in this allowance but actually decreased it for some DISCOs, arguing that this was because they had not made use of the capex allowance that they had previously been allocated. The absence of loss reduction or other investments by Kaduna Electric and other DISCOs was due to their inability to justify the borrowing needed to fund capital expenditure in the absence of cost-reflective tariffs[5]. A reduction in its capital allowance was not the case for Kaduna Electric, given that it was privatized later than the other DISCOs, although it may experience an equivalent capex reduction in the future. Discos are allowed to file for upward revisions if and when they can demonstrate that the expenditure is necessary and are able to prove that they have sufficient funding sources for planned capital expenditure.

Table 21 Summary of Kaduna's non-access investment requirements (US$ million)

Year	Metering	Distribution Network	Other	Total
2015	34.4	9.1	16	59.5
2016	34.5	11.1	13.5	59.1
2017	29.7	22.5	11.3	63.5
2018	27.6	24.3	13.3	65.2
2019	22.4	18.6	14.3	55.3
Total	148.6	85.6	68.4	302.6

Source: Kaduna Electric 2013 Business Plan updated to 2015 for inflation and exchange rate fluctuations, May 2016.

The metering investments are necessary to comply with commitments made to NERC and to customers[6]. Kaduna Electric's business plan (updated to 2015 as shown in Table 21) allocated US$148.6 million for metering over the five-year period to install 480, 897 meters (single and three phase whole current as well as current transformer operated LV and HV maximum demand meters) combining existing and future customers. These loss reduction investments are needed to meet the target for ATC&C losses agreed with NERC, bringing losses down from around 48% (47.6%) currently to 4.8% by 2020[7], in other words an approximate one third reduction each year. Included within this loss is an implied reduction in technical losses from 12.1% down to 5.1% within two years, although it should be noted that Kaduna Electric are not separately targeting technical and non-technical losses. These proposed reductions are the most challenging of all the eleven DISCOs. Since privatization, the only significant loss reduction capital expenditure made by Kaduna was the purchase of 50,000 meters through from the proceeds of a loan from the African Export-Import Bank in August 2016. However, it should also be noted that Kaduna Electric was vested on 4th December 2014, much later than the other DISCOs.

Furthermore, the geospatial analysis disclosed that approximately 2.1 million households would need a meter, in order to achieve the target of 100% metering in five years as set in the Performance Agreement, a target more than 4 times bigger in numbers of households than what detailed in the Business Plan (which targeted the deployment of 480, 897 meters)[8]. If these are smart meters[9], at a cost of around US$275 per meter, the total cost would almost achieve US$ 578 million, which is almost 75% higher than detailed by Kaduna Electric above (US$148.6 million).

The new MYTO 2015 also removed losses coming from MDAs' non-payments from the ACT&C figures contained in the tariffs, which in the case of Kaduna Electric considerably accounts for nearly

9 percentage points of the overall losses since Kaduna was for a long time the administrative centre for Northern Nigeria and a large number of government offices are still located in the area[10]. Because of the delay in the adoption of cost-reflective tariffs (two years after completion of the privatization process) and the removal of FGN arrears from collection losses, the DISCOs are currently negotiating with BPE and NERC to re-sculpt the collection targets over the next five years, which is further delaying the implementation of the loss reduction measures.

In addition, the achievement of Kaduna Electric's financial projections is hampered by the deficit that all DISCOs have been accumulating since privatization. In aggregate, DISCOs have only been able to pay for around 70% of the electricity purchased from NBET[11] and by the end of 2015 their accumulated arrears had amounted to nearly US$2 billion[12].

Although figures on the deficit accumulated by Kaduna Electric since privatization are not publicly available, Kaduna Electric is estimated to have accumulated US$80 million since privatization[13]. The utility has been significantly underperforming with regards to it payments for energy received from generation companies and in 2015 was able to pay less than 24% on average of NBET invoices (see also Annex 1).

In addition, to manage the increase in tariffs for end consumers, the new MYTO 2015 implemented in February 2016 was designed to smooth the tariff path by allowing under-recovery of revenues initially and over-recover in later years over a ten-year period. For the whole sector, this is expected to lead to an increase in the DISCOs' collective deficit to nearly US$ 3 billion by the end of 2016[14], corresponding to an under-recovery of 16% of expected total revenues. Kaduna Electric is expected (by MYTO) to have fully cost-recovery tariffs (i.e. no under-recovery) by the start of 2017 and so it would only keep accumulating deficits until then[15].

The achievement of the loss reduction investment targets set out in MYTO 2015 would also be difficult as Nigerian commercial banks are currently unwilling to finance the DISCOs' investments or to finance revenue shortfalls when securitised against the DISCOs' revenues on terms that are consistent with the MYTO allowed revenue formula. Commercial banks are not familiar with the distribution segment of the power sector nor have yet developed long-term lending instruments necessary for infrastructure development. Borrowing by the DISCOs on commercial terms to finance investments that are needed to create a stable platform to supply their existing customers is currently already problematic[16].

Finally, the projected 10% per annum increase in sales will also be affected by power availability[17], which is currently hampered by transmission constraints and more recently by a resurgence of militant attacks in the gas producing regions of Nigeria. The utility is currently allocated 8% of total generation capacity, but in 2015 it only received 240 MW[18] due to transmission constraints in the wheeling of power. Total available power supply for Nigeria has been 3,500 MW on average in 2015, and has decreased to an average of 3,150 MW in the first quarter of 2016 due to attacks by militants on natural gas pipelines.

The fall in bulk electricity supply over the past months due to gas supply problems and optimism in the power supply figures during the last major MYTO review should, in theory, in accordance with the MYTO tariff formula be corrected through an increase in allowed revenues. However, it is estimated that the tariff increase would be of 50% for the whole sector (including foreign exchange devaluation[19]), and would very unlikely be implemented without triggering further public opposition.

4.2 Financing gap for the electrification programme (2018–2023)

The 2005 Electric Power Sector Reform Act prescribes the regulatory framework governing the DISCOs, such that the companies should earn revenues that cover their costs and provide a reasonable market return on capital invested. For the DISCOs, any investment they make in the expansion of electricity access would therefore need to be undertaken on a commercial basis.

The current owners of the DISCOs largely financed the acquisitions of the companies with loans securitised against the parent companies' assets, not against the DISCOs' own profits. As Nigerian commercial banks are currently unwilling to finance the DISCOs' investments or to finance revenue shortfalls when securitized against the DISCO's revenues on terms that are consistent with the MYTO allowed formula, any major borrowing on commercial terms on any scale to expand the network is unlikely over the first phase (2018–2023) of the electrification access programme. As noted, borrowing to finance investments that are needed to reduce losses and create a stable platform to supply their existing customers is already problematic[20]. Furthermore, given the scale of the of the required investment, it would be a challenge to secure substantial commercial funding for the initial six-year period to cover the capital costs of between US$390 and US$570 million (shown in Table 22 below).

Under current regulations, DISCOs are not permitted to charge residential customers a connection fee, so that customer contributions will not, at least under the current framework, reduce the financing necessary for the electrification programme. Kaduna Electric's owners may themselves wish to finance some of the investment—the rate of return allowed in current NERC regulations does make such investment attractive in theory. However, given regulatory uncertainties over tariffs experienced over the past 12 months, the risks for equity investment is potentially high.

The investment requirements of the least-cost access scale-up programme are substantial. For the grid component, capital expenditures of about US$3.3 billion are estimated over a 15-year period, with an annual average of US$100 million per year over the implementation period. For the time frame covered by this Prospectus (2018–2023), the on-grid financing needs for the two rollout scenarios are summarised in Table 22 below.

An overall capital cost for grid electrification of US$ 390 million will be required for the conservative scenario and US$ 571 million will be needed for the implementation of the best-practice scenario. The financing gap for 2018–2023 is projected to be of US$351 million for the conservative scenario and of US$514 million for the best-practice one.

Table 22 Capital investment requirements – grid electrification (US$ mn.)

	Conservative	Best practice
Capital investment requirement (2018–2023)		
2018	20	34
2019	27	50
2020	34	50
2021	68	77
2022	99	105
2023	142	255
Total capital investment	**390**	**571**
Minus: Assumed Kaduna Electric equity (assumed 10%)	39	57
Connection charges	—	—
Total financing gap	**351**	**514**

Relevant experience from other countries that have successfully navigated a universal access rollout unambiguously indicates that nowhere has universal access been achieved without significant and sustained levels of public funding to finance a substantial portion of the capital investment requirements, irrespective of whether the distribution sector was privatised or state-owned. Combined with the adoption of a National policy for Universal Access with targets and timetables, Governments' financial commitment constitutes a key driver of performance for the success of a large scale electrification programme[21].

For instance, in Brazil the state and regional governments provided 85% of the investment costs through grants and concessionary loans while the private owners contributed 15%. In India, the electrification programme was 100% government funded with 90% provided by central government and 10% by the state governments. In Chile, the electrification programmes were awarded on the basis of the provider offering the lowest subsidy requirement. Successful programs, that have either achieved universal access or are well advanced in their rollout, were also undertaken in Morocco, Tunisia, Kenya, Rwanda, Vietnam, Thailand and Indonesia, amongst others.

The financing gap shown in Table 22 provisionally adopts an equity contribution by Kaduna Electric's shareholders of 10% of the capital required[22]. This assumes that Kaduna Electric's shareholders are comfortable that the regulatory framework going forward will reward them sufficiently for the risks entailed in such investments and that the market reforms continue to show results in terms of improved availability of electricity at the wholesale level. This equity may come from retained profits or from external calls on cash from the shareholders—essentially it is the same source. Investment in distribution is normally regarded internationally as a low risk business but the returns on investments in distribution in Nigeria are currently uncertain and for this reason we have suggested only a 10% equity contribution.

For the reasons described above commercial borrowing is not anticipated. To the extent that NERC regulated tariffs—guided by FGN policy on access—combined with other revenue sources potentially available to a utility (e.g. equity, connection charges, bill surcharge on non-poor customers) will not allow recovery over time of 100% of the capital expenditures of the access scale program, public funds will be needed to bridge the shortfall (i.e. the investment financing gap associated with the access rollout implementation each year). Therefore, the resultant financing gap for both scenarios (US$351 Million for the conservative scenario and of US$514 million for the best-practice one—or 90% of the investment requirements) is assumed to be financed by FGN and potentially State Governments and Local Governments, consistent with international best practices, through grants and concessionary loans. FGN could also obtain financing from Development Partners and will on-lend to the utility (directly or indirectly) on terms that ensure its commercial viability.

Although the mix of financing provided here are placeholder values we note that the equity share assumed (10%) is broadly consistent with the share adopted for example in Brazil's electrification scheme, though higher than in India (see Annex 5). The equity and loan contribution would have to be discussed with Kaduna Electric's management and owners and other potential financing institutions. The split among financing sources (equity, grants, concessionary loans) will be determined at syndication.

Based on international electrification rollout experiences[23] (described in Annex 5), we suggest the establishment of an **Electrification Fund,** similar to that adopted in Brazil, that will be used to provide financial support to the private DISCOs when expanding access. The Fund will on-lend to DISCOs using publicly raised funding on terms that are commercially viable to the DISCOs, whether in the forms of grants or concessional loans, and will also keep DISCOs accountable for the financing received by monitoring and auditing their progress. Grant funding will make it easier for the electrification targets to be accepted by all parties and co-funding of investments through donor grants and concessionary loans will also help lower the actual or perceived risks for Kaduna Electric's owners. As shown by international experience, it would be FGN's responsibility to (i) secure the funding and (ii) ensure its availability before the electrification rollout takes off.

Various arrangements have been adopted world-wide for this kind of institution. The Fund management will act as a trust fund payment agent and will be subject to specific rules and reporting requirements, with the supervision of NERC, governing cash-flow management and in particular how the financial resources are to be dispersed, monitored and, in the case of loans, returned. Finally, if the Fund is to be housed at an already existing agency (e.g. NERC), firewalls will have to be raised between the two entity to ensure the independence of both.

For the Kaduna Electric investment programme, loans will be made to Kaduna Electric. These loans may be provided by the proposed Fund together with grants. If concessionary loans are provided this may not, under the current regulatory framework, benefit end-users because the rate of return allowed by NERC is independent of the actual cost of borrowing (this should be remedied by changing the regulatory formula so that the benefit of concessionary debt is passed on to end users). Grants will be made to Kaduna Electric (through FGN or from FGN through the Fund) but grant-funded assets should not be included in the regulatory asset base and the company should not be allowed to recover these costs from customers through a return on net fixed assets and depreciation charges. Ultimately, Kaduna Electric's customers will repay the equity and loan components of the investment programme through tariff revenue designed to cover operating costs including depreciation (on non-grant financed assets) and a return on net fixed assets (again excluding grant-financed assets).

4.3 Investment needs in generation and transmission

The analysis reveals that the electrification programme will lead to an increase in electricity demand of between 220 MW and 310 MW by 2023 (and around 1,500 MW by 2030 in the best practice scenario)—this is just for Kaduna Electric (if the programme is rolled out to other DISCOs, a similar increase in demand would be expected for the other ten DISCOs). Generation capacity is a pooled resource and this demand will be supplied from the TCN grid and allocated to Kaduna Electric and other DISCOs. Kaduna Electric's current allocation is 8% but this could potentially be negotiated upwards if its demand increases faster than other DISCOs and sufficient capacity is available. Kaduna Electric's demand resulting from new connections will be in addition to the anticipated underlying increase in electricity demand which is expected by NERC to grow at 10% per annum, with generation rising to over 14,300 MW by 2028[24] from NERC's assumption of approximately 4,120 MW available in 2015[25].

