Costing for National Electricity Interventions to Increase Access to Energy, Health Services, and Education

Senegal Final Report

A Report to the World Bank by the Agence Sénégalaise d'Electrification Rurale (ASER) and the Energy Group, Columbia Earth Institute

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CURRENCY EQUIVALENTS

Currency Unit = CFA Franc
CFA 1 = US$0.002
US$1 = CFA 500

ABBREVIATIONS AND ACRONYMS

AML	Arc Macro Language
ASER	Agence Sénégalaise d'Electrification Rurale
EI	Earth Institute
ECOWAS	Economic Community of West African States
ERIL	rural electrification projects initiated locally
GIS	Geographic Information System
HH	household
kV	kilovolts
kVA	kilovolt-amperes
kW	kilowatts
kWh	kilowatt hours
LV	low voltage
MDG	Millennium Development Goals
MFP	Multi-functional Platform
MV	medium voltage
MW	megawatts
MWh	megawatt hours
PPER	Rural Electrification Priority Program
PV	photovoltaic
SENELEC	Société Nationale d'Electricité
STEG	Société Tunisienne d'Electricité et du Gaz
UNICEF	United Nations Children's Fund
UNDP	United Nations Development Program
Wp	peak watts

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Preface and Acknowledgements

This report was prepared by the Agence Sénégalaise d'Electrification Rurale (ASER) led by Ousmane Fall Sarr and the Energy Group at Columbia Earth Institute which included Vijay Modi, Lily Parshall, Aly Sanoh, Shashank Mohan, and Dana Pillai.

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Préface et Remerciements

Ce rapport a été préparé par l'Agence Sénégalaise d'Electrification Rurale (ASER) menée par Ousmane Fall Sarr et le Groupe Energie de Earth Institute de l'Université Columbia composé de Vijay Modi, Lily Parshall, Aly Sanoh, Shashank Mohan, and Dana Pillai.

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Executive Summary

A national electricity scale-up is necessary for meeting the Millennium Development Goals over the next ten years, and one of the priorities is to electrify all health centers and schools. Rapid electrification of rural institutions and households in Senegal likely will require coordination across sectors and a range of energy technologies, including decentralized solutions.

Electrification targets

Currently, an estimated 47% of Senegal's total population has access to electricity. The urban and rural access is 80% and 13% respectively. In this report, cost estimates are based on scaling this access up to achieve a 66% national electrification rate with 100% urban and 36% rural access within the next 10 years. In addition to household electrification, the estimates also include the goal of enabling electricity access for all educational and health institutions in the country.

Earth Institute Electricity Planning and Investment Costing Model

The Columbia Earth Institute electricity costing model provides an overall view of needed investments for scaling-up electricity distribution to meet these targets. The tools also provide mechanisms for multiple stakeholders to share resources for energy planning. The model is a set of inter-linked tools including a Microsoft Excel spreadsheet model, ArcGIS/ArcInfo for spatial processing and analysis, and Java programs to algorithmically generate an extended grid and process results. The model allows country teams to input financial and socio-economic data along with policy criteria to evaluate the feasibility and costs of electrification scenarios and quickly compare alternatives.

Total cost of electricity distribution scale-up

- All costs, capital and recurrent, including costs of electricity purchase, maintenance/replacement of equipment, capital replacement and billing/collection costs over a ten-year investment period to go from a national electrification rate of 47% to 66% are estimated to be $860 million (in 2007 dollars).
- Of the $860 million, the capital costs for increasing urban access to 100% (290,000 new households) is $88 million, whereas the capital cost of increasing rural access to 36% (190,000 new households) is $283 million. These costs include the cost of institutional access in these areas. An additional $48 million over the ten year investment is the capital cost of increasing the electrification rate of all rural institutions to 100%.
- The corresponding five year capital cost figures are $45 million for 120,000 new urban households and $145 million for 91,000 new rural households. (Table E-1 and E-2). All capital costs shown above are discounted.
- Of the 480,000 households, urban and rural, to be electrified over the ten year period in the above scenario, 73% would be grid connected.
- Capital costs account for 73% of the cost of rural grid extension, 38% of the cost of diesel mini-grids, and 64% of the cost of PV-MFP systems.

- For small villages (< 500 people) far from the existing grid, PV-MFP (e.g. photovoltaics for household and a shared Multi-functional Platform for community productive use) is the most cost-effective option.
- For larger villages (500 – 5,000 people) far from the grid, a diesel mini-grid is the most cost-effective option.

Table E-1. Investment needs to meet a 66% national electrification target over ten years. All the costs in this table are discounted aggregated costs over the period of investment. They are for both off-grid and on-grid as well as for both households and institutions.

	Total Cost, Years 1-5 ($mil)	Total Cost, Years 1-10 ($mil)
Urban and Peri-urban Electricity*		
Capital	**45**	**88**
System Maintenance Cost	8	32
Electricity / Fuel purchase	46	191
Billing/Collection Cost	6	25
Urban Total	**105**	**336**
Rural Electrification		
Capital	**145**	**283**
System Maintenance Cost	15	67
Electricity / Fuel purchase	35	96
Billing/Collection Cost	6	18
Capital Replacement	5	12
Rural Total	**206**	**476**
Additional Rural Institutions**	**11**	**48**
Grand Total	**322**	**860**
Capital Investment of Grand Total	**201**	**419**

*Costs to increase the penetration rate in urban areas from 80% to 100%. **Cost to electrify rural institutions that are outside of villages that will be covered by the main rural electrification program.

Table E-2. Total number of households covered

Household coverage (in thousands)	Current	Year 5	Year 10
Urban households	**506**	**634**	**795**
Rural			
Grid # households	68	105	140
Diesel mini-grid # households	3	38	43
PV-MFP # households	7	27	83
Rural households	**78**	**170**	**266**
National Households	**584**	**804**	**1,061**

Undiscounted Capital Costs per household[1]

- $1,140 per-household average capital cost for rural grid connections, including initial MV line extension cost to the village
- $965 average capital cost for households connected to a diesel mini-grid
- $716 average capital cost for the PV part of the PV-MFP system. This cost rises to $1,155 when the MFP is taken into account
- $409 per-household average capital cost for urban grid connections

Institutional coverage

Currently, less than 20% of rural social institutions (schools and health clinics) have access to electricity. Reaching 100% of these institutions carries a capital cost of $8.23 million. The average undiscounted capital cost of basic electrification of a rural school is $825 and for a health clinic is $726. Costs may be substantially higher for larger institutions with many rooms and more intensive electricity requirements (e.g. for computers and laboratory equipment in schools or sterilization equipment in health clinics).

Generation scale-up

Current generation capacity in Senegal is approximately 500 MW, and energy demand was 1.74 million MWh in 2003. Needed generation capacity to meet the scale-up in distribution is about 100 MW depending on the type of power plant. Economic growth may require a substantial increase in generation capacity. If the elasticity of electricity demand growth is 1.5 and economic growth is assumed to occur at 5% per year, and if this demand is assumed to be decoupled from the demand estimated here, an additional generation capacity of 500 MW will be needed. Note that investments to scale up generation capacity are not included in cost estimates made in this report.

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1 These costs per household for each technology are averaged over all households for which that technology is most cost-effective. For example, the average capital cost of US$716 for PV-MFP systems is averaged over all households for which PV-MFP is the most cost-effective technology. These households tend to be in small villages with low demand. Therefore, it is important to stress that these numbers cannot be interpreted as a basis for selecting the most cost-effective technology nation-wide. In other words, an average cost of US$716 for PV-MFP as compared to US$965 for diesel mini-grid neither suggests that PV-MFP is the cheapest technology for the country nor that policies should push for more PV-MFP systems.

1 Introduction

In Senegal, as elsewhere, rural electrification is critical to poverty reduction. A national electricity scale-up is necessary for meeting the Millennium Development Goals over the next ten years, and one of the priorities is to electrify all health centers and schools.[2] Rapid electrification of rural institutions and households in Senegal likely will require coordination across sectors and a range of energy technologies, including decentralized solutions.