Generation has been privatised and the current framework envisages that new generation capacity will be developed by the private sector and sold to the bulk trader (NBET). Some significant new power plants are currently under development with state funding through the NIPP (see also Annex 1). The first private sector power plant reached financial closure in December 2015 (Azura-Edo, part of a 2,000 MW IPP[26]) and the framework for attracting private investment in power generation therefore exists (specifically, the wholesale tariffs available for generators are attractive), guarantees are available, and a number of conditional licenses have been issued by NERC. Partial risk guarantees are being provided by the World Bank and AfDB. The World Bank has provided or is providing loans to support the upgrade of hydropower projects[27]. Relatively small-scale but grid connected renewable generation is being developed in Nigeria—these projects are being provided with grant support from the German government/EU/GIZ and the Clean Technology Fund (under World Bank management). JICA is also providing grants for a grid connected solar power plant.

It must be assumed that in time there will be adequate generation capacity to satisfy the growing demand. There will be substantial investment financing needs of the private sector for generation to satisfy the growth in demand. This is not covered by this Investment Financing Prospectus. We note that a generation masterplan study is underway, financed by JICA[28].

Transmission remains state-owned (Transmission Company of Nigeria – TCN) and substantial investment will also be required both to satisfy the underlying demand growth and to meet the demand to be generated by an electrification programme. Because of the transmission constraint, Kaduna Electric is not able to take its full 8% allocation of generation from the wholesale market. For example, the average allocation to Kaduna Electric is around 240 MW and although it can rise to 360 MW, on some occasions the allocation can be as low as 14 MW, which was the situation in May 2016 during the Consultant's visit.

The pipeline infrastructure is currently leaving as much as 1,500 MW of installed power generation capacity stranded[29] in the sector and the management contractor has identified several areas of critical investment that are needed for the transmission system (estimated at about US$8 billion) to achieve a wheeling capacity of at least 20,000 MW by the year 2020. Some of the financing for TCN is provided from the World Bank, AfDB[30], AFD[31] and JICA[32]. We also note that a transmission planning study has been contracted by TCN with World Bank funding. Again, the investments required for transmission network expansion, reinforcement and rehabilitation are not covered by this Investment Financing Prospectus.

Endnotes

1. Verbal communication with Kaduna Electric.
2. For all DISCOs, bids were won on the basis of the loss reduction targets to be implemented over a five-year plan.
3. The delay in the enforcing of the Performance Agreements signed at privatization was due to absence of cost-reflective tariffs, which were introduced for the first time in January 2015 but then abandoned in March 2015 during the elections.
4. Although privatization bids were won on the basis of targets for loss reduction, at that time an accurate assessment of ATC&C losses was not available, and an agreement was reached between NERC and the DISCOs to assess and validate them for their incorporation in the following round of MYTO revision (adopted in January 2015). MYTO 2015, adopted in February 2016 is based on the same set of validated losses. For Kaduna Electric, losses were established at almost 49% whereas in the MYTO model they were assumed to be 37% in 2011 and 18% in 2012.
5. After the adoption of cost-reflective tariffs in January 2015, which determined the activation of the privatization Performance Agreements, tariffs were reverted back to their previous levels in March 2015 because of the Presidential elections.
6. Perversely, metering is not required to improve revenue collection. This is because the DISCOs estimate the usage of unmetered customers and do not necessarily suffer financially when bills are estimated. The DISCOs do suffer financially from unbilled consumers and from customers who do not pay. Metering is urgent because customers want it and Kaduna Electric has a duty to provide metering.
7. Kaduna Electric estimates its current losses at 45%. NERC has allowed it a baseline of 47.6% for 2015 in the MYTO calculations, but with the assumption that this will drop to 32% on average in 2016.

8. Kaduna Electric Five-year Business Plan submitted at privatization. The target for meter deployment included closing the metering gap of existing customers (289,633) and meter provision for new connections (191,260) but these mostly referred to regularize existing consumer and the target is therefore comparable to components A and B identified by the geospatial plan.
9. As per discussions with the utility, Kaduna Electric intends to mostly deploy smart meters.
10. 41% with MDA debts and 31% without, according to Energy Markets and Rates Consultants (EMRC), formerly Mercados EMI, a consultancy providing advisory services to Nigerian DISCOs.
11. Verbal communication with NBET.
12. World Bank estimates, February 2016.
13. World Bank estimates, August 2016.
14. World Bank estimates, February 2016.
15. World Bank estimates based on the MYTO model, March 2016.
16. World Bank analysis, February 2016.
17. The increase in sales is also due to the projected reduction in ATC&C losses, but primarily due to increase in electricity availability in the national grid, as noted at the beginning of the Section.
18. As per discussions with Kaduna Electric.
19. World Bank estimates, March 2016.
20. World Bank analysis, February 2016.
21. For an overview of the key drivers of performance and successful experiences world-wide see also IEG (2015), "World Bank Support for Electricity Access FY2000–2014", Washington D.C.
22. At the time of drafting this Report, the shareholders, IFIs and development partners were not in a position to comment on their likely willingness to provide equity, debt or grants. The mix of financing provided here are therefore placeholder values.
23. Brazil, India and Chile, for instance.
24. The basis for NERC's forecast is unclear and, in particular, it is unclear how much is assumed to relate to increased electrification and how much to increased supply to existing customers and consumers. Strictly speaking, the NERC forecast is a supply forecast rather than a demand forecast.
25. This differs slightly from the figure provided by NBET for 2015 of 4,500 MW of available generation capacity.
26. The facility is expected to produce 450 MW in the first phase, and then increase production up to 2,000 MW. The plant is supported by guarantees from the World Bank Group. For more information, visit: *www.azurawa.com*.
27. Approximately US$100 million for rehabilitation of power plants, focusing particularly on water resource management. Some.is funded from the Carbon Fund.
28. Japanese International Cooperation Agency.
29. Also due to lack of policy and regulatory reform in the gas sector, together with outdated commercial frameworks and price ceilings.
30. US$ 150 million soft loan for budget support to the Ministry of Power that is being used for transmission investment.
31. US$ 170 million loan.
32. US$ 200 million loan.

CHAPTER 5

Current tariff regime and the electrification program

5.1 The current tariff regime

The latest electricity tariffs were approved in February 2016 through version 2015 of MYTO. These removed the fixed charge from tariffs and substantially raised the kWh charges for all DISCOs including Kaduna Electric.

A key policy aspect of the current tariff design is maintains a 'lifeline' tariff, classified under the label 'R1' and has been fixed at NGN 4/kWh (US$0.02/kWh) for many years without a fixed monthly charge. In MYTO 2015, the R1 tariff has been fixed again at this same level until 2024. The R1 tariff of NGN 4/kWh compares with Kaduna Electric's MYTO 2015 tariff for the standard non-lifeline residential customer (R2) which is six times greater[1].

The R1 tariff is available to customers who are assessed to have a monthly consumption of less than 50 kWh per month. However, this is not an increasing block tariff and customers paying the R1 tariff may consume in excess of 50 kWh per month. A regulation issued by NERC allows the DISCOs to convert R1 customers to R2 if their consumption exceeds 50 kWh per month for three months in succession. The R2 category currently represents the largest group by customer numbers and kWh sales.

Cost reflective residential tariff designs would normally mean that residential customers pay ***more*** than commercial and industrial customers per kWh. The R2 tariff already incorporates some element of cross-subsidy from non-residential customers to R2 customers and the R1 customers are very heavily subsidised from non-residential consumers.

The regulatory framework determining electricity revenues and tariffs is set out in the 2005 Electric Power Sector Reform Act and the tariff regulations have been developed by NERC using a building-blocks model to establish the allowed revenues and tariffs on a multi-year basis. Allowed revenues for the DISCOs are calculated on the basis of operating costs including depreciation on fixed assets plus rate of return on net fixed assets plus pass-through of elements such as the bulk purchase tariff and the fees for TCN, NBET and NERC. At the start of the control period, the tariffs are fixed for its whole duration (with periodic adjustments for the non-controllable components) and the DISCOs are expected to manage their costs efficiently. If they can make above average profits by being cost-efficient, they

Table 23 Kaduna Electric selected tariffs (February 2016 after tariff revision)

	Feb. 2016 tariff	2015 tariff		
		Fixed charge	Enegy charge	Average (100 kWh)
Tariff category	NGN/kWh	NGN/ month	NGN/ kWh	NGN/ kWh
R1: residential <=50 kWh/month, single phase	4.00	—	4.00	4.00
R2: residential >50 kWh/month, single phase	26.37	800	20.33	28.33

Source: Kaduna Electric website, and ECA calculations.

are allowed to keep the profits and the shareholders receive good dividends but if DISCOs are inefficient, they make low profits and the shareholders receive no or low dividends.

There is currently no allowance for an electrification programme in the multi-year tariff calculations approved by NERC and the tariffs hence do not allow the DISCOs to recover large scale electrification costs. Combined with the absence of an electrification allowance, the DISCOs have no incentive to embark in a large scale effort as there are no targets set in place, nor mechanism for rewards and penalties, and the "sculpting" of the tariffs (with MYTO 2015) is not even allowing for cost recovery. The companies are currently focused on facing the inefficiencies inherited from years of under investments in the sector and on stabilizing their business and generating cash flow.

However, if the capital expenditure programme requirements of the access roll-out are reflected in the allowed revenue calculations used to design the MYTO tariffs, and if the tariffs are affordable (to be examined by NERC), then customer revenues would be sufficient to allow the DISCOs to make a respectable return on their investment and to service their debts. Looking forward, with the right regulatory, commercial and incentive framework, expanded electrification access should be an attractive option for the companies to grow their business and expand their customer base. According to NERC, the inclusion of electrification financing into the tariff could also be approved during a minor tariff review (conducted every six months), provided that the DISCOs submit their plans and a proof of some degree of implementation[2].

5.2 Equity concerns and strategic rollout of the electrification programme

Ensuring the affordability of electricity services will be key for the success of the electrification programme and for the equitable development of the country. The design and implementation of the enabling policy and regulatory framework for the access programme will therefore have to go hand in hand with ensuring affordability and shared prosperity.

The analysis of the available datasets on income, expenditure and geographic distribution of poverty (described in detail in Annex 2) indicates that the R2[3] tariff is not affordable by around 70% of the population. On the other hand, the R1 is affordable by 85% of the population (it is unaffordable by the bottom 15% of households).

Large sections of new customers of the electrification programme would therefore belong to the R1 tariff category, which would not be attractive for a profit-maximizing company. We assume that the regulation adopted by NERC in 2012 requiring that DISCOs do not impose connection charges would be maintained during the first phase of implementation of the rollout plan (2018–2023), although it could be revised at a later stage. Since the maximum tariff that could be earned from lifeline customers is NGN 4/kWh and the cost of supply is over NGN 20/kWh, the utility would sell every unity of electricity sold at a significant loss (even before account is taken of connection costs) and would rather connect profit-making customers, leaving large sections of the population—and the ones most in need—without electricity provision.

This is a common issue for any large scale electrification program. For this reason, targets must be mandatory but the allowed revenues from all customers (those who pay below the cost-reflective tariff and those who pay above the cost-reflective tariff) must also be sufficient to cover the utilities' fixed and variable costs. In fact, experiences world-wide show that new connections should be strategically approached with the combination of low-income customers with profit-making ones. This tactic would prove to be particularly successful during the first stages of the rollout as there is a large base households and businesses to connect. Over time, economic growth will increase energy consumption and the base from which to collect the cross-subsidy narrowing the financial gap to be recovered when connecting new customers. The utility should therefore evaluate these strategic options when designing its access roll-out strategy.

The alternative would be an increase in the cross-subsidy, which we modelled for illustration purposes only, as it can and therefore should be avoided.

5.3 Potential cross-subsidy implications of the access rollout

In this sub-section we consider the potential consequences on revenue requirements and tariffs of connecting large numbers of R1 customers through the electrification program. The impact is illustrated using the conservative electrification scenario. The more ambitious best practice trajectory would have an even higher impact.

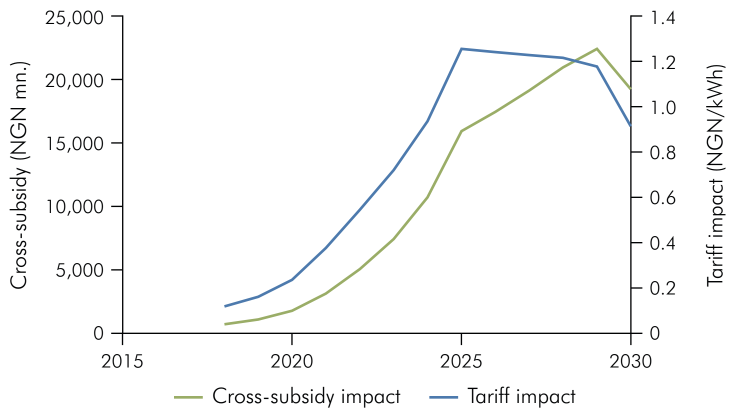
Although R2 customers currently constitute Kaduna Electric's biggest category of sales, since a large proportions of the population of North West Nigeria will not be able to afford the conventional residential R2 tariff[4] we assume that 70% of the new households connected to an access roll-out plan will initially be connected as R1 customers and then migrate to the R2 tariff after 5 years.

We model the conservative connection scenario to determine the total requirement for cross-subsidy to new R1 connections, with the following assumptions:

- Kaduna serves only 818 R1 customers at the present time[5]
- 70%[6] of the additional 2.6 million customers added through the conservative scenario by 2030 through intensification and grid extension will be connected as R1 customers
- These R1 customers will increase their consumption and become R2 customer after five years[7]
- The R1 tariff will remain at NGN 4/kWh
- Kaduna Electric's cost to serve R1 customers is the same as the cost to supply the average R2 customer[8]
- The difference between Kaduna Electric's R2 tariff and the R1 tariff is the required cross-subsidy[9].

Following these assumptions, we forecast that the value of cross-subsidies required will increase steadily, reaching **NGN 19 billion per year (US$ 100 million)** in 2030 (see Figure 5). This is a relatively large amount compared with Kaduna Electric's annual revenues today (approximately US$435 million billed[10], but significantly less collected), but by 2030 this is predicted, based on NERC's growth assumptions, to represent a much smaller share of the total. While the cross-subsidy amount steadily increases in absolute terms, the number of non-R1 customers, and their consumption, also increases steadily, thereby increasing the base across which the cross-subsidy can be collected. We calculate that the incremental amount needed on top of the average cost-recovery tariff to meet the cross-subsidy will rise to **NGN 0.9/kWh** by 2030 (US$ 0.005/kWh) or around 3% of Kaduna Electric's commercial tariffs. Initially, however, the increase would be even more modest at around NGN 0.2/kWh in 2020.

Figure 5 Impact of cross-subsidy requirements on tariffs



The above assumes that the consumption of non R1 customers connected through the electrification program, and of those R1 connections moving to the R2 tariff category after five years, grows at 10% per year, allowing a large base of consumption from which to collect the cross-subsidy. If this grows instead at, for instance, 5% per year, the impact on tariffs will be greater. Finally, the tariff increase assumes that new R1 customers will progressively migrate to the R2 category after five years, which may or may not happen.

Endnotes

1. It is noteworthy that the new tariff, despite the increase in the price per kWh, actually implies lower bills for customers using 100 kWh per month. This is because the fixed charge was dropped by NERC in MYTO 2015.
2. Based on discussion with the Regulator.
3. Here we use the 2020 tariff as the benchmark as this is when the electrification programme is likely to take off. The tariff then is expected to be NGN 18.75/kWh with no standing charge.
4. Though R2 is far from reflecting the costs of supplying residential customers, it is the closest approximation we have available.
5. From NERC's MYTO model. 2015 value.
6. This is an assumption. The income profile of customers over the period to 2030 is not known so the household expenditure data provides only partial guide to the proportion connecting as R1 customers.
7. This is an assumption. KEDCO has relatively few R1 customers compared with R2 and it is therefore

likely that customers relatively quickly exceed 50 kWh per month.

8. This assumption is incorrect since the cost to supply new (mostly R1) customers will be greater than that to supply customers in more urban areas, but it is a first approximation.
9. This is also incorrect as the R2 tariff is itself cross-subsidised. This is clear because the R2 tariff is below the non-residential tariffs but the cost of supplying residential customers is almost invariably higher than the cost of supplying non-residential. But the extent of the cross-subsidy is not known.
10. From the NERC MYTO model for 2014.

CHAPTER 6

Off-grid electrification

The geospatial analysis revealed that given the demographic settlement patterns and relevant technical, economic and financial parameters provided primarily by domestic sources (including Kaduna Electric), connection to the grid is the least-cost solution in the long-run for most of the population. However, the analysis also allows the identification of the potential and scope for an off-grid electrification programme, to be coordinated (in space and time) with and to complement grid developments. In particular, two categories of beneficiaries can be identified: long-term off-grid and pre-electrification. The use of off-grid solutions for power back-up is also discussed, although not strictly belonging to an off-grid access programme.

Long-term off-grid refers to small communities or households geolocated in remote, isolated (defined as areas with households that are, on average, more than 100 metres from neighbouring households) or scattered areas where the grid is not recommended as the least-cost option by 2030. They constitute a small percentage of the population, less than 1%, corresponding to about 2,500 in 2030.

The largest component of the off-grid electrification program potentially consists of beneficiaries of **pre-electrification** solutions, that is, households and communities which are targeted for grid connections in the latter part (beyond the medium-term) of the 15-year MV grid extension plan and thus will be required to wait potentially for several years (5 to 10, if not longer) for electricity access. Depending on the electricity access services provided, pre-electrification beneficiaries could be characterized by two subcomponents:

(i) **Tier 1&2 access delivery**[1] **–** The *economic* potential of this off-grid sub-programme refers to the ~3 million households that are not expected to receive access to the grid during the first 5 years of the electrification programme (up to 2023) identified by this Prospectus (illustrated in Table 12), regardless of the conservative or the best-practice trajectory implemented. The successful experience of the World Bank Group Lighting Africa and Lighting Global initiatives in Africa (see, for instance, the experiences of Kenya, Ethiopia and Tanzania) and Asia demonstrated that Tier 1&2 products can be rapidly scaled-up, although not yet at the scale of ~3 million households.[2]

(ii) **Tier 3+ access delivery –** the *technical* potential for isolated mini- and micro-grids is identified in the latter segment of grid development (in space and time), requiring the extension of MV lines and affecting 2.1 million households (also illustrated in Table 12). Although no country has yet scaled-up a mini- or micro-grid programme, well designed pilot schemes (a pilot scheme has been recently launched by GIZ) can aide in the identification of viable business models to support the spreading of distributed generation.[3]

To ensure shared well-being and shared prosperity across the country, these communities could be provided access with sufficient power for essential electricity services such as household lighting, charging of mobile phones and other batteries and devices, and basic connectivity for schools and clinics to power computers, vaccine cold chain, and other services. Grid-coordinated pre-electrification plans will have to be developed as transitional measures when the grid is still the least-cost solution in the long-run, while at the same time designed to protect investors' businesses after the arrival of the grid (i.e. ensuring technical compatibility between off-grid solutions and the distribution network). These pre-electrification transitional off-grid solutions could then become power supply back-ups and/or feed into the grid network. The electrification possibilities for such pre-electrification areas are described in Annex 3.3.

Not strictly belonging to the off-grid access programme, but a potentially important segment of the off-grid market is, in fact, constituted by the use of off-grid solutions for **power back-up** purposes. This

Table 24 Cost per household and for full program, for pre-electrification off-grid access

Service Standard (kWh/yr)	Service Standard (Wh/day)	System Type	Average Initial Cost/HH USD	Off-Grid as Percentage of Grid Access Program ~1% 40,000 HHs	~2.5% 100,000 HHs	~5% 200,000 HHs
120	330	Mini-grid	$1,100	$44,000,000	$110,000,000	$220,000,000
60	160	Mini-grid	$600	$24,000,000	$60,000,000	$120,000,000
30	80	Solar Home System	$300	$12,000,000	$30,000,000	$60,000,000

Source, Earth Institute, 2016.

market refers to households already provided with electricity access in 2015, or to be connected during the rollout plan, that could choose to rely on off-grid technologies for power back-up as long as the power supply provided by the grid is not reliable. Nigeria is affected by chronic high voltage fluctuations, blackouts and load shedding, making the country the second market for self-generators, far more expensive than efficient off-grid solutions would be.

Given the country's richness in solar resources, the technologies identified to provide off-grid services are solar lighting/charging products, solar home systems or diesel or hybrid mini-grids, although a though geospatial resource mapping of the country, completing the exercise started by GIZ, could reveal more renewable energy opportunities. For the Kaduna service zone, the costs associated to these technologies identified by the Earth Institute are in the range of US$50–100 for pico-solar, US$300 on average for solar home systems, and between US$500 to 1,200 for mini-grids, depending on the service standard[4].

The costs associated with an off-grid programme will eventually depend on its size (that is, on the number of beneficiaries, their needs, and the technologies deployed) and are potentially substantial. For instance, given per- household SHS costs, the needs of the long-term off-grid beneficiaries could be met for less than US$ 1 million. As regards pre-electrification purposes, the full rollout of the Tier 1&2 programme could require almost US$ 395 million (with an average combination of pico-solar and SHS solutions). For illustrative purposes, the Geospatial analysis provides plausible range of costs for programs of different sizes varying both the service standard (in kWh) for mini-grids and solar home systems and targeting the last 1%, 2.5% or 5%[5] of the households in the electricity access program (Table 24 above), as these connections will be the most expensive and delayed compared to much of the grid access program.

However, these examples illustrate only the very latest segments of MV extension—up to the final 5% of the grid access program—whereas the number of households not receiving a connection in the near to medium term would likely be much larger. Thus, while the prioritized grid rollout plan can aide in the cost-effective identification of potential target sites for an off-grid program, the details of such a plan—including the actual number of beneficiaries, target areas, cost and timing, particularly for the pre-electrification component—will eventually depend upon other factors. These factors include (i) the actual implementation and year-to year- sequencing of the grid rollout plan, undertaken by Kaduna Electric and to be approved by NERC; (ii) the adoption of an off-grid enabling policy and strategy in space and time for Tier 1&2 and Tier 3+ market penetration and scalability, comprising technical standards to ensure grid compatibility (in the case of interim solutions); and (iii) availability of public and private resources.

6.1 Enabling factors for the development of an off-grid programme

Notwithstanding its potential, the growth of the solar market in Nigeria is currently constrained. It is estimated that only 0.3% of households are using solar lighting products compared to 2–3% in countries such as Kenya, Tanzania and Ethiopia. Annual sales of solar lighting products are estimated at around

100,000 units, compared with 900,000 in Kenya. Two of the main factors that need to be tackled to support large scale off-grid developments: (i) lack of access to finance for importers, distributors and consumers and (ii) lack of an enabling policy and regulatory framework[6]. For the improvement of both the financial and the policy/regulatory dimensions, capacity strengthening support could be provided to sector stakeholders in the form of Technical Assistance.

A financing plan needs to be developed to support off-grid developments. The plan will have to be tailored to the current market structure and could envisage a combination of private sector and public sector-led programs and financing. International best practices can inform off-grid developments as well, and the establishment of a **line of credit and/or a credit facility** for the rollout of off-grid solutions such as used in Ethiopia and Bangladesh (described in Annex 6.4). A line of credit could be opened to support DISCOs or small and medium sized private sector enterprises, and the facility/line of credit could either become an integral part of the Electrification Fund suggested for the on-grid rollout or established separately. The financing mechanism can be designed to create a market-driven, private sector-led approach addressing some of the main issues preventing the off-grid market from taking off such as: access to finance at relatively lower cost of capital, access to foreign currency, and improvements to the general lending environment (e.g. fair-market collateral values), and identification of commercially viable delivery models.

On the public sector side, FGN could build upon the National Renewable Energy and Energy Efficiency Policy adopted in April 2015 to develop an off-grid program providing access to public institutions across the country. The National Policy was established to remove the key barriers that put renewable energy and energy efficiency at economic, regulatory or institutional disadvantages relative to other forms of energy in Nigeria. The policy states that PV power will be utilized to power low to medium power applications such as communication stations, water pumping and refrigerator in public facilities in remote areas and to extend modern energy service to rural and remote off-grid areas, through the use of solar home systems.

The successful implementation of a large-scale off-grid plan would also require providing a policy and regulatory enabling environment. In particular, institutional roles and responsibilities of sector institutions (e.g. Rural Electrification Agency, NERC and DISCOs) and stakeholders should be identified in the new market structure. Furthermore, rules governing the off-grid space, fostering market penetration and the coordination of private and public efforts, should be developed and enforced. This rules should include service standards for off-grid technologies, which may be differentiated for long-term and pre-electrification off-grid areas. Quality standards and warranties systems should be adopted for Tier 1&2 building on the best practices emerged internationally in this field, and for Tier 3+ grid compatibility should be ensured, not lastly to protect private investments. NERC should also be responsible for compiling a list of approved selected organizations. Subsidy frameworks could also be identified to ensure the scalability and affordability of the programme[7], particularly given the high cost of off-grid generation and current low penetration of off-grid solutions (support could be provided in the first phases for e.g. the marketing and distribution of products[8]). Problems of affordability of electrification that were described for grid-connected households will be magnified in the off-grid space. The geospatial distribution of poverty reveals that the areas with high poverty risk are also the areas furthest form the existing grid, with the lower population densities, and the highest cost of grid electrification. Hence, households that are expected to be connected in the later phases of the electrification rollout, or already targeted for off-grid solutions, are also mostly affected by poverty (see also Annex 2).

Although a specific rollout plan for off-grid will to some extent depend on Kaduna Electric's determination to undertake a rollout plan in the next few years and its year-by-year geographic implementation and sequencing, this should not prevent the adoption of all off-grid solutions. In fact, while the deployment of mini-grids may take longer, particularly in light of the absence of a regulatory framework (see Paragraph below), the distribution of pico-solar solutions and installation of SHS—supporting services up to general lighting, phone charging, and the use of a small television and a fan—should be firmly pursued.

The paragraphs below provide an overview of possible Kaduna Electric-led as well as non-utility-led development of small grids isolated from the current distribution network that may supply consumers before they become connected to Kaduna Electric's grid in the future.