The Columbia Earth Institute has developed a comprehensive energy planning methodology using straightforward Excel- and GIS-based tools. The toolset based on this methodology allows country teams to make investment estimates for a range of electrification scenarios given various technology options, coverage targets, fuel costs, etc. The tools also provide mechanisms for multiple stakeholders to share resources for energy planning.

The tools calculate the cost of scaling up electricity distribution. They output costs broken down into various components (e.g. capital, recurring, and replacement) but do not provide a complete financial analysis of the rate of return on particular investment schemes.

This report details the Earth Institute methodology, describes data obtained in Senegal, and presents cost estimates for selected electrification scenarios.

1.1 Study objectives

The main objectives of this study included:

- Refining the Earth Institute energy planning methodology through collaboration with Senegalese counterparts
- Bringing together energy, health, education, and other stakeholders as part of a multi-sectoral approach to electricity scale-up
- Estimating needed investments in electricity distribution to meet MDG targets
- Creating a publicly-available package of models and documentation

1.2 Electricity in Senegal

Senegal's national utility, SENELEC, maintains an electricity grid that reaches most of the country's urban centers, but only 9% of rural villages and 13% of the rural population.[3] All settlements with fewer than 5,000 people or about 500 households are

[2] For more on how energy and electricity relate to the Millennium Development Goals, see Modi et al., 2006.

[3] Note that the percentage of villages covered is lower than that of the rural population with access to electricity because larger villages tend to be the ones that are already electrified.

defined as rural. Villages are organized into rural communities (322), districts (56), departments (31), and regions (11).

SENELEC (Société Nationale d'Electricité) has primary responsibility for electricity transmission and distribution in Senegal. After two failed attempts at privatization in the 1990s and power cuts in 2000, the government took control of the company and opened up generation to the private sector. According to some estimates, demand in Senegal rises by an average of nearly 10 percent per year, straining 20- to 40-year-old power installations.[4,5,6] SENELEC's high-voltage transmission lines are 225 kV (some of which are being used as 90 kV lines) and its medium-voltage (MV) distribution lines are 30 kV. In 2007, a new General Manager, Cheick Diakhate, took over management of the company.

As part of its reforms in the late 1990s, the government created the Agence Sénégalaise d'Electrification Rurale (ASER), an autonomous agency under the Ministry of Energy and Hydraulics. ASER currently is managing two major programs: (1) the rural electrification priority program (PPER), which allocates concessions for rural electrification to the private sector and (2) locally-initiated rural electrification projects (ERIL).[7] Since its formation, a six-year-old ASER has electrified more than 160 rural villages.

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[4] Installed Capacity: As of 2007, Senegal had 392 MW of thermal power installed by SENELEC and 50 MW installed by independent producers as well as 60 MW of hydroelectricity (SENELEC 2007, http://www.senelec.sn/content/view/15/66/)

[5] ACP-EU Commission on Economic Development, Finance and Trade,2006. According to the Report on the problematic of Energy in the African, Caribbean, and Pacific Countries. Senegal is one of the leading Sub Saharan countries in renewable energy with an approximate installed capacity of 1MW of solar power.

[6] Columbia University and UNDP Energy Workshop, 2006.

[7] Ibid.

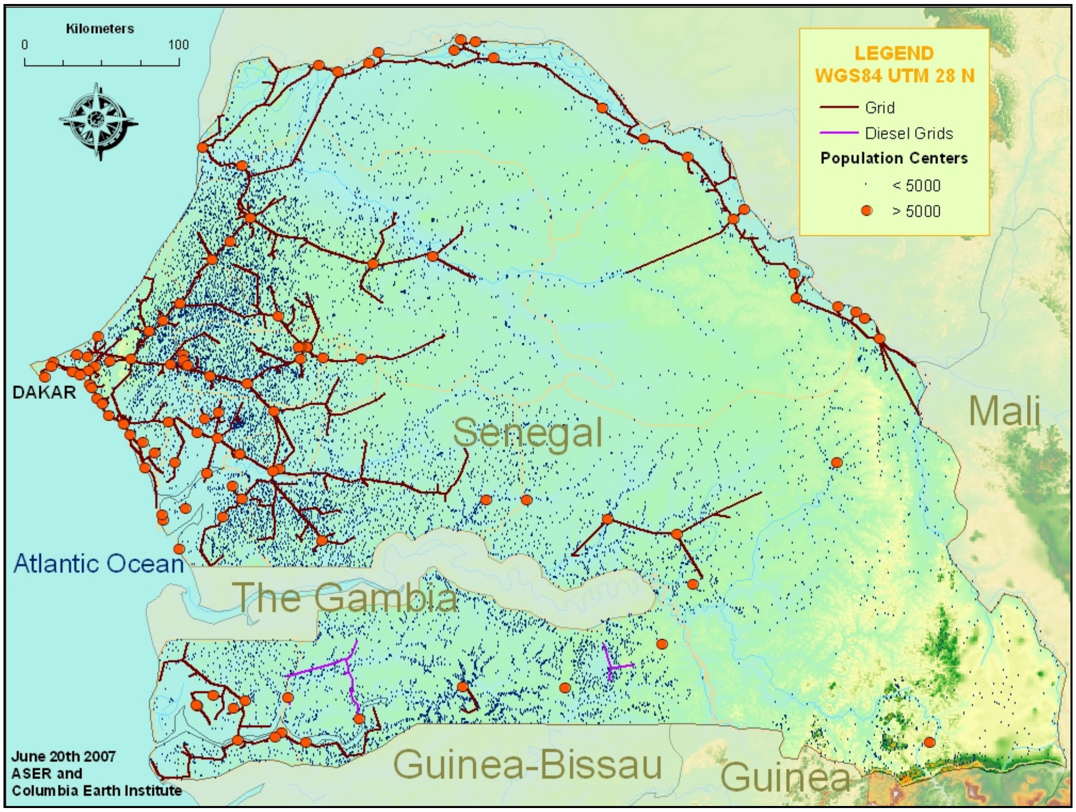

Figure 1. Senegal's existing electricity grid, urban centers, and rural villages based on data received from ASER and SENELEC in January 2007.

Senegal's goal is to achieve a 66% national electrification rate and a 36% rural electrification rate (with 60% penetration in each electrified community) within 10 years, an objective adopted by the member states of the Economic Community of West African States (ECOWAS) in January 2005.[8] These goals are consistent with the MDGs. The electrification rate is defined as the percentage of households with access to electricity (Figure 2). In addition to household electrification, meeting the MDGs will require all schools and health clinics to be electrified.

Currently, an estimated 47% of Senegal's total population and 13% of the rural population is covered by the existing electricity grid, diesel-powered mini-grids, or stand-alone photovoltaic systems (Figure 3).[9] The western portion of the country, which includes the regions of Dakar, Thies, and Diourbel, has higher population densities and is better served by the electricity grid (Figure 4). In the southern regions of Kolda and Tambacounda, many urban centers and large rural communities have their own diesel generators or are linked by diesel-powered mini-grids (Figure 5). Approximately 270 villages in the region of Fatick have solar home systems, but it is unknown how many households and/or institutions are actually electrified in each village.[10]

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[8] ECOWAS Decision A/Dec.24/01/06, 12 January 2005.

[9] Electrification rates – and particularly rural electrification rates – are sensitive to the penetration rate in each electrified community. ASER data show a current rural electrification rate of 13%; this assumes a penetration rate of greater than 60% in electrified rural villages.