6.2 The current regulatory framework for isolated grids

Under Nigerian regulations, isolated grids (also known as mini-grids) are known as ***Independent Electricity Distribution Networks*** (IEDNs). They are currently regulated under the Nigerian Electricity Regulatory Commission (Independent Electricity Distribution Networks) Regulations, 2012, but we understand that these regulations are currently under review, with support from GIZ. At this stage, it is uncertain when revised regulations will be made available, but we anticipate this to happen sometime in early 2016. Some of the important provisions in the regulations are summarised in Annex 4.

At present, there is nothing in the regulations to guide the options for operators of isolated IEDNs when the DISCOs extend their network to within proximity of the IEDN. This question is a critical one in the context of the access expansion plan that is proposed, particularly if it is anticipated that private operators will be a key agent in developing IEDNs. In other countries, IEDN operators are comfortable with the approach of main grid networks, provided there is certainty over the timing of when the grid will arrive, and the operator's options when this happens.

We understand that the revised IEDN regulations will cover the options for IEDN operators when the main grid arrives. We also understand that the regulations will focus on systems between 100 kW and 1 MW.

6.3 DISCO-led off-grid electrification and targeted support

Although the main role of the DISCOs is to provide grid-based electrification services and electricity supply, they could have a role in providing electricity through isolated grids or, indeed, through off-grid options (pico-solar lighting, solar home systems). In many countries in Africa and elsewhere, the distribution companies also provide electricity through isolated grids (for example, Kenya, Malawi, Tanzania and Tunisia).

There should be no obstacles to Kaduna Electric becoming involved in developing IEDNs and providing electricity services using off-grid solutions (solar home systems and solar pico-lighting). The utility should, in principle, be eligible under their existing licence to include the proposed costs of such investments in their projected Regulated Asset Bases and required revenues, and to recover the costs through tariffs. They might also consider establishing subsidiary companies with separate licences to allow greater flexibility in charging customers for these services.

Targeted support could be made for increasing electricity access through off-grid programmes. The power supplied by IEDNs and other off-grid technologies tends to be more expensive than that from main grids on a fully cost-reflective basis. If Kaduna Electric (or indeed any operator) is able to charge tariffs higher than approved R1 levels for grid customers, it will need to consider both the cost to serve and the willingness of customers to pay. Tariffs cannot be greater than customers' willingness to pay, but if this level is lower than the full cost to serve, the operator will require a subsidy. This may be targeted towards one-off capital costs or recurring operating costs (the former is preferred for transparency and sustainability).

If Kaduna Electric management decides to be involved in off-grid developments, then following the principle that tariffs should be set at cost-recovery levels, tariffs for such off-grid customers would either need to be set higher than those for main grid customers, or alternatively, those customers on the main grid with relatively cheaper costs to serve could cross-subsidise those customers not connected to the grid.

The approach for cross-subsidisation could be either ***implicit*** or ***explicit***. An ***implicit*** approach would 'hide' the additional cost for the cross-subsidy within the tariff, where customers simply observe that they are charged the same tariffs regardless of their connection type. An ***explicit*** approach would set an additional amount in the tariff to cover off-grid customers, identified clearly on all main-grid customers' power bills. As either approach should achieve the same effect economically, the choice is perhaps more one of public or consumer acceptability.

6.4 Non-DISCO-led off-grid electrification

The DISCOs should not be barred from being involved in off-grid electrification, but at this juncture it would be counter-productive to make this mandatory. Off-grid electrification is likely to involve high costs and require a disproportionate allocation of management time, without a commensurate flow of revenue. These factors will discourage Kaduna Electric from becoming involved in off-grid electrification. One advantage of their doing so, however, would be providing scope for cross-subsidisation between higher-paying customers on the grid and the off-grid consumers. For this to become a significant feature of electrification in Kaduna Electric coverage area, the cross-subsidy requirements would need to be analysed and explicitly incorporated in the MYTO calculations and approved by NERC.

To the extent that the Kaduna Electric declines to take up off-grid electrification but publishes plans showing communities without grid electricity for some time into the future, the Rural Electrification Boards (REBs) could take the lead in developing isolated mini-grids and solar home system programmes for these communities. Similarly, while traditionally the Rural Electrification Agency (REA) has focused on grid-based electrification, recognising that DISCOs will not be able to achieve full grid electrification by 2030, a better focus for the Agency would be on off-grid electrification (solar home systems, pico-solar lighting) and isolated grids in areas that are not expected to be grid-electrified in the near future.

Furthermore, while the approach for cross-subsidies between main grid and off-grid customers assumes a transfer within Kaduna Electric's business, the principle may be applicable between the utility and a private operator, whereby Kaduna Electric is required to collect tariffs that exceed its costs to serve particular customers in order that the surplus is transferred to reduce the cost to serve off-grid customers. In such an instance with different operators, it would be easier to collect and transfer the subsidy if it is explicitly itemised and collected in a customer's bill. This principle makes the economic outcome of off-grid supply indifferent to the system's ownership.

There may be scope for some local networks to be operated as small power distributors, with Kaduna Electric merely providing the bulk power, and distribution, metering and billing being undertaken by the community or a local entrepreneur. As these local grids may later to be absorbed into the utility's distribution grid, appropriate regulatory arrangements need to be implemented to allow for a fair recovery of costs when this absorption takes place.

6.5 The Future Role of REA and REBs

The 2005 Electric Power Sector Reform Act established the Rural Electrification Agency (REA) and the associated Rural Electrification Fund (REF) and REA began operation in 2006. The law and associated policy documents outline the principles for rural electrification to[9]:

> *"Facilitate the provision of steady and reliable power supply at economic rates for residential, commercial, industrial and social activities in the rural and peri-urban areas of the country.*
>
> *Facilitate the extension of electricity to rural and peri-urban dwellers.*
>
> *Encourage and promote private sector participation in grid and off-grid rural development using the nation's abundant renewable energy sources while ensuring that Government Agencies, Co-operatives and Communities, participate adequately in enhancing electricity service delivery."*

The Rural Electrification Agency's focus was on grid electrification based on funding from the Federal budget through the extension of existing grids to rural areas[10] (and handing over these networks to be operated by the then state-owned PHCN). Its current focus is the completion of around 2,000 electrification schemes that had begun but before 2009 but not completed. No information is currently available on the degree of their completion.

In the current new sector structure with privatized DISCOs, REA's old role is no longer operative and a new mandate and portfolio will have to be redefined at the FGN level. Recognising that DISCOs will not be able to achieve full grid electrification by 2030, a better focus of REA could be on off-grid electrification (solar home systems, pico-solar lighting) and isolated grids in areas that are not expected to be grid-electrified in the near future. When redefining the role of REA in the off-grid space, careful attention will have to be paid to avoid any conflict of interest that could hamper the development of a competitive, transparent and vibrant market for off-grid solutions with the participation of the private sector.

Electrification targets and rollout plans, reviewed and cleared by the Ministry of Power and NERC for each DISCO, will need to be published by the DISCOs and NERC to inform and guide the players of the off-grid space (potentially REA and REBs, but also independent electricity distribution network -IEDN- providers, private investors, and other off-grid providers and contractors) in choosing where to focus and align their efforts consistently with the updated energy access policy.

The role and funding of state-level Rural Electrification Boards (REBs) will also have to be redefined in the new sectoral context by a new mandate at the FGN and State Government levels. The REBs have resources and capability to undertake grid electrification and could potentially reorganise themselves as contracting agencies able to compete with private sector contractors for electrification projects commissioned and paid for by the DISCOs. This would be a policy decision for the State Governments.

Endnotes

1. A Multi-Tier Framework for electricity access was developed by the World Bank Group under the Sustainable Energy for All (SE4All) engagement. The framework defines five different tiers of access for electricity supply corresponding to different electricity services is further discussed in Annex 4.
2. International experiences suggest that ~30% of the ~3.3. million identified as potential beneficiaries could be easily provided with access. World Bank Team Task Leaders estimates, 2016. For more information, visit: https://www.lightingafrica.org/.
3. International experience suggests that the market potential for this off-grid development is to date around 10% (i.e. 180,000 connections of the 1.8 million potential beneficiaries). World Bank Team Task Leaders estimates, 2016. The WBG Lighting Global recently started to operate in the Tier 3+ access delivery market.
4. The geospatial analysis identified the cost for a mini-grid with a service standard of 120 kWh/HH-year to be in the range of US$1,000–1,200 and for a 60 kWh/HH-year per customer service, between US$500 and US$700.
5. Although 1%–5% is a somewhat arbitrary range, it is intended as a catch-all to include two groups: i) isolated households not captured perfectly by the VTS/Gates Foundation dataset; and ii) the very latest-stage, highest-cost grid recommended homes. The few communities that were determined during NetworkPlanner modeling to be recommended for off-grid or mini-grid systems for the long term totalled only 2,000 homes, which represents only a very small faction of even the smallest program envisioned here. It is, essentially, a rounding error.
6. Lighting Nigeria also mentions as major obstacles for the development of an off-grid market: low levels of awareness of solar products, their advantages and ways to distinguish good quality products and low availability of products due to lack of distribution networks in rural areas.
7. Typically, for mini-grids, this implies grants to cover up to 80% or 90% of the capital costs.
8. Lighting Africa has supported the promotion of pico-solar lighting products to the base-of-the-pyramid households for a number of years but is no longer proposing direct subsidies the products. However, this kind of subsidies could also be considered.
9. This is extracted from the REA website.
10. This focus was described in a presentation by a Special Advisor to the Minister of Power during a Presidential Retreat in January 2012.

Annexes

1 Summary of Kaduna Electric rapid readiness assessment

A Rapid Readiness Assessment was undertaken by the ECA team for Kaduna Electric in May 2016. This assessment was intended to understand the potential major barriers for delivering affordable and reliable electricity access, efficiently and sustainably nationwide. It also considered the capacity strengthening initiatives needed to de-bottleneck an electrification access roll-out. The Readiness Assessment is summarised in 1.1 below. The capacity strengthening needs are summarised in Annex 0.

1.1 Summary of readiness assessment

The Readiness Assessment concluded that Kaduna Electric, together with the other DISCOs, will need to focus on stabilising its businesses and generating cash flow in order to establish a solid financial and electrical foundation for moving forward. For all DISCOs, expanded electrification access is not an immediate priority. Looking forward, with the right regulatory, commercial and incentive framework, expanded electrification access should be an attractive option for the companies to grow their business and expand their customer base. For this reason, the electrification programme discussed in Chapter 2 is assumed to commence in 2018.

Progress in sector reform: Major milestones for the implementation of the 2010 Power Sector Reform Roadmap and the establishment of a competitive market have been met. The unbundling and privatization of the vertically integrated sector utility, Power Holding Corporation of Nigeria (PHCN), was completed in November 2013[1] and the Nigerian Electricity Regulatory Commission (NERC) has been fulfilling its mandate of economic regulation including management of tariff reviews. The Nigerian Bulk Electricity Trader (NBET) was established to be the initial counter-party to bilateral contracts pending declaration of the TEM when the bilateral contracts between DISCOs and generation companies become effective.

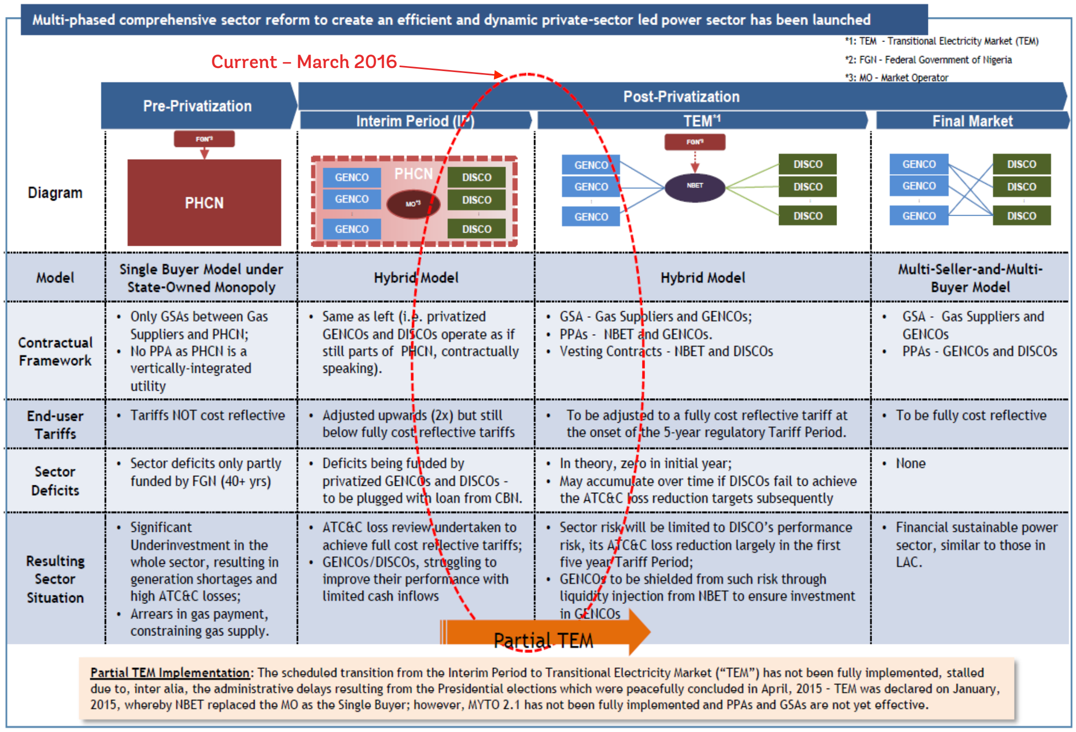
In February 2016, tariffs were re-set to cost-recovery levels (MYTO 2015), initially adopted in January 2015 but then reversed in April 2015. Following the adoption of cost-reflective tariffs in January 2015, the Performance Agreements (PA) and the Minimum Performance Targets (MPT) submitted at privatization came into effect (See Figure A1).

Since cost-reflective tariffs were adopted two years after privatization, the MPT (ATC&C losses reduction, metering and new connections[2]) may need to be re-sculpted over the next 5 years and reflected accordingly in the business plans and in new targets. An assessment of the progress achieved by Discos since privatization (estimates of improvement in efficiency) could also be reflected in the new targets. Discos argue that there is also a need to reflect the removal of MDA non-payments from collection losses in the overall loss reduction targets. Negotiations between Discos and BPE are ongoing which is further delaying the implementation of measures to achieve the targets.

The adoption of MYTO 2015 (February 2016) shows progress in the assessment of ATC&C losses. Although bids were won on the basis of business plans for ATC&C losses reduction at the time of privatization an accurate assessment of losses was not available, hence tariffs were not adequately estimated. An agreement was then made between NERC and DISCOs to assess and validate the losses for their incorporation into the MYTO round approved in January 2015. The validated losses for Kaduna Electric were established at 47.6% (instead of the 40% indicated in the Business Plan). MYTO 2015 is based on the same set of validated losses with committed reductions starting in 2015.

The adoption of MYTO 2015 was meant to coincide with the activation of the Transitional Electricity

Figure A1 Post-privatization market structure



Source: World Bank, 2016.

Market (TEM), one of the pillars of the reform set out in the 2010 Roadmap to Sector Reform. TEM is the stage of market development which occurs after the activation of PPAs (with generation companies), GSAs (with gas suppliers) and vesting contracts (with distribution companies) thereby enabling full payments across the power sector value chain. Whilst it was originally envisaged that the TEM would be declared before or at the time of the completion of the privatization of the PHCN successor companies, its commencement had to be delayed until the adoption of cost-reflective retail tariffs. Following the implementation of the new tariffs, few conditions precedent remain before contracts can be activated (the most important being LCs provided by the Discos). The activation of the TEM will be a step forward in the contract-based market for electricity trade in Nigeria, essential for market discipline and for the financial viability of the electricity market. Furthermore, it is a step forward towards the ultimate goal of a robust competitive market where DISCOs will purchase directly from generation companies (without the need of a single buyer)—as set out in the Electric Power Sector Reform Act of 2005.

Although the tariffs have been raised to cost- and losses-reflective levels, the FGN decided to "sculpt" them to manage the increase for end-consumers, while DISCOs are expected to pay in full for the supply received. DISCOs will under-recover revenues in the first few years and over-recover later to have a fully cost-reflective outcome over a 10-year period (included into MYTO 2015). The FGN is expected to raise a bond and on-lend funds to Discos so as to enable them to make full payments up-stream from 2016 onwards. However, the timing and the size of the bond are uncertain, and DISCOs may be forced to fund the under-recovery from commercial banks. This could be problematic though as the deficit accumulated has surpassed their value at privatization (US $1.8 billion). The size of the under-recovery has been estimated at almost US$ 700 million in 2016 (16% of expected total revenue) for the whole sector, to be combined to the ~US$ 1 billion deficit accumulated in 2015 only (after the abandonment of MYTO 2.1 in April) and the ones accumulated from privatization until the end of 2014 (in the absence of cost-reflective tariffs) amounting to US$ 1 billion, for a total of almost US$ 3 billion owed by the DISCOs to the rest of the value chain by the end of 2016[3]. The losses accumulated until the end of 2014 are expected to be covered by the Nigerian Electricity Market Stabilization Fund (NEMSF) through loans provided by the Central Bank of Nigeria (CBN) but there is uncertainty about how the deficits for 2015 and 2016 onwards will be tackled.

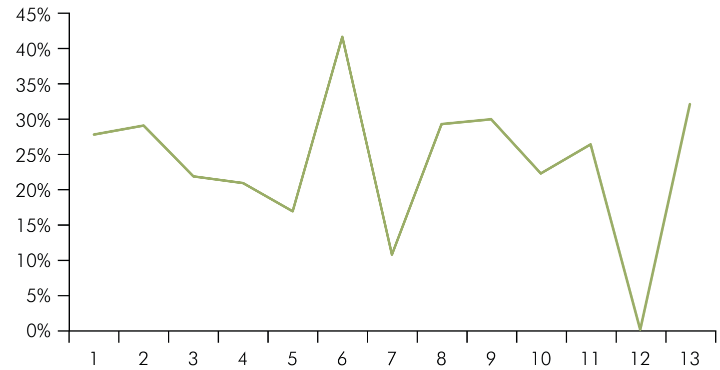
Policy, institutional and regulatory framework: A policy, institutional and regulatory framework for expanded electrification access needs to be adopted with the inclusion of targets and timetables, funding mechanisms, and roles and mandated of sector institutions[4]). The policy on electrification targets would need to be formally introduced by the Federal Government of Nigeria (FGN), with NERC responsible for implementing this policy by recognising the targets when approving the next multi-year tariff order (MYTO) and for approving the tariff designs in that Order. NERC will also be responsible for implementing the incentive framework to help ensure that the targets are met without damaging the commercial viability of the DISCOs.

The 2015 round of MYTO (approved in February 2016) has not anticipated major electrification investment expenditures. Although MYTO is set for ten years and is normally reviewed every five years, there are provisions for earlier reviews. Such a review should be undertaken ahead of an electrification programme commencing in 2018. Given the need time needed to properly develop a new MYTO and the importance of ensuring that the DISCOs are creditworthy and able to attract commercial financing for their normal business, the review should begin early in 2017.

Financial readiness: Unlike other DISCOs, the handover of Kaduna Electric was completed in December 2014. From then and until the end of 2015 the utility has accumulated US$79.5 million. Kaduna Electric currently has a negative cash flow and as shown by Figure A2 below, it is currently able to meet an average of only 24% of payment obligations to the bulk trader (NBET).

Because of the "sculpting" introduced with MYTO 2015, Kaduna Electric is expected to have cost-reflective tariffs (with no under-recovery) by the start of 2017 and so it would only keep accumulating deficits until then[5]. Like the other DISCOs, Kaduna Electric financial position is also worsened by the removal of fixed charges form MYTO 2015 and of MDAs debts, which in the case of Kaduna

Figure A2 Kaduna Electric payment of NBET invoices (Apr 2015–Apr 2016)



Source: World Bank, 2016.

Electric considerably accounts for nearly 9 percentage points of the overall losses since Kaduna was for a long time the administrative centre for Northern Nigeria and a lot of government offices are still located in the area. In addition, MYTO 2015 was based on optimism in the tariff review process over the power supply figures (of 5,000MW whereas a more realistic figure would have been 4,000MW–4,500MW), further decreased by recent militant pipeline attacks in the producing zones of the country. In 2015, total available supply was of 3,500MW and in the first quarter of 2016 of 3,150MW. Estimates foresee an average (for the whole sector) increase in tariff by 50% (including forex[6]) to reflect the new available supply conditions, which is likely not going to be approved by NERC[7].

The newly approved MYTO 2015, covering the period to 2024, made no provision for electrification investment and, because of the "sculpting", tariffs are currently not covering for all operational costs. The companies urgently need to make other investments including metering, management and billing systems, and rehabilitation and upgrade of existing networks and these will have a higher priority than expanded electrification. Although a bottom-up assessment of progress in loss reduction and efficiency since privatization is not available for Kaduna Electric nor for other utilities, it is worth noting that the only known significant loss reduction capital expenditure made by Kaduna Electric was the purchase of 50,000 meters from the proceeds of a loan from the African Export-Import Bank received in August 2016. However, the handover of the utility to the new owners was also completed later than for other DISCOs. During the last round of tariff revision, the DISCOs complained that insufficient capex had been allowed in the MYTO calculations to allow the Discos to meet the Minimum Performance Targets contained in the Performance Agreements. However, NERC did not approve an increase in this allowance. In MYTO 2015 the capex allowance was actually decreased for some DISCOs; NERC argued that this was because the DISCOs had not made use of the capex allowance that they had previously been allocated. Unfortunately, the DISCOs had not made investments because in an environment where tariffs were non-cost-reflective, they were unable to raise capital to fund capital expenditure, implement their business plans and invest in metering and loss reduction activities. A reduction in its capital allowance was not the case for Kaduna Electric, given that it was privatized later than the other DISCOs, although it may experience an equivalent capex reduction in the future. Discos are allowed to file for upward revisions if and when they can demonstrate that the expenditure is necessary and are able to prove that they have sufficient funding sources for planned capital expenditure.

Technical readiness of Kaduna Electric and the supply chain: Kaduna Electric has demonstrated a willingness and ability to rapidly implement major change. For example, within the first eight months of operation, staffing was reduced by 1,757 PHCN legacy staff (mainly senior managerial) in July and August 2015. Some PHCN staff were retained as mentors. A total of 2,500 new staff were employed in the company on the 1st of September 2015, bringing the company staff strength to a total of 3,200. Drivers and Security staff were moved to an outsourcing company. Twenty-nine business centres were brought under central control at the same time.

Two main issues will have to be tackled in order to embark in an extensive access program (i) revenue collection (ii) infrastructure building:

i. **Revenue collection and customer management**
The majority of Kaduna Electric's ATC&C 47.6% losses are due to collection issues (responsible for about 27.5% of ATC&C losses[8]). The utility needs to implement an aggressive meter deployment rollout and build the capacity to support new metered connections. With the adoption of MYTO 2015 in February 2016, and the removal of fixed charges and MDAs debts from the tariffs without a mechanism for defrayal, and the rejection by NERC of a further diversification of the R2 category, the liquidity and collection pressure has become even greater. Given the negative implementation record of the Credit Advance Payment for Metering Initiative (CAPMI)[9], KEDCO should either build the capacity in-house or rely on trustworthy vendors. Kaduna Electric has already shown strong commitment to improve its revenue collection capacity through customer enumeration. The utility developed an in-house adaptation of the Earth Institute geospatial mapping system that identified and enumerated consumers directly to the distribution system assets using a mobile phone application and GIS coordinates. All the additional software was written in-house after receiving the GIS mapping training from the Earth Institute and building on the improved knowledge of the network infrastructure emerged by the digital mapping of Kaduna Electric physical assets by the utility's staff. A pilot using this software involved visiting the identified consumers, installing meters and subsequently billing them as customers. The back-office systems were able to display the distribution system and connected customers on large screens, enabling the potential development of an integrated customer service and billing system, as well as displays for system control and asset management purposes. The return on investment payback period for the customer enumeration pilot was estimated to be two weeks. Further trials are expected.

ii. **Infrastructure building**
Kaduna Electric has limited experience of extending electricity grids on any scale, and limited human, materials and technical resources for undertaking a major programme of connecting customers through intensification or grid extension. The company accept that to a large extent the electrification work will need to be contracted out to the private sector in order to avoid diverting in house staff from essential rehabilitation, maintenance and fault repair activities. Kaduna Electric will need capacity building to enable it to supervise and manage a major electrification programme. The private sector in North West (NW) Nigeria is experienced in undertaking electrification works, though not on the scale necessary to achieve the electrification roll-out needed for Kaduna Electric. Kaduna State has a strong manufacturing base and have

private companies that manufacture poles, overhead line steelwork and conductors for the electricity sector. It also has private contractors who undertake electricity distribution works (procurement and construction)[10] typically working in NW Nigeria. The economy in the NW of Nigeria has been undermined by security problems in recent years and the private sector currently has underutilised resources[11]. An electrification programme would help boost the economy and increase utilisation of staff and equipment of manufacturers and contractors. Some distribution equipment is imported (e.g. transformers). This is normally procured by the utilities and by private construction companies on the open market but Nigeria often faces bottlenecks at the ports and customs and this will inevitably result in some bottlenecks that will impact the electrification programme at times. This is a chronic problem in Nigeria that cannot easily be resolved (at least not by NEAP). For both companies, some contracts have been placed for equipment such as metering, where the foreign supplier has provided international finance as a means of overcoming foreign exchange issues.

Private contractors typically provide in-house training for linesmen, fitters, jointers, etc. The Industrial Training Fund (ITF) is used for training engineers and technicians for more complex equipment and processes. In the electricity sector, training is provided by the National Power Training Institute of Nigeria (NAPTIN). NAPTIN was formerly part of PHCN but is currently owned by FGN and provides a range of training services under contract to the electricity companies. NAPTIN has a training facility in Kaduna and another on the outskirts of Kano city that provide training for the electricity companies in the north-west of Nigeria. These facilities are equipped with modern equipment. NAPTIN's Kaduna training centre has some facilities to train linesmen, fitters, jointers, etc) needed for electrification access. The Kano training centre does not currently provide training in the skills needed for the expansion of the distribution network but it has substantial space on the site to allow such training if requested by the DISCOs or the private sector. Support for the expansion of one or both facilities would be valuable in enabling the roll-out of the electrification programme in the Kaduna and Kano service zones. The training facilities might also provide training suited to the development of isolated grids.