[10] Based on geo-referenced data received from ASER in January 2007.

$$Community\ Coverage = \frac{Population\ of\ Electrified\ Communities}{Total\ Population}$$

$$Penetration\ Rate = \frac{Electrified\ Population}{Population\ of\ Electrified\ Communities}$$

$$Electrification\ Rate = \frac{Electrified\ Population}{Total\ Population}$$

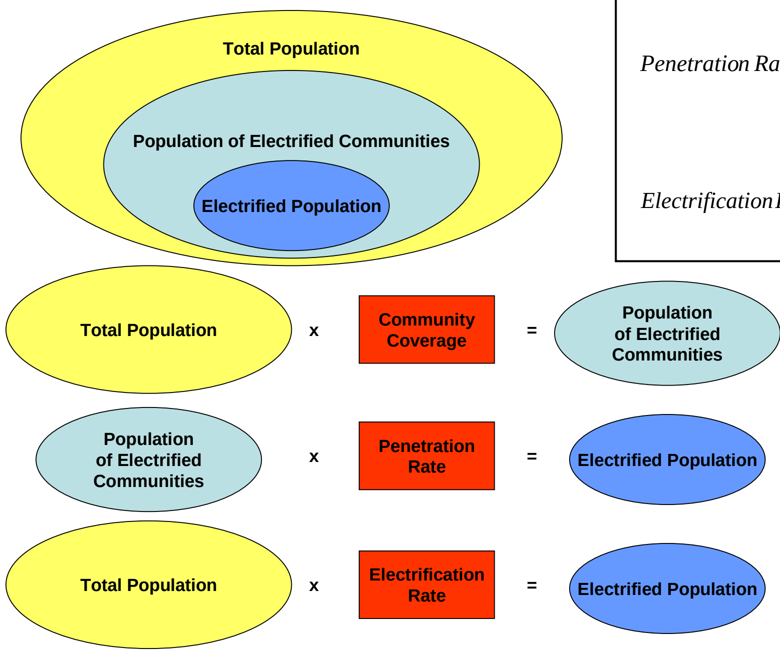

Figure 2. Definitions of electrification rates. Source: Columbia University and UNDP Energy Workshop, 2006.

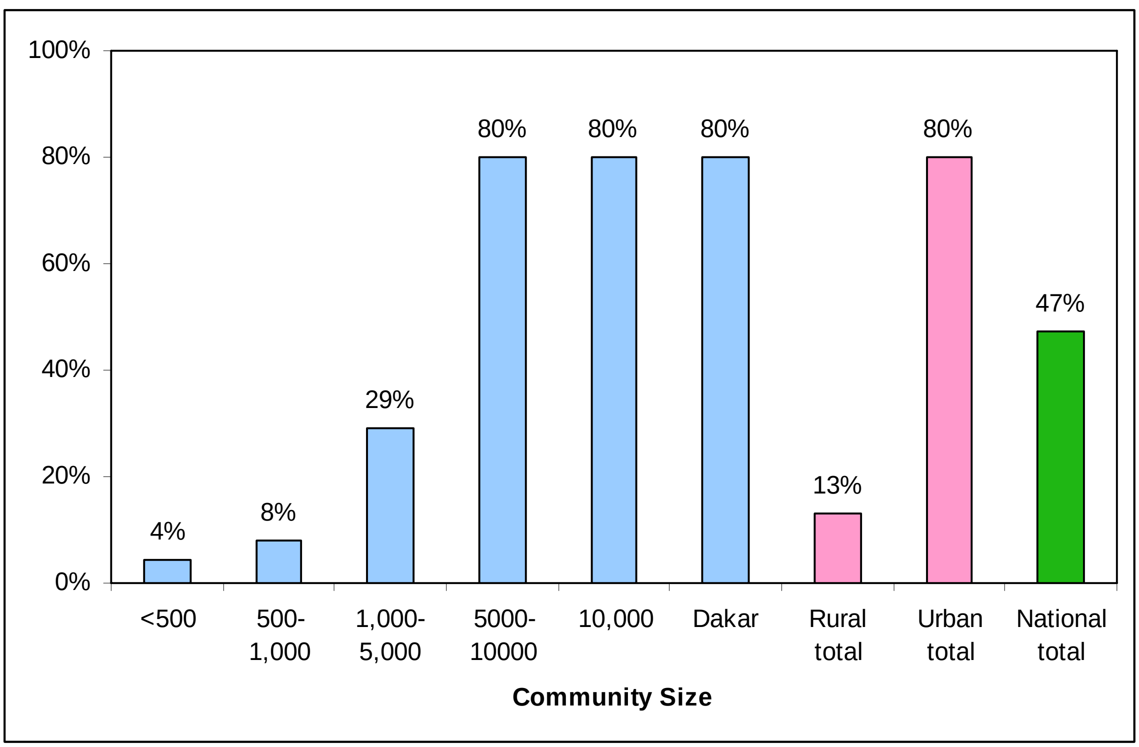

Figure 3. Current electrification rates for each village size. These figures assume a rural penetration rate of 60% and an urban penetration rate of 80% for both outside and inside Dakar.

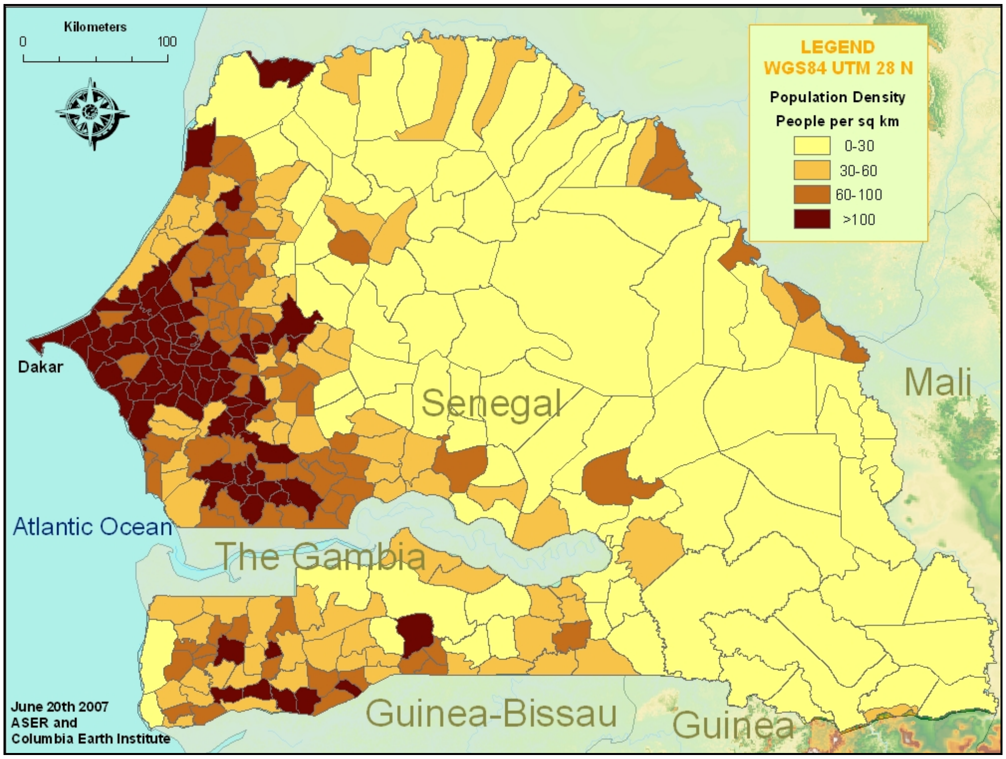

Figure 4. Population density aggregated to rural communities (administrative units).

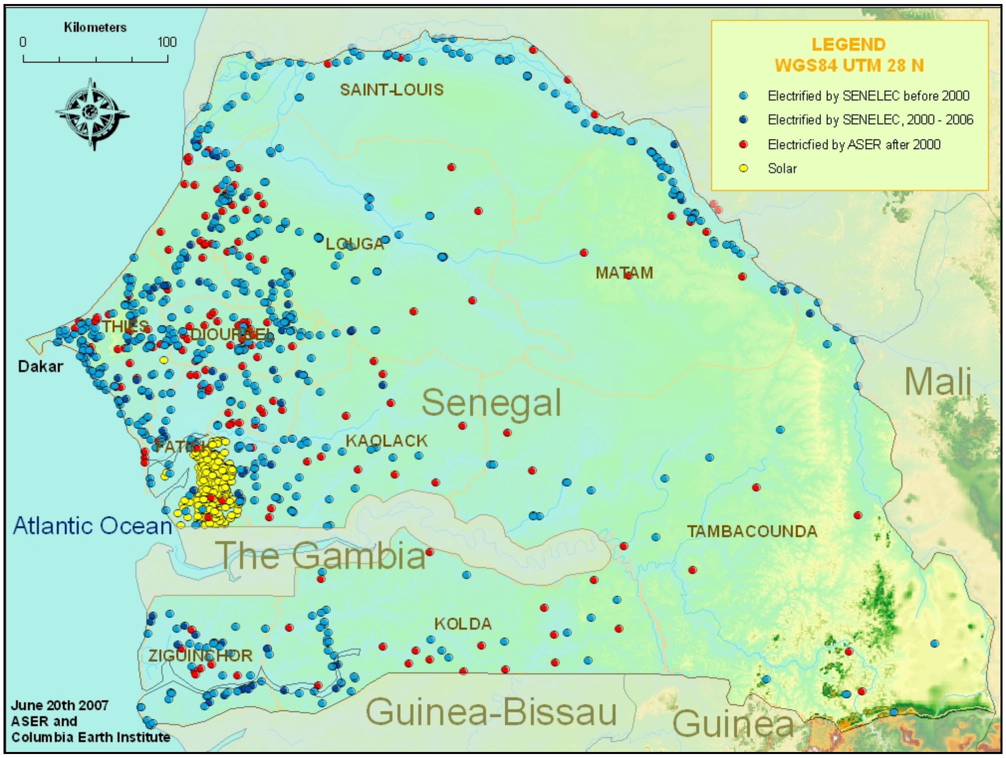

Figure 5. Electrified communities, as of 2006. Region names are also shown.

1.3 Coverage of social institutions

Around 40% of villages do not have access to a primary school (within 3 kilometers) and around 70% of villages do not have access to a health post (within 5 kilometers).[11] In the western portion of the country, most villages have access to essential services – including schools, health posts, and water pumps – but quality of service may be constrained due to inadequate access to power. In the eastern and southern regions of the country, many villages have neither access to social institutions nor electricity.[12]

1.3.1 Schools

UNICEF estimates that more than 80% of the country's 5,795 schools are without electricity.[13] Most villages that are electrified have access to a primary school (Figure 6), but even in the heavily urbanized region of Dakar, nearly 30% of schools are not electrified. Beyond the problem of inadequate electricity coverage, at least 1,700 additional schools are needed to ensure that the entire rural population has access to a primary school within 3 kilometers.[14]

1.3.2 Health clinics

Senegal's public health services are divided into several levels. In rural villages, the first line of intervention is the case de sante, often a small single-room structure dispensing health information and basic medication. The next level of intervention is a health post, some of which provide maternity services. Rural communities tend to have between 1 and 3 health posts. Most districts have at least one health center, the district-level anchor. Each region has at least one regional hospital, and Dakar hosts 8 national hospitals. Currently, health centers and hospitals tend to be electrified whereas health posts and case de sante tend not to be electrified.

A Ministry of Health survey recently tabulated 859 public health facilities in Senegal, excluding case de sante.[15] The Earth Institute team estimates an additional 2,544 case de sante, virtually none of which are electrified (Figure 7).[16] The team also estimates that at

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[11] According to geo-referenced data from a survey on access to services in rural communities commissioned by the Department of Statistics (DPS) in Senegal and released in 2000.

[12] In addition to schools and health clinics, the costing model also covers community centers/markets and streetlights.

[13] Data received from B. Zevounou at UNICEF-Dakar on 20 November 2006.

[14] DPS defines access to a primary school as being within 3 kilometers of a school. Therefore, a 4 km by 4 km grid was overlaid on the map of Senegal, as it is approximately 3 km from each corner to the center of each cell in such a grid. Each grid cell with at least one electrified village (based on ASER data) was coded as being electrified. Each grid cell with at least one village with access to a primary school (based on DPS data) was marked as having access to a school. 1,769 squares were identified where all villages were neither electrified nor had access to a school. An additional 98 squares were identified where at least one village was electrified, but no village had access to a school.

[15] Carte Sanitaire Senegal, Ministry of Health.

[16] This estimate was arrived at by extrapolating from the rural community of Leona, for which the Earth Institute has detailed data, to the rest of Senegal. In Leona, there are 18 case de sante serving 101 communities (excluding Leona itself, which has a health post with maternity services). This works out to 1 case de sante per 5.6 rural villages, or a case de sante in 17.8% of all rural villages.

least 1,300 additional case de sante are needed for every rural resident to live within 5 kilometers of a health clinic.[17]

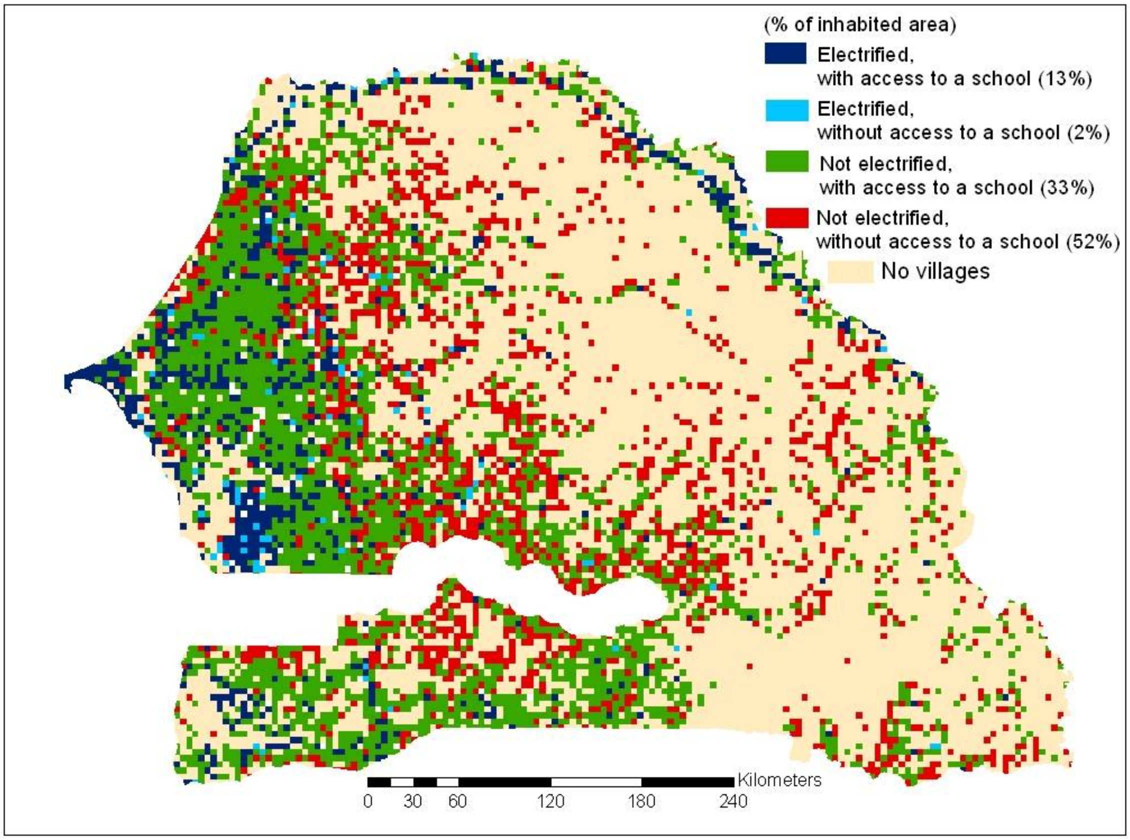

Figure 6. Access to a primary school. (Gridded data shown at 4 km by 4 km resolution. The center of each square is approximately 3 km from each corner to reflect the definition of school access as having a school within 3 km.)

[17] DPS defines access to health services as being within 5 kilometers of a health clinic. Therefore, a 7 km by 7 km grid was overlaid on the map of Senegal, as it is approximately 5 km from each corner to the center of each grid cell in such a grid. Each grid cell with at least one electrified village (based on ASER data) was coded as being electrified. Each grid cell with at least one village with access to health services (based on DPS data) was marked as having access to health services. 1,368 squares were identified where all villages were neither electrified nor had access to a health clinic. An additional 77 squares were identified where at least one village was electrified, but no village had access to a health clinic.