Wholesale generation adequacy: There is currently insufficient generation to meet consumer demand. Wholesale generation is generally rationed to the DISCOs with Kaduna Electric and KEDCO each being allocated 8% of electricity available. Since privatisation, the availability of existing generation plants has improved substantially and the supply to DISCOs has increased[12] but generation shortages and load shedding remain chronic and in the early part of 2016 gas shortages meant that production from the power plants fell substantially. The average allocation to Kaduna Electric is around 240 MW and, although it can rise to 360 MW, on some occasions the allocation can be as low as 14 MW, which was the situation in May 2016 during our visit[13]. New generation projects in the pipeline are the FGN sponsored National Integrated Power Projects (NIPP) originally launched in 2005. The first private sector power plant reached financial closure in December 2015 (Azura-Edo, part of a 2,000 MW IPP[14]) and the framework for attracting private investment in power generation exists (specifically, the wholesale tariffs available for generators are attractive) and guarantees are available, and it must be assumed that in time there will be adequate generation capacity to satisfy the growing demand.

Transmission adequacy: A series of transmission investments have been prioritised by the Transmission Company of Nigeria (TCN) to relax the transmission constraints on the supply to Kaduna Electric and to improve supply reliability.

Current plans include:

- Installation of 1x60MVA 132/33KV transformer to replace the burnt out 30MVA unit and relieve the second 60MVA transformer, which is currently overloaded.
- Completion of the 132kV line and installation of 40MVA transformer to relieve extreme low voltage caused by excessive feeder length and overload on the 33kV Yelwa feeder at Yalwa/Yawuri axis.
- Upgrading the existing 30MVA 132/33kV transformer at Zaria to 60MVA to alleviate suppressed load and cater for additional load.
- Commissioning of 2x60MVA 132/33KV transformers at Kafanchan to eliminate the low voltage experienced at Saminaka. Additional feeders are planned for the southern Kaduna axis.
- Creation of a dedicated 33kV feeder to supply Suleja 2x7.5MVA transformers with NIPP substation to have a separate feed.

- The transformer limitation at Sokoto substation means that the feeders cannot be fully utilised. Remedial work is currently being planned.

As with generation capacity, it must be assumed that transmission investments will be made and that the transmission network will be adequate to allow supply to match demand in the Kaduna Electric zone.

Distribution adequacy: Kaduna Electric estimate their unconstrained consumer demand to be 1.62 GW and that their distribution system has a delivery capacity of 947 MW. Thus reinforcement of approximately 700 MW would be required to supply the franchise area's fully unconstrained demand before the launching of the access rollout programme.

Network Reliability Improvements include the rehabilitation of 33 kV, 11 kV and LV feeders. It should be noted that Kaduna Electric no longer permits the connection of customers directly at 33 kV in urban areas. Over time this will significantly improve the reliability of the 33 kV network by eliminating potential weaknesses.

The company is planning a yearly deployment of 100,000 meters, which will provide benefits including improved data for system management purposes.

To improve productivity, provision of working tools and operational vehicles are included in the budget.

Plans also include network expansion—hundreds of km of extensions to the predominantly (95%) overhead distribution network, and significant upgrading of transformer capacity is planned, for example upgrading of 7.5MVA transformer to 15MVA transformers. The following are also included:

- 33 kV and 11 kV network rehabilitation
- Transformers repair and reconditioning
- LV network rehabilitation
- US$21 million capital expenditure budget for distribution network upgrade in 2016.

Endnotes

1. With the exception of Kaduna, which was privatized in 2014.
2. Discussions with KEDCO revealed that the for new connections the utility intended for the most part to regularize exiting ones.
3. World Bank estimates, June 2016.
4. The Nigerian Electric Power Policy of 2001 established a target of 75% electrification by 2020 and universal coverage by 2030 but this was a broad strategy and more specific targets by DISCO need to be introduced within the existing regulatory framework.
5. World Bank estimates based on the MYTO model, March 2016.
6. World Bank estimates, May 2016.
7. A further increase in tariffs would also trigger public discontent.
8. The baseline of losses integrated into the new MYTO 2015 reports 27.5% of collection losses, 17.9% of non-technical losses and 12.1% of technical losses. Note that the aggregate ATC&C losses of 47.6% is not additive but it is defined by a formula.
9. The Minister of Power, Works and Housing requested NERC to stop the CAPMI scheme in April 2016 because meters were not being deployed.
10. Their main clients were the REBs but this work has partially fallen away following privatisation. There is ongoing work with the local government and for isolated schemes.
11. We understand that some factories used for manufacturing poles and conductors are temporarily closed but could be re-opened at relatively short notice.
12. Some DISCOs are said to be rejecting load. It is believed that, despite high demand, it costs DISCOs more than they earn in revenues on electricity sold to some consumer groups. This is largely because of the high commercial, technical and collection losses and low tariffs. With the tariff increase in February 2016 this situation may no longer be true.
13. Caused by sabotage of gas pipelines to the power plants.
14. The facility is expected to produce 450 MW in the first phase, and then increase production up to 2,000 MW. The plant is supported by guarantees from the World Bank Group. For more information, visit: *www.azurawa.com*.

2 Customer income, expenditure and affordability

The analysis of affordability reviewed the available datasets to inform the access rollout program and ensure that shared prosperity across the country is pursued during the design and implementation of the programme.

Current expenditure in energy (whether electricity or alternative sources, such as kerosene, battery lamps, etc.) can be used to assess people's ability to pay for electricity. Table A1 provides a summary of the average level of household expenditure on energy and a measure of how these values of average expenditure translate into kWh per month at the standard residential tariff[1].

The measures of expenditure above, despite their limitations, provide similar results on the average level of expenditure of households (about ***2,000 NGN per household per month***, equating to ***an average consumption of 90 kWh at the R2 tariff for 2020***).

The following sub-sections provide additional details on the distribution of expenditure among potential electricity customers, and the affordability of electricity prices.

2.1 Income and expenditure distribution

Table A2 shows the level of expenditure in NW Nigeria for income quintiles, broken down by type of expenditure[2].

More detailed figures from the distribution of the broader category *Expenditure on non-food non-durable goods* of the General Household Survey (GHS) proxies for the distribution of the average expenditure in energy goods reported by Lighting Africa and NIAF (of about 2,000 NGN/HH/month[3]). The results of this are shown in Figure A3 below.

At the standard residential tariff for Kaduna Electric (R2 tariff – see Section 5.2) for 2020, 50 kWh would cost a household NGN 938 per month. The above implies that 50% of the population normally pay less than NGN 938 per month on electricity-type energy consumption. From a policy perspective, it suggests that 50% of the population may not be able to pay for electricity at the standard tariff. It also suggests that 15% of the population may not even be able to afford the lifeline tariff of only NGN 4/kWh (US$0.02).

2.2 Geographic distribution

Figure A4 shows the poverty rate (% of poor households) for the Kaduna Electric service area based on research from Oxford University on behalf of the World Bank. This is based on geostatistical modelling using geospatial covariates that are correlated with poverty (e.g. travel times, population density, aridity, night lights, etc.). The poverty data was used by the Earth Institute to highlight areas with low

Table A1 Current expenditure on energy

Reported average expenditure (NGN/HH/mo)	Equivalent in kWh/month at the R2 tariff[a]	Source	Scope and limitations
1,773	90	General Household Survey (GHS), wave 2, post-harvest dataset (2012–2013), LSMS	Average for NW region, includes all types of energy (for lighting, cooking, transportation, etc.), but excluding batteries and phone charging (which, unfortunately, may be the most relevant substitues of electricity.
2,258[b] 2,375[c]	114	Lighting Africa Nigeria Insights Study, August 2013	Limited to Kano state, mainly Base of Pyramid population domiciled in rural and urban locations (without electricity)—includes expenditure on rechargeable lamps, kerosene and petrol genstes. Does not include phone charging.
1,639	83	NIAF surveys	Surveys in 3 rural villages in Jigawa state. Average expenditure in battery lamps, kerosene and phone charging.

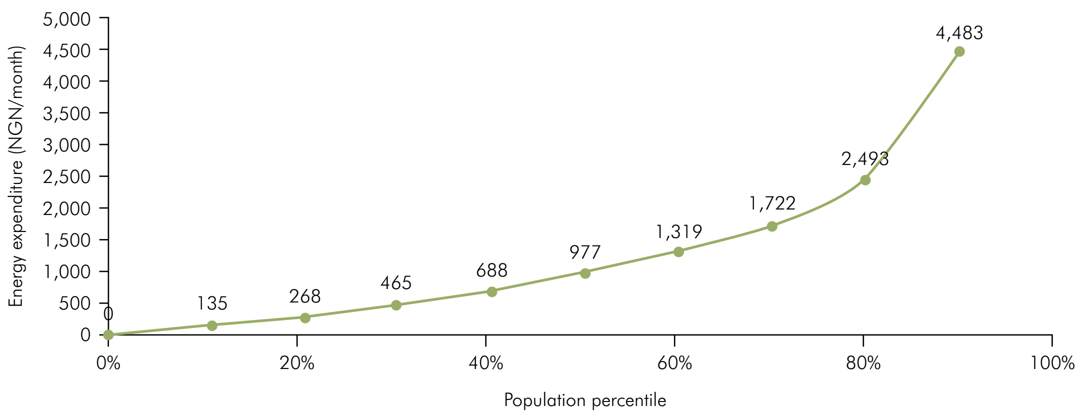
Sources: General Household Survey, Lighting Africa, and Nigeria Infrastructure Advisory Facility.
[a] *At Kaduna Electric's tariff for R2 customers in 2020 according to MYTO 2.2 of NGN 19.74/kWh.*
[b] *Variable.*
[c] *Total, including cost of purchase of device (e.g. lamp, genset).*

Table A2 Expenditure in NGN/month

Quintile	Total expenditure[a]	Expenditure on non-food non-durable goods	Durable goods	Energy expenditure[b]
0–20	10,876	683	374	0
20–40	16,625	1,749	813	400
40–60	23,050	3,355	1,386	1,200
60–80	35,049	6,342	2,483	2,400
80–100	331,114	243,343	33,300	61,000
Average	**27,238**	**5,089**	**1,744**	**1,773**

Source: General Household Survey.
[a] *Includes food, other non-durable goods, and durable goods.*
[b] *Includes goods and services that are not strictly relevant to this analysis, as they will unlikely be replaced by electricity (e.g. petrol used in transportation, firewood and charcoal used for cooking).*

Figure A3 Estimated distribution of relevant energy expenditure

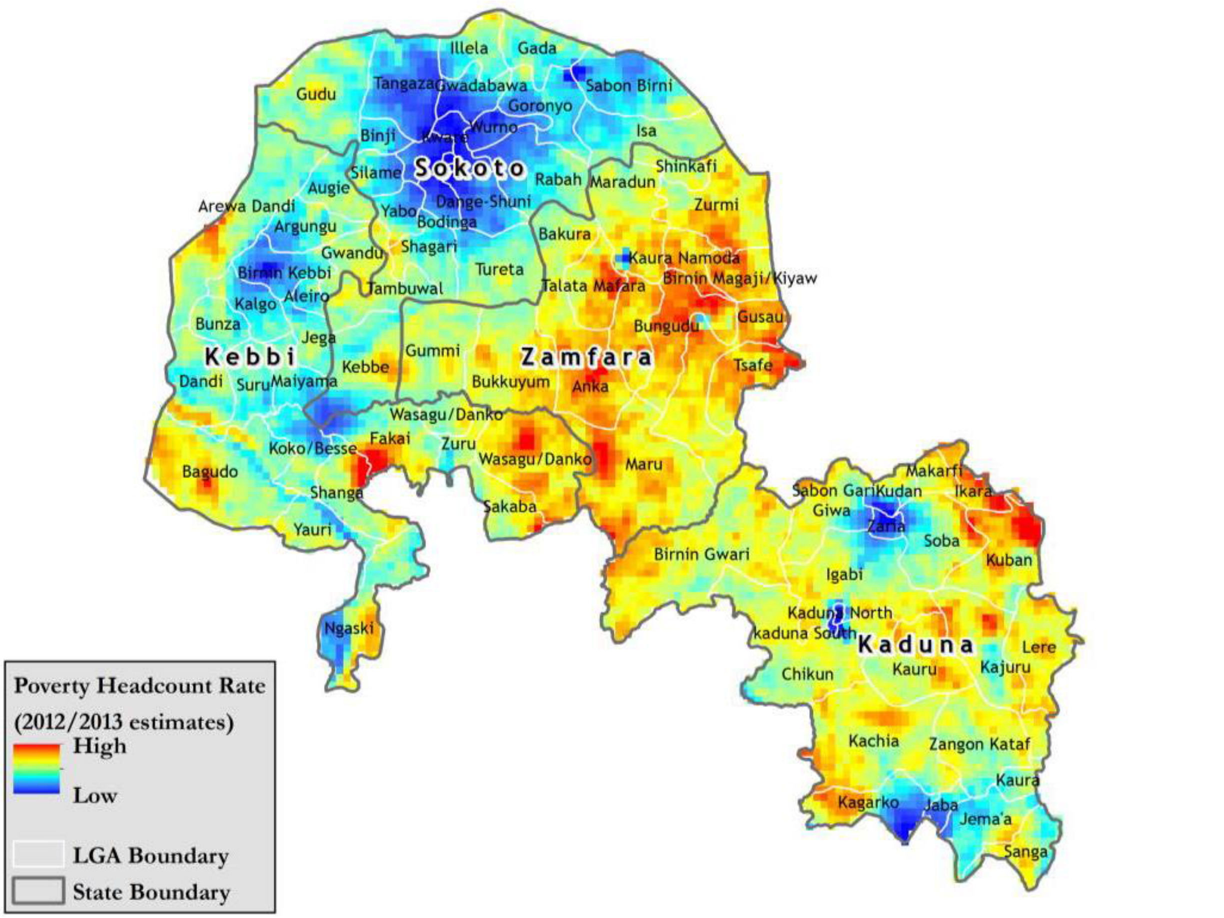


incidence of poverty (the dark blue areas) around cities. Elsewhere there are areas with high incidence of poverty.