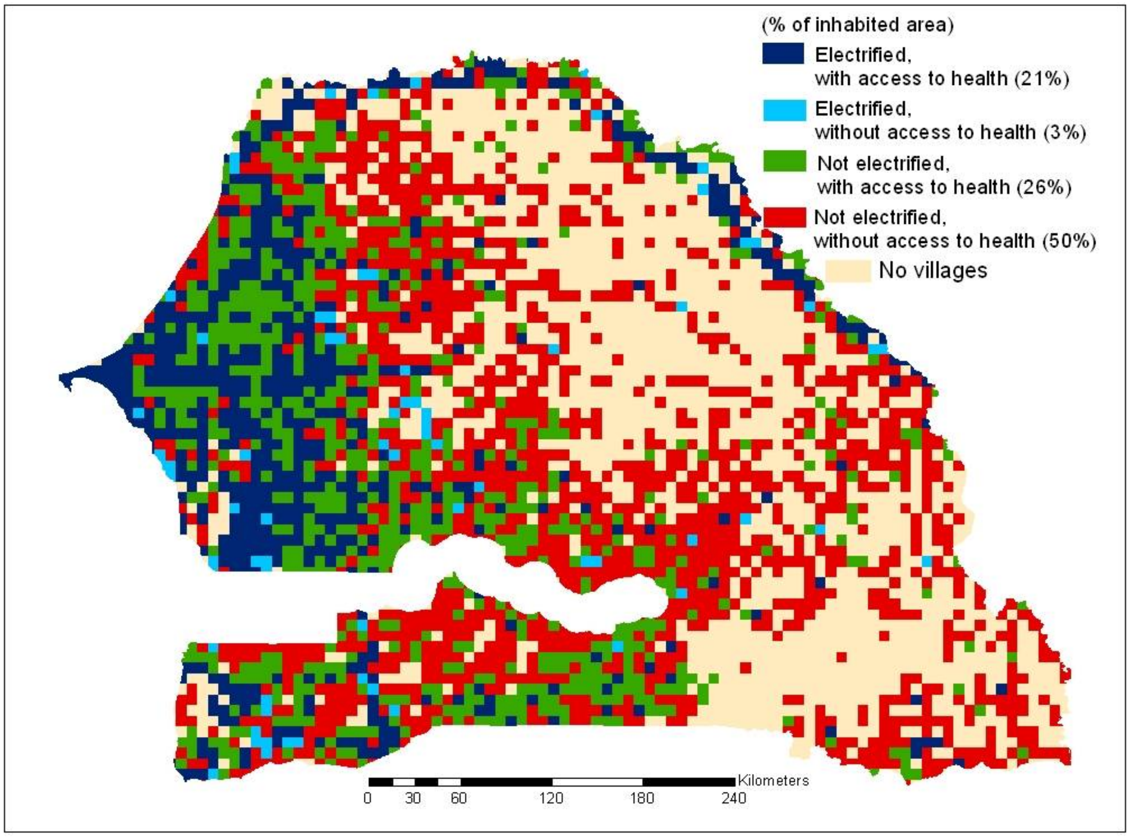

Figure 7. Access to health services. (Gridded data shown at 7 km by 7 km resolution. The center of each square is approximately 5 km from each corner to reflect the definition of health access as having a health clinic within 5 km.)

2 Earth Institute Electricity Planning and Investment Costing Model

The Earth Institute has developed a costing model for national electrification. The model provides cost estimates for achieving specific electrification targets within a defined time frame given various technological options, providing decision-support for policy-makers evaluating rural electrification scenarios. Initial insights and estimated costs that emerge from the tool are intended to motivate national, multi-sectoral planning and financing for electricity.[18]

The model is a set of inter-linked tools including a Microsoft Excel spreadsheet model, ArcGIS/ArcInfo for spatial processing and analysis, and Java programs to algorithmically generate an extended grid and process results. The model allows country teams to input

[18] The tool is not meant to replace detailed engineering analyses of grid roll-out, including load evaluation, which would be needed as part of the implementation process. In other words, the tool can be used to guide planning within Ministries, Rural Electrification Agencies, and donor organizations, but cannot be used as a stand-alone implementation tool.

financial and socio-economic data along with policy criteria to evaluate the feasibility and costs of electrification scenarios and quickly compare alternatives.

The Excel tool compares available technologies given costs and anticipated demand. The net present value of the discounted cash flow is the metric used to compare the options. ArcGIS and Java are then used to generate an extended grid base on the spatial distribution of population centers, the location of existing medium voltage distribution lines, and policy requirements (e.g. target electrification rate). Finally, the model computes the required investment for each scenario summarized as capital and recurring costs, on-grid and off-grid, and urban and rural. Detailed output for each location can be joined to GIS data for spatial visualization and post-processing (e.g. exploring and summarizing results for particular regions or technologies (Figure 8).

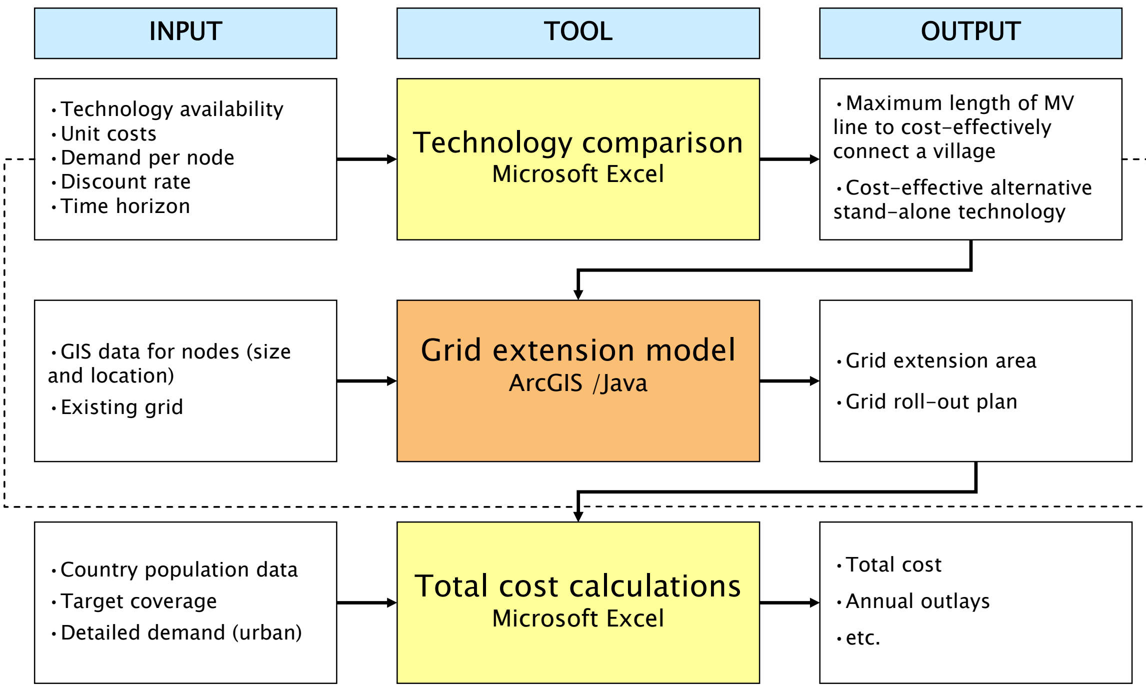

Figure 8. Electricity costing model framework showing how the inputs and outputs of the tools are linked.

Key model inputs include:

- Cost estimates for each technology option – e.g. grid extension and decentralized options such as a diesel generator or a PV-MFP system
- Estimated demand for households, institutions, and productive use
- Target household and institutional coverage
- Discount rate and time horizon
- Geo-referenced data on village size and location
- Geo-referenced data on the existing electricity grid.

Key model outputs include:

- Per-household capital cost of urban and rural electrification
- Annual investments needs to meet targets
- Coverage of health, education, and other institutions
- Percentage of households covered by each technology
- Maps and summary tables for visualizing electrification scenarios

The model can be run at the national or regional scale, and additional geographical (e.g. road locations, rivers) and technical constraints can be considered if data are available.

2.1 Technology comparison tool

The technology comparison tool determines the most cost-effective electrification option for each village given its projected demand for electricity. Demand is estimated based on population (including anticipated population growth), the rural penetration rate, and existing social and economic infrastructure.

The options considered for Senegal are:

- Grid extension with purchase of electricity from SENELEC[19]
- Diesel generators with a low-voltage (LV) mini-grid for the village
- Individual photovoltaic (PV) systems for each household and institution in the village and a Multi-functional Platform (MFP) for the whole village.[20]

There are two main outputs from the tool:

- The maximum length of medium-voltage (*MVmax*) per capita for which it is more cost-effective to extend the existing electricity grid than to implement a decentralized technology (e.g. Diesel mini-grid or PV-MFP).
- The most cost-effective decentralized option given the projected demand of a village of a particular size.

2.1.1 Evaluation of energy demand

A village's energy demand includes both household and community demand (social and economic infrastructure). Peak demand for various infrastructure may occur at different times, and this is accounted for through a coincidence factor. For a complete list of inputs affecting energy demand and technology cost comparison, see Appendix 1.

[19] The tool assumes that generation and transmission capacity are no constraints to grid extension.
[20] Since photovoltaic systems are not able to provide mechanical power, they must be combined with a multi-functional platform (MFP) for connecting motors used in productive activities, etc. The MFP involves a single diesel engine that can power several different machines for both water pumping and agro processing needs. The MFP can also be used to provide electricity directly, or for battery charging.

Household Demand

Household demand includes electricity for domestic and productive uses. Domestic use is defined as the number of light bulbs and other electrical equipment such as TV or radio in a village's households. Domestic demand is highly sensitive to the penetration rate.

Productive use is defined as household level of access to productive infrastructure such as water pumps, agro-processing equipment, and mills. Tables 1 and 2 list assumed electricity consumption levels for households in villages of varying size based on socio-economic surveys of electrified and non-electrified communities by SOFRECO and LAHMEYER INT. commissioned by ASER . These surveys identified four levels of service, each one of which corresponds to a set f equipment with specific energy demand (See Appendix 2).

Table 1. Domestic consumption in rural villages.

Village size (# of people)	Service Level	Energy (kWh/hh/day)
< 500	Level 1	73
500-1,000	Level 2	110
1,000-5,000	Level 3	450
> 5,000	Level 4	1398

Source: ASER first Concession study

All numbers were adjusted based on consultation with the team from ASER and SENELEC during the "Energy Planning and Costing Workshop" organized by the Earth Institute from June 11th to 16th, 2007

Table 2. Productive consumption in rural villages.

Village size (# of people)	Villages with this equipment (%)	
	Mill*	**Pump***
< 500	11	-
500-1,000	33	-
1,000-5,000	50	33
> 5,000	73	40

Source: LAHMEYER INT. June 2006.

*The assumed capacities of the mill and pump are 3kW and 2.5kW respectively. The assumed duration of use is 4 hours per day.

Community demand

Community demand covers the electricity demand for collective social and economic infrastructure including health centers, schools, markets, and streetlights. Electricity demand for institutions including streetlights were assumed from studies already done by ASER. Since the per-household demand increases for larger villages, so does the per-institution's demand. Larger villages are also assumed to have a greater number of institutions (Appendix 3). For streetlights, an assumption of one 70-watt light bulb per 25 households was recommended by ASER. Every village is assumed to have at least one street light (even if there are fewer than 25 households).

Coincidence factor

The coincidence factor accounts for the fact that peak demand of different equipment and users does not occur at the same time. Table 3 lists assumptions about the contribution of to peak demand of each type of electricity use for each village size. The total demand for a village is the sum of household and community demand.[21] The annual growth in demand is equal to the adjusted annual population growth.

Table 3. Percentage of energy usage that occurs as peak demand for each type of electricity use.

% of use that occurs as peak demand	Village size (# of people) < 500	500 – 1,000	1,000 – 5,000	5,000 – 10,000
Households				
Domestic	49	40	30	25
Productive	10	10	10	10
Community				
Health Center	30	30	30	30
Schools	10	10	10	10
Market Center	90	90	90	90
Streetlights	100	100	100	100

Source: LAHMEYER INT. JUNE 2006. Local Electrification Plan Kaolak-Nioro Fatick-Gossas.

2.1.2 Choice of technology

The three technologies – MV grid extension, diesel mini-grid, and individual PVs combined with an MFP– are compared based on the kWh delivered and the net present value of their ten-year discounted capital and maintenance costs. The model first determines the necessary size of each decentralized technology (e.g. size of diesel generator, number of solar panels, and size of battery) and then compares the cheapest decentralized system with the cost of MV grid extension.

Medium voltage grid extension

This technology involves connecting a locality to the national medium voltage line and serving domestic and productive demands through a low voltage distribution network. Extension of the medium voltage grid will be done based on the existing national electricity grid managed by SENELEC and therefore must meet its required standards. These standards concern the distribution technology, the distribution network voltage, and the area of the conductors. SENELEC requires the use of three-phase technology[22] (three-phase conductors), Almélec conductors, H61 transformers, and a distribution network voltage of 30 kV.

[21] Technologies are compared based on the initial aggregate demand.
[22] ASER: Etude Technico-Economique d'un Projet ERIL, Electrification Rurale d'Initiative Locale

Conductors of 148 mm², 75.5 mm² and 54.6 mm² are used on the main MV lines while 54.6 mm² and 34.4 mm² are used on extensions toward villages within 20km. The combination of the different choices depends on the demand and the distance to the village. In general, $148mm^2$ is recommended for MV lines serving regions of high demand. For villages with lower demand, the $34.4mm^2$ with 5.5 kV distribution voltages can be introduced. While SENELEC does not allow the use of single-phase[23] (two conductors: phase + phase or phase + neutral) distribution technology, nevertheless, there is potential to reduce initial cost by as much as 30 % through the use of single-phase in rural areas.[24]

Diesel mini-grid

This option involves the local production of electricity using diesel generators serving domestic and productive demand through a low voltage distribution network. This technology is very flexible as it allows usage of high capacity generators during peak demand and low capacity during normal hours.[25] This works well in urban centers of higher demand, with varied consumers and many productive uses of electricity. It is also a viable technology for rural villages because small generators are available. The technology comparison model considers generators ranging in size from 10 to 50 kVA. The LV distribution network is three phase, as in the case of MV grid extension.[26]

Photovoltaics and MFP

For this option, the PV is used for electrifying individual households and institutions while the MFP is used for meeting only the productive demand. PV is different from the other technologies because its maximum output is limited by daily solar irradiation (a country wide average of 2000 kWh/sq meter/year or 5.7 kWh/day for Senegal). Linking PV systems through LV distribution lines is not attractive since the benefits from scale-economies are insignificant compared to the cost of wire. Therefore a stand-alone PV system is selected for each household and institution. Since inter-household distances can be as high as 30 meters (on average) in Senegal, this technology is the most cost-effective option for some of the smallest habitations. (See Appendix 4 for more information on inter-household distance assumptions). The sizing of the system takes into account the

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[23] Single-phase technology is commonly used for small power needs and does not require modification of the main network. For illustration this technology has been widely implemented in countries such as Cameroon. It could be a viable option for localities of low density such as the eastern and southern parts of Senegal.

[24] This cost assumes the same maintenance cost for both three-phase and single-phase lines, and it does not include the cost of the three-phase/single-phase transformer that may be needed.

[25] Although not considered in the present study, diesel mini-grids also have the advantage of being feasible for clusters of small villages. Production cost per kWh decreases as energy demand and generator capacity increase. Therefore the cluster option (5.5 or 20 kV mini-grid) might be cheaper than installing mini-diesel in each village.