Endnotes

1. KEDCO data for R2 customers, May 2015, shows an average of NGN 22.8/kWh but this includes a fixed charge of NGN 667/month and a price per kWh of NGN 16.01.
2. The questionnaire omitted expenditure on batteries (disposable dry-cell batteries or battery charging, including phone charging), which are significant to this analysis.
3. This excludes cost of buying appliances (lamps, gensets).

Figure A4 **Poverty rate (% of poor households) for the Kaduna service area**



Source: Nigeria Electricity Access Program (NEAP4[a]) based on geospatial data from Oxford University (Gething & Molini).

[a] Final Report, Geospatial Implementation Plan for Grid and Off-Grid Rollout (2015–2030), Earth Institute, Kaduna.

3 Transitional electrification options

3.1 Choices

The main choices for pre-grid electrification are isolated mini-grids, SHS and pico-solar lighting products. The choice between these options depends on how long it will be until the main grid arrives, population densities, load densities and capital constraints. The choice is discussed further in Annex 3.3. Pico-solar lighting products are ideal for bridging the gap in the short-term until power arrives; this can be for a period of a year up to perhaps three years. Even after the grid arrives, these products will still have value in providing lighting and battery charging during power cuts from the main grid. If the main grid is not expected to arrive within five years, but is expected between five and ten, then a mini-grid could provide a transitional arrangement. If the main grid is not expected for many years because the population is highly dispersed, distributed solar will be the preferred solution in this case.

The regulation governing IEDNs (see Section 6.2) will be revised and will hopefully introduce a framework that makes it attractive to develop isolated grids[1] even where they may be engulfed by the Kaduna Electric grid in the foreseeable future. Assuming this is the case, the optimum policy on electrification technology is then determined by economic principles and financing constraints. This recognises that electrification based on isolated grids and distributed solar may face fewer financing constraints than grid electrification provided that the framework is appropriate[2].

A decision tree for this calculation is provided in Figure in Annex 3.3.

3.2 Electrification to target poverty

The geospatial distribution of poverty is described in Annex 2.1. Further analysis of the geospatial data through correlation analysis reveals that the areas with high poverty risk are the areas furthest from the existing grid and with the lower population densities and the highest costs of grid electrification, and therefore these are the areas least likely to be connected to the Kaduna Electric grid early in the electrification programme. This suggests that programmes designed to support off-grid electrification will have important social dimensions because these are also likely to be areas with high poverty.

Our approach to solutions for the off-grid component of the programme is built around electrification access 'tiers'[3] whereby electricity access is not simply defined by reference to a grid connection or not, but is graduated through tiers 1 to 5 where tier 1 households have access to simple low wattage lighting (solar, rechargeable batteries or conventional batteries) and phone recharging through to tier 5 where households have access to a reasonably high quality, continuous, and reliable electricity supply that is capable of powering significant electrical appliances such as electric irons, fridges and TVs. The tiers have multiple attributes of capacity (W or kW), duration (hours/day), reliability (interruptions per week), quality (stable voltage), legality (a formal connection, or an informal or illegal one) and safety (see A5 below).

We assume that 'un-electrified' households will have access to pico-solar lighting (and battery charging) solutions through local markets. Consideration could be given to supporting this group of products perhaps in areas where market penetration is low—particularly to areas where poverty levels are greatest. Support need not necessarily be provided through subsidies to the product itself, though this is an option, but potentially through support to the marketing and distribution channels for pico-solar lighting. Lighting Africa has supported the promotion of pico-solar lighting products to the base-of-the-pyramid households for a number of years but is no longer proposing direct subsidies for the products. Pico-solar lighting is an excellent short-term product providing lighting and mobile phone charging until more substantive solutions can be introduced. We assume this is the solution to be adopted for those households who will remain 'un-electrified'. The Lighting Africa Market Study[4] conducted in 12 Nigerian states including Kano, found that the majority of households were aware of pico-solar lighting products. We could not find information from the survey on the penetration of solar in the market in the Kaduna zone or in North West Nigeria in general, but the publicly available findings indicate some reservations, particularly among urban households, around the limitations of pico-solar lighting products.

3.3 Off-grid electrification strategies

Below we consider the choice between pre-electrification strategies:

- wait and do nothing
- distributed solar (SHS and pico-solar), or
- isolated mini-grids

Figure A5 Multi-tier matrix for access to household electricity supply

ATTRIBUTES		TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
1. Capacity	Power[1]		Very Low Power Min 3 W	Low Power Min 50 W	Medium Power Min 200 W	High Power Min 800 W	Very High Power Min 2 kW
	AND Daily Capacity		Min 12 Wh	Min 200 Wh	Min 1.0 kWh	Min 3.4 kWh	Min 8.2 kWh
	OR Services		Lighting of 1,000 lmhrs per day and phone charging	Electrical lighting, air circulation, television, and phone charging are possible			
2. Duration	Hours per day		Min 4 hrs	Min 4 hrs	Min 8 hrs	Min 16 hrs	Min 23 hrs
	Hours per evening		Min 1 hrs	Min 2 hrs	Min 3 hrs	Min 4 hrs	Min 4 hrs
3. Reliability						Max 14 disruptions per week	Max 3 disruptions per week of total duration < 2 hours
4. Quality						Voltage problems do not affect the use of desired appliances	
5. Affordability					Cost of a standard consumption package of 365 kWh per annum is less than 5% of household income		
6. Legality						Bill is paid to the utility, prepaid card seller, or authorized representative	
7. Health and Safety						Absence of past accidents and perception of high risk in the future	

Source: ESMAP[a].
[a] *Beyond Connections: Energy Access Redefined, Conceptualization Report*, ESMAP, June 2015.

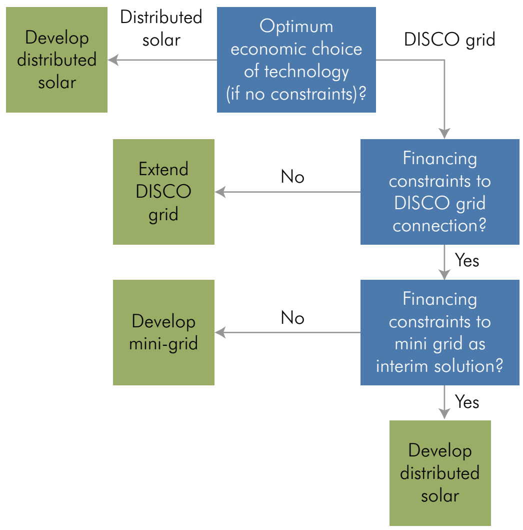
We cannot offer a precise time criterion to decide when to choose between do nothing, distributed solar (SHS or pico-solar) or mini-grids. The mini-grid is a more expensive transitional solution but if the mini-grid can be incorporated into the main grid, the investment will not be lost when the main grid arrives. It is a trade-off between having no power for, say, five years versus introducing a more expensive mini-grid in, say, one year. This requires a complex economic cost-benefit analysis, possibly on a case-by-case basis.

An example of a study in India that attempted to provide a systematic basis for choosing was undertaken in India and published in Energy Policy: *A techno-economic comparison of rural electrification based on solar home systems and PV microgrids*[5]. However, the primary focus was the choice between grid electrification and isolated grids rather than a pre-grid electrification programme. Moreover, costs of solar PV have declined substantially since 2010 and the rule-of-thumb parameters would need to be updated.

Off-grid electrification involving SHS and pico-solar lighting products has a relatively low capital cost but the equipment has relatively short lives. Pico-solar lighting solutions in particular are cheap and have a life of only perhaps 5 years because of the current battery technologies, and this makes them particularly suited as interim solutions for bridging the gap until power arrives; this can be for a period of a year up to perhaps three years. Even after the grid arrives, they will still have value in providing lighting and battery charging during power cuts from the main grid.

SHS have higher capital costs than pico-solar lighting and longer economic lives. For areas that do not currently have electricity but are expected to be electrified within a few years, investment in SHS could incur relatively high capital costs (compared with pico-solar lighting) that may be largely wasted

Figure A6 Decision tree for non-Kaduna Electric grid electrification



once the grid arrives. They may have some residual value when the grid arrives as backup for grid interruptions or to supplement the supply from the grid or potentially they could be recycled for use in other areas[6]. However, SHS may also be suited to more remote areas with low population and load densities for whom the geospatial analysis reveals that neither grid connection nor isolated mini-grids are economically justified at least not within the time horizon of 2030.

Investment in isolated grids in areas that will be connected in a few years' time will not be wasted if those isolated grids can simply be connected into the main grid when it arrives. The generation plants used to supply the isolated grids could, when the isolated grid is connected to the main grid, be relocated to other isolated areas or alternatively they could be used to inject power into the main grid and/or support the network in that area[7]. These generation investments will not then be wasted though if relocation takes place this will incur some cost (relocation will not in any case be possible for some technologies such as small hydro).

From the perspective of optimum economic policy, the choice of interim technologies for areas that will eventually be connected to the Kaduna Electric grid is therefore complex. One way to approach this is to categorise areas as in Namibia's off-grid masterplan[8] with one category called "pre-grid areas". These are expected to be electrified within five years. In Namibia these were excluded from the off-grid masterplan except where there were delays in grid electrification. In Kenya, an area that is not expected to be electrified within 10 years was considered suited to off-grid electrification (but because of the absence of a grid roll-out plan, a criterion of 50 km distance from the main grid was also adopted as an alternative).

Population densities in Nigeria are generally higher than in Kenya and Namibia and grid coverage is very widespread so that few households are far from the existing grid. The rule-of-thumb policies in Kenya and Namibia ignore the benefits of developing isolated grids using grid technical standards that can then be absorbed into the main grid and fully compensated by Kaduna Electric, or kept as small-power distributors (SPDs) and purchase electricity wholesale from Kaduna Electric.

Endnotes

1. i.e., financial compensation from KEDCO to the grid developer following takeover by KEDCO or the conversion of the isolated grid to a small power distributor (SPD), plus a feed-in tariff for renewable energy purchased from the generator.
2. Experience in Cambodia is relevant here. Electrification initially took place successfully with a large number of isolated grids that are now being connected to the main grid as the main extends further outwards. The isolated grids may be connected as SPDs or may be fully absorbed into the main grid.
3. *Beyond Connections: Energy Access Redefined, Conceptualization Report*, ESMAP, June 2015.
4. Lighting Africa, *Nigeria Consumer Insights Market Study*, 2013.
5. A. Chaurey, T.C.Kandpa, *A techno-economic comparison of rural electrification based on solar home systems and PV microgrids*, Energy Policy, 38(2010)3118–3129.
6. Though experience elsewhere suggests that the re-use value of SHS is relatively low because of rapid technological development and the deterioration in the batteries and other equipment.
7. Solar plants that are suitably designed can be relocated. Small hydro can be used to inject power into the existing grid.
8. Off-grid energisation masterplan for Namibia, January 2007.

4 Independent electricity distribution networks

Under Nigerian regulations, isolated grids (also known as mini-grids) are known as ***Independent Electricity Distribution Networks*** (IEDNs). They are currently regulated under the Nigerian Electricity Regulatory Commission (Independent Electricity Distribution Networks) Regulations, 2012, but we understand that these regulations are currently under review, with support from GIZ. At this stage, it is uncertain when revised regulations will be made available, but we anticipate this to happen sometime in early 2016.

Some important characteristics of an IEDN under current regulations:

- May be developed, owned and/or operated by a DISCO or other entity
- Include both purely isolated systems and those connected to existing DISCO networks
- May have their own embedded generation source, or purchase power from the DISCO operating the network to which it is connected
- Allowed to operate within a DISCO's concession area, provided there is no other distribution system 'within the geographical area'
- [Must be at least 5 MW]

The regulations currently allow and/or require:

- Cost-reflective tariffs
- Meeting 'relevant Technical Codes and standards'
- Compliance with the System Operator's requirements (if connected to the main grid)
- Provide non-discriminatory open access to its distribution system by any other Licensee, if it has the capacity to do so
- No increase charges to accommodate losses above the MYTO limit
- Meter any new customers
- Apply the connection charge approved by NERC[1]
- Meet voltage standards based on the capacity of the generation in the system

In addition, a relevant reference in the Electric Power Sector Reform Act, 2005, states:

- Distribution systems with capacity under 100 kW do not require a license

Endnotes

1. Currently NERC does not approve connection charges for residential customers.

5 Examples of international experience

Nigeria is unusual in Africa, though not unique, in having privatised electricity distribution companies. The expansion of electricity access through electricity grids in developing countries is typically handled by state-owned companies or through agencies created for the primary purpose of electrification. However, international experience suggests that expansion of access to electricity can be effective in countries where electricity distribution is privatised. A report prepared by IFC[1] notes that:

> *A rigorous 2009 study looked at data on 250 electricity companies across 50 countries[2]. The study found that utilities that had been privatized, or which operate under PPPs, extended access more rapidly than publicly owned utilities.*

The IFC report also notes that:

> *Almost all examples of grid-based electrification business models have involved a PPP with some degree of capital subsidy to attract private investment. Governments have most often awarded contracts with legally binding coverage targets and quality-of-service requirements. This sometimes comes with public financing to help cover the cost of such obligations. This subsidy is most often allocated on the basis of the lowest-cost but highest-quality service offering, and is applied to cover the viability gap on capital but not operating costs.*

International experience therefore offers some useful lessons for the expansion of electricity in Nigeria. An example of Brazil is provided below. Other examples of countries that have combined substantially increased electricity access with private electricity supply include Chile and India.