[26] For small villages, single-phase technology could be used for secondary lines (derivations) in the LV network, while maintaining a three-phase main line. In Dakar, the number of three-phase LV meters is not more than 4%, which means that in low income areas this technology may not be needed cost wise. Even in the case of productive usages (2.5-3 kW in rural areas) single phase could still be used because there are generators of this type on the international market for up to 7.5 kW capacities that Senegal could import.

efficiency of the panels as well as the losses in batteries and converters. The smallest panel in consideration is 50Wp**.**

Hybrid systems and other technologies
Like most countries in Sub-Saharan Africa, Senegal has substantial good solar irradiation, but limited site-specific sources of wind energy along its coast.[27] Options such as stand-alone wind plants or hybrid systems such as PV-diesel or wind-diesel could be cost effective but were not included in this study. These systems are not yet widely enough used in Senegal to allow for a good understanding of their cost structures. Costs for a hybrid PV-diesel system were obtained from ASER but were less competitive than a non-hybrid diesel system. The PV solution considered in this report includes a separate diesel engine (MFP) to provide mechanical power for productive uses. ASER believes that as hybrid systems become cheaper in the future, they will be competitive option for Senegal.

2.1.3 Sensitivity analysis

A sensitivity analysis was conducted on model inputs that may have a critical effect on the output parameters (e.g. *MVmax* per capita and the cutoff point between diesel mini-grid and PV-MFP). These inputs include the discount rate, penetration rate, and the cost of electricity per kWh. The World Bank recommended a discount rate of 10% with a sensitivity range of 5-15%. Changing the discount rate did not affect the cutoff point between diesel mini-grid and PV-MFP, but a lower rate increased the competitiveness of grid connections relative to decentralized options and increased *MVmax* per capita.

The penetration rate varies widely in rural areas and can be as low as 20%. A rural penetration rate of 60% was selected through conversations with ASER. A lower penetration rate increases the competitiveness of decentralized options relative to grid connections, lowering *MVmax* per capita and reducing the number of villages that are connected to the grid.

The price of electricity purchase from SENELEC has been going up as world fuel prices have increased. For example, between 2005 and 2006, the price jumped from 50 CFA/kWh to 83.4 CFA/kWh. An increase in SENELEC's electricity prices raises the competitiveness of both decentralized options.

2.2 Grid extension tool

The grid extension tool accounts for the spatial location of each of Senegal's more than 14,000 villages. The tool uses a GIS-based analysis to investigate where it is cost-effective to extend the existing electricity grid and what percentage of rural demand is best met through grid extension rather than with decentralized options.[28] The model also

[27] Senegal also shares hydro electricity potential of 1400 MW with neighboring countries. ASER, June 2004.
[28] The grid extension algorithm is run by exporting GIS data to a Java program that creates a minimum spanning tree.

estimates the length of MV line needed to connect each village.[29] At present, the tool does not model lines of varying voltages, feeder lines, or reinforcement of the existing grid, nor does it consider generation or transmission needs to support the scale-up in distribution.

The model decides whether to connect a village based on its distance from the electricity grid and other villages, its population (a proxy for demand), and output from the technology comparison model (*MVmax* per capita). If *MVma*x per capita multiplied by the number of people in the village is greater than the amount of line needed to connect the village (proxied by the distance between the two villages), then it is more cost-effective to connect the village to the grid than to electrify it with a decentralized option. A simplified version of the algorithm is shown below; for a detailed explanation of the grid extension algorithm, see Appendix 5.

Connect if: *MVmax* (meters per capita) x village population ≥ distance (meters)

It is important to understand that "cost-effective" is defined in *relative* rather than *absolute* terms. If grid extension is cheap *relative* to the best stand-alone option, then the model will connect the village to the grid.

A main innovation of the model is its ability to search for cost-effective extensions in a non-sequential manner (Figure 9). This allows small villages to become grouped into larger demand hubs, ultimately connecting a greater number of villages that are small and/or far from the existing grid.[30]

The grid extension tool produces a geo-referenced extended grid that can be displayed spatially using ArcGIS. This grid represents the total grid compatible area in the country. Decisions about which villages to electrify first are a matter of policy and priority. At present, a Java algorithm is used to assign years of electrification to villages based upon their proximity to the existing grid and target electrification rates. Since all connections that are one level away from the existing grid are connected first, followed by connections two levels away from the existing grid, etc., the final grid will always be a continuous network. However, the evolution of this network remains dependent on the country's total grid compatible area and the most cost-effective way of ultimately connecting all villages within this area.[31]

[29] The model treats demand centers as nodes, and grid lines are represented as straight lines connecting nodes into a network of uniform-voltage MV lines.
[30] This feature could benefit many small southeastern villages that are not considered grid compatible today, but could have their own MV network if grouped together.
[31] As part of ongoing research, the EI is exploring other ways of prioritizing grid connections, including focusing on those branches of the extended grid that have the lowest average cost per connection.

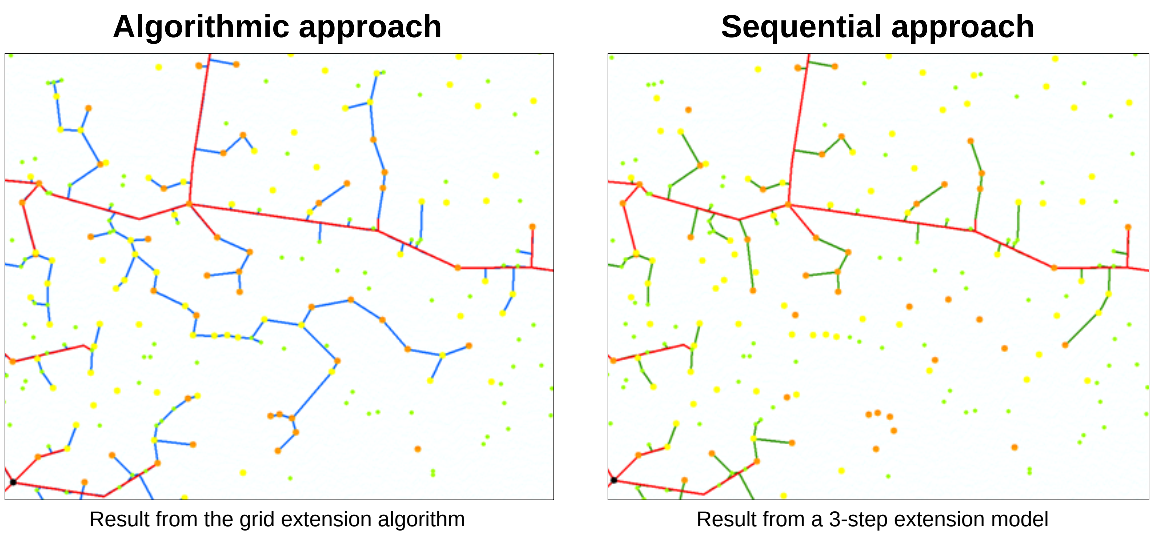

Figure 9. Illustration of grid extension algorithm, which allows villages to become grouped, and a sequential approaches which looks for connections close to the grid and then moves outward. The existing grid is shown in red.

2.3 Total cost calculations

The total costing tool estimates the cost of achieving the targeted level of electrification within the desired time period (e.g. 10 years) based on the most cost-effective options as established by the technology comparison model and the grid extension tool. The model calculates total costs for on and off-grid electrification as well as rural and urban electrification given targets, projected household and institutional demands, technology choices, and cost structures.[32] Outputs include total and per-household capital and annual recurring investments as well as annual household electrification rates. The tool is flexible enough to allow for the comparison of costs across a range of priorities and scenarios. Output from the tool can also be joined back to GIS data for post-processing (e.g. to spatially explore the evolution of the grid from year-to-year, or to analyze results for particular regions).

Target coverage and minimum needs

To meet the MDGs and ECOWAS electrification targets, Senegal's goal is to electrify 100% of urban households, health centers and schools and 36% of rural households, with a penetration rate of at least 60% in each electrified rural village. The overall goal is for 66% of households to be electrified nationwide.

Urban households' minimum level of consumption corresponds to level of service 4 as presented in Table 1, adjusted from ASER's level of service 2 (5 light bulbs of 11W, 1 Radio of 20 W) (Table 4). Rural household consumption corresponds to service levels 1 to 3 depending on the size of the village.

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[32] The model accounts for population growth, and consequent changes in the number of households and institutions, over the investment period.

Table 4. Annual household and institutional consumption in kWh.