5.1 Brazil

Brazil, like Nigeria, has a large population (approximately 190 million) and a Federal and State administrative structure. By 2009 Brazil had reached an overall electrification rate of 98% achieved largely through grid extension. Electricity distribution is mainly privately operated through geographically based concession arrangements. The Ministry of Mines and Energy (MME) is the policy making entity for the power sector and the companies are regulated by the Electricity Regulatory Agency (ANEEL). Until the 1990s, rural electrification policies were implemented largely at the State level, using State budgetary resources. Electrification programmes had been introduced during the 1970s, 1980s, 1990s and early 2000s but the discussion below focuses on the last programme that was began in 2003—the Luz para Todos (Light for All, or LpT), which achieved virtual universal access to electricity by 2010.

LpT is based on an obligation for concessionaires to provide universal electricity access using substantial federal and state resources channelled to the companies, and on low electricity tariffs for low-income and rural consumers.

Lpt was to provide 2 million new rural connections, subsequently revised to 3 million, over a five-year period to 2008. Each household was also to receive power plugs, lamps, and other necessary material needed to undertake the internal wiring and lighting. The deadline was later extended to 2010.

ANEEL (the regulator) set and verified the annual electrification targets for the companies while Eletrobrás (the Federally-owned holding company owning a large part of the generation plant and the transmission grid) managed the electrification programme including carrying out the technical and financial analyses of the connections to be installed by the companies and the allocation of funds to the companies and the monitoring to ensure the claimed installations had been made. MME co-ordinated the LpT programme and set the policies governing it.

The LpT programme mainly targeted those living in the northern and north-eastern states where electricity access at the beginning of the programme was lowest. These two regions accounted for more than 75% of the planned installations.

The overall cost of LpT was around US$ 7 billion (original estimates were US$ 4.2 billion). It was funded largely by Federal and State governments in the form of grants and concessionary loans to the concessionaires. The State governments' contributions averaged 13% of the total capital costs while the Federal government was the main source of funding (72%) through Global Reversion Reserve (RGR) which provided grants and concessionary loans. RGR is funded by annual levies on the concessionaires supplemented by funds from various other sources (payments for the use of public assets, fines received by ANEEL). The concessionaires' equity participation in financing the electrification was around 15% of the capital cost. No connection charges were levied on rural consumers. Operating costs for rural consumers were to be covered by the utilities through general electricity tariffs. The tariffs were subsidised for consumers with low consumption. Around 35% of all consumers have low consumption and benefit from subsidised tariffs. These represent an even higher proportion in rural areas.

5.1.1 Key lessons learned

- Rural electrification access, whether undertaken by the private sector or the public sector, will need substantial external financial support.
- Widened electrification access can go hand-in-hand with privatised distribution.
- Electrification targets need to be set for the distribution concessionaires.
- A framework is needed to monitor the connection of rural households and to disburse funds based on verified connections of designated consumers.

5.1.2 Information sources

- *Comparative Study on Rural Electrification Policies in Emerging Economies, Keys to successful policies, IEA, Alexandra Niez, 2010.*

5.2 Chile

Chile has a long history of rural electrification as local cooperatives were formed as early as the 1930s to support agricultural development. The national distribution companies were split up and privatised in the 1980s but did not hold an exclusive right to serve customers. Electrification rates increased gradually under private ownership and in 1990 rural coverage reached just under 50% of households. The Chile Rural Electrification Program (PER) aimed at increasing rural electrification was implemented in 1994 and was supposed to increase rural electrification coverage from 50% to 75% by the year 2000. The program offered governmental subsidies to private entities in order to incentivise rural electrification. PER was given sufficient authority to develop and guide the policy initiative and long-term governmental goals were established. A strict project selection method was created and built on top of the already stable private distribution companies and cooperatives. The goal of 75% electrification was reached in 1999 and due to the program's success a goal of 90% electrification by the year 2005 was set.

The project selection methodology ruled out all projects which were assumed to have a positive IRR as it provided sufficient incentive for the private market to develop. The selection method accounted for economic benefits of electrification within the region and projects and utilities rated based on the lowest subsidy required per user. In some cases, this created a competition among the private utilities to find innovative ways of reducing operational costs to receive the contract. This helped lower the cost of rural electrification in some areas. In others, where no competition existed, the private utility sometimes deliberately adopted assumptions designed to increase potential profit. As a response, PER adopted standard measures, based on local data, for subsidy calculations.

The aid offered by PER was constructed in a way to help utilities during the first stages of implementation, and then decrease with time. Due to Chile's long history with private utilities, a clear set of rules and standards for infrastructure was already in place. This eased the transition into subsidised rural electrification projects as most problems and disputes could be resolved by referring to standards and precedents. The Chilean National Energy Commission (CNE) was the central entity responsible for the design of PER and allocation of funds to regional governments who then allocated them on a project basis.

5.2.1 Key lessons learned

The need for a clear and transparent project assessment methodology is vital to this type of a program. It limits political and commercial influence on the program and makes sure projects are ranked on the basis of merit.

Governmental support is very important to the credibility of a program. CNE's role in PER was vital as it provided a leadership and monitoring role while maintaining authority within the regional governments. CNE built enough public and political momentum for the program to continue across administrations and shifts in Chile's political landscape.

By adopting construction and material standards, construction costs can be kept at a minimum.

5.2.2 Information sources

- *Integrated Transmission Planning and Regulation Project: Review of System Planning and Delivery*, Electric Policy Research Group, Imperial College London/University of Cambridge, 2013.

- *Challenges of power transmission expansion in a fast growing country*, Prof. Hugh Rudnick, Pontificia Universidad Católica de Chile, Workshop on International Experience in Transmission Planning and Delivery, Imperial College, London, 11–12th January 2013
- *Market Based Transmission Planning: Chilean Experience*, Juan Carlos Araneda, Transelec, Workshop on Transmission Network Security Standards, Imperial College London, March 9th, 2009
- *Electricity distribution tariffs, the Chilean Experience*, Hugh Rudnick, Pontifícia Universidad Católica de Chile, International Seminar on Electricity Tariffs, Brazil, June 2009
- *International transmission pricing review*, Frontier Economics, a Report prepared for the New Zealand Electricity Commission, July 2009

5.3 India

India has the largest rural population in the world, totalling 876 million people in 2014, making rural electrification a major challenge. One of the major barriers to rural electrification expansion has been a general lack of electricity generating capacity in India. Technical and commercial electricity losses also rank among the highest in the world and have acted as a barrier to electrification.

The Electricity Act of 2003 compelled the utilities to supply electricity to all households, including rural areas. The National Electrification Policy of 2005, the Rural Electrification Policy of 2006, and the National Tariff Policy of 2006, were all designed to encourage rural electrification efforts. Additionally, they improved the financial and institutional status of the state utilities, generation, transmission, and distribution. This included unbundling state utilities, widening the scope for state government action in rural electrification efforts. The Electricity Act of 2003 also increased competition by giving the private sector access to all power sector operations, including investing in rural electrification projects. Administrative mechanisms were established to allow for the private setup of decentralised generation projects and stand-alone systems.

Institutional and regulatory reforms undertaken over the past 15 years have included unbundling the State Electricity Boards (SEBs), increasing private sector involvement in generation, transmission, and distribution, and looser rules on electricity tariffs. These reforms also initiated the "Power for all by 2012"goal, which aimed to ensure sufficient power to achieve GDP growth targets, reliability, quality, optimum costs, and commercial viability.

Rural electrification accelerated under the 11th Five-Year Plan (ending March 2012), which provided both political will and funds. The Plan allocated US$241 billion for electricity including, with US$65 billion for generation and US$30 billion for transmission and distribution for rural areas. Two electrification programmes began in 2005: the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) scheme and the Remote Village Electrification (RVE) programme. The latter focused on off-grid electrification and non-grid solutions. The RGGVY scheme was aimed at grid electrification and is the focus of this case study.

5.3.1 Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) scheme

Launched under the "Power for all by 2012" initiative, the RGGVY programme involved a major grid extension and reinforcement of rural electricity infrastructure. The primary approach was through grid extension, with stand-alone systems if grid extensions were not feasible.

The policy initially aimed to provide electricity access for all households (an additional 87 million households) by 2009 in the without subsidy for households above the poverty line, but the rollout was slow and was extended. Only 30% of household connections and 51% of villages targeted under the initial plan had been achieved by 2009. The main reason for the delay was the high technical and commercial losses in India's rural distribution network, which meant that utilities were disinclined make rural electrification connections.

As the RGGVY programme was refined, the central and state governments were given joint responsibility for rural electrification, with state governments required to prepare rural electrification plans that outlined methods and electrification technologies. Plans were then coordinated across state governments and utilities by the Rural Electrification Corporation Limited (REC).

90% of funding was provided by the central Ministry of Power (MoP), with state governments covering the rest through their own funds or loans through the REC or other institutions. State governments were then responsible for implementation through their state power utilities, with the MoP directing the states to establish Coordination Committees to track progress and identify issues. Milestone-based monitoring mechanisms were put in place from project approval to completion, including a web-based monitoring system at the village level, and with the release of funds being dependent on milestones being met. Independent, random evaluations were also used to verify the connections claimed. MoP noted that progress in rural electrification projects improved with these mechanisms in place.

By 2012, India had reached an urban electrification rate of 93%, but only 53% for rural areas, bringing an overall electrification rate of 65%. As of 2015, India claimed 97% of villages were electrified, but a more stringent definition of rural electrification based on households connected would lower this rate to approximately 70%.

5.3.2 Key lessons learned

High levels of losses and poor revenue collection is a significant barrier to enhanced electricity access.

Notwithstanding the privatised distribution companies in India, there is a need for state funding of electrification access.

It is possible to adopt different technical standards for different states.

Use of milestone-based monitoring improved rural electrification progress, with the release of funds made dependent on states reaching milestones

5.3.3 Information sources

Information derived largely from Comparative Study on Rural Electrification Policies in Emerging Economies, Keys to successful policies, IEA, Alexandra Niez, 2010.

5.4 Off-grid developments: Bangladesh and Ethiopia

The Bangladesh SHS program has been widely acknowledged as the most successful national off-grid electrification program in the world. Since its inception, more than 3 million SHSs have been installed, two-thirds of which in the last 3 years and reaching 100,000 installations a month. The programme was developed under The Rural Electrification and Renewable Energy Development World Bank project.

The programme is managed by Infrastructure Development Company Limited (IDCOL), a semi-governmental infrastructure finance organization, which works through a pool of partnering microfinance institutions and it demonstrates the feasibility of having beneficiaries pay for a substantial portion of the SHS asset in affordable instalments (quality standards are vetted by a technical standard committee).

SHS systems are affordable through a combination of consumer credit/refinancing and (declining) subsidies. The idea was to bring monthly expenditures as close as possible to existing household spending on kerosene and dry cells. Partner organizations provide microfinance loans to households, who are required to make a down payment equivalent to 10–15 percent of the cost of the system. The remainder is repaid in 2–3 years at prevailing market interest rates (typically 12–15 percent). Sixty to eighty percent of the credit that the partner organization extends to the household is eligible for refinancing from IDCOL at the prevailing market interest rate of 6–9 percent, with a 5/7-year repayment period and a 1–1.5-year grace period. Partnering organizations are responsible for collecting payments, providing maintenance, and training customers in both operation and maintenance. Beneficiaries are given a buy-back guarantee with the option of selling their system back to IDCOL at a depreciated price if a grid connection is obtained within a year of purchase, however most customers have preferred to hold on their solar system as grid supply remains unreliable.

The World Bank Electricity Network Reinforcement and Expansion Project (ENREP)

The Electricity Network Reinforcement and Expansion Project (ENREP), approved in 2012, targets the private sector-led development of stand-alone renewable energy and energy efficient products in Ethiopia. The design of the financing mechanism creates a market-driven, private sector-led approach and addresses the following main issues to enhance the market for renewable energy in Ethiopia: access to finance at relatively lower cost of capital, access to foreign currency, and improvements to the general lending environment (e.g. fair-market collateral values).

As a result, ENREP's design entails a US$20 million credit line (as a Financial Intermediary Loan) for renewable energy and energy efficiency products administered by the Development Bank of Ethiopia (DBE). The credit line has two main elements: retail lending to private sector enterprises and whole sale lending to the microfinance institutions. There are no limitations placed on the technologies/products being supported, so long as they are of approved quality standards (e.g. Lighting Global).

To date, ENREP's credit line has been a huge boost to Private Sector Enterprises and has resulted in the local sale of almost 250,000 (15,000 targeted by the project) Lighting Africa quality verified solar portable lanterns, is on track surpass 2 million products by the end of 2016, and provided 750,000 people with access to modern energy services.

Endnotes

1. *From Gap to Opportunity: Business Models for Scaling-up Energy Access*; IFC, undated, probably 2012. p.111.
2. *Does Private Sector Participation Improve Performance in Electricity and Water Utilities?* Gassner, Popov, and Pushak, World Bank, 2009.

WORLD BANK GROUP
1818 H Street, NW
Washington, DC 20433
USA
Telephone: +1 202 473 1000
Internet: www.worldbank.org