Consumption* kWh/year	Dakar	Large urban (>10,000)	Small urban (>5,000)	Large rural (>1,000)	Mid rural (>500)	Small rural (<500)
Households	1762	1762	729	344	200	109
Health Centers	885	885	885	590	394	262
Schools	1785	1785	1785	1160	772	515

* The consumption levels are adjusted for 15% transmission losses.[33] The numbers are obtained by multiply domestic and productive demands by daily hour usage (4hours) and factoring losses. Demands are given in Appendix 1.

2.4 Costing v. planning

The Earth Institute model is a costing tool that can help set investment priorities for energy planning to meet electrification targets. The model is intended for use during early planning stages, when it is possible to consider a wide range of technological options, a longer-term planning horizon, and encourage consideration of electricity needs across sectors. Before implementing a grid roll-out, the model must be supplemented with design-phase planning tools including cadastral maps and load curves.

3 Data

The technology comparison model requires cost estimates for each component of each electrification technology that will be considered, and it is fairly straightforward to perform sensitivity analyses around particular inputs. The grid extension tool requires geo-referenced data on village location and size, as well as a digitized version of the existing electricity grid. If these data are not available, it is still possible to obtain cost estimates using the total costing tool based on estimates of the number of new villages to connect to the grid and the amount of line needed to connect the average village.

Often, geo-referenced datasets are available from several different departments and ministries that may not know of the existence of each other's data. Bringing together and sharing these datasets has been a valuable exercise for stakeholders and is expected to have a positive long-term effect on energy planning.

3.1 Costing data

Unit costs of each technology were obtained from SENELEC and ASER, including listed market prices for medium voltage line, low voltage line, transformers, diesel generators, and solar panels. Costs include all components of the technology as well as transportation and installation of equipment. Costs of MV line include the cost of poles. Some prices were adjusted based on local electrification reports done by consulting firms for ASER and/or were updated to reflect current market conditions.

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[33] These losses take into account only thermal losses along the high, medium, and low voltage network. They do not include non-thermal losses such metering mistakes, non-billed consumption, and frauds.

Cost assumptions for MV grid extension

The costs are estimates for a 30 and 17.2 kV MV line coupled with an aerial transformer placed on top of the poles. Costs vary depending on whether the distribution technology to serve the village is single-phase or three-phase. The numbers were given by the Senegal team during the Workshop "Energy Planning and Costing" organized by the Earth Institute from June 11th to 16th, 2007. 8 million CFA was taken to be the cost of one km of 3-phase 148mm^2 MV line. For the LV line, 6 million CFA was used. Transformers were put in the range of 2 - 4 million CFA from the 5 to 100 kVA.

Transformers and low voltage line maintenance costs are 3% of their capital costs. SENELEC's maintenance of MV lines is 2% of the initial cost. The price of electricity to be purchased from SENELEC is 83.4 CFA/kWh as of January 2007. Technical losses on the overall grid system are assumed to be 15%.

Cost assumptions diesel mini-grid

The diesel mini-grid cost structure includes a diesel generator and an LV distribution network (mini grid). As in the case of grid extension, the mini-grid could be either three-phase or single-phase, and the cost structure is the same as the LV portion of the grid extension technology.[34] Studies commissioned by ASER and conducted by PERACOD in Senegal show that the cost of generators as a function of their apparent power is linear (Equation 1, Figure 10, and Table 5).

4,460,800 FCFA and 67,729 FCFA are the estimated linear regression coefficients

Cost of generator = CFA 4,460,800 + 67,729 * *Generator Apparent Power* (kVA)   (1)

[34] The mini-diesel LV network could be single-phase, three-phase, or both in a village but SENELEC is reluctant to standardize single-phase technology.

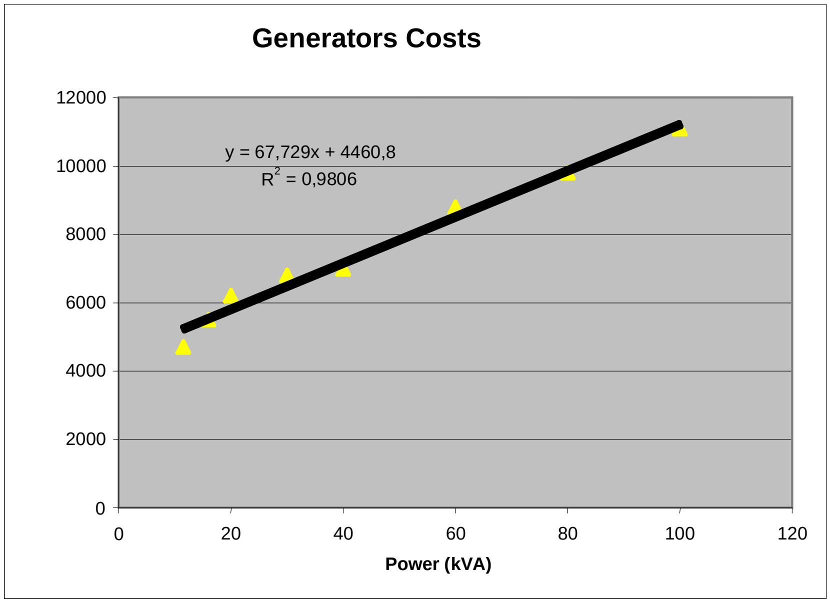

Figure 10. Generator cost (CFA) as a function of power (kVA). Source: ASER.

Table 5. Capital cost estimates for generators.

Generator Power (kVA)	10	20	30	50
Cost[35] (CFA)	6,421,250	7,267,500	8,113,750	9,806,250

Generators are estimated to have a lifetime of five years and consume 0.4 liter of diesel fuel per kWh. The cost of fuel was 540 CFA per liter as of January 2007. The mini-grid technical losses are 5%. Maintenance of the system is 5% of the initial engine cost.

Cost assumptions PV-MFP

The costs of PV components without the MFP are based on ASER data. Available system sizes are 50, 75, and 150 Wp. Lifetimes of different components are given in Table 6, and costs are given in Table 7. A fully equipped MFP includes a diesel engine, thresher, paste maker, de-husker, grinder, motor pump, hoses, water tanks, etc… In Senegal, not every village will need a full equipped MFP. Therefore, cost was disaggregated by village type. For a village of less than 500 people 1/6 of the cost of a full MFP was taken based on the assumption that 6 villages of this type could share one MFP. This cost does not however include transportation related to this sharing. 1/3 of the cost of a full MFP was assigned to villages of 500-1000 people while every village of 1000-5000 people is assigned one MFP. In this study an initial unit cost of CFA 650,000 was used for the 16hp diesel engine.[36] Installation cost represents 25% of the above capital cost. Recurrent costs

[35] Costs include transport, civil engineering, fuel tank, and installation.

[36] A typical MFP can run on grid or a diesel engine. The costs used in this study are for a diesel powered MFP. In Senegal, machines for grinding and de-husking have average capacity of 4kW while motor pumps

include maintenance and replacement of the engine, fuel cost and the wage of the operator of the system (See Appendix 6 for assumptions and cost breakdown of typical Diesel MFP used in agro-processing and water pumping)

Table 6. Lifetime of PV components.

Lifetime (years)	50 Wp	75 Wp	150 Wp
Panel & Fixing	30	30	30
Regulator	10	10	10
Batteries	3	3	3
Lamps	5	5	5
Accessories	5	5	5

Table 7. Cost estimates for PV systems (CFA).

Service Level	1	2	3
Power (Wp)	50	75	150
Capital			
Panel & Fixing	215,000	330,000	660,000
Regulator	28,000	28,000	28,000
Batteries	70,000	75,000	125,000
Lamp and accessories	20,000	20,000	25,000
Installation	25,000	25,000	50,000
Total Initial Cost	**358,000**	**478,000**	**903,000**

Source: ASER Unit Costs 2007

For all three technologies, components that have a lifetime less than the duration of the project generate depreciation costs. These components are the diesel engines; and batteries, lamps, and regulators of the PV system. For this equipment, an annual recurrent cost is set equal to the cost of the equipment divided by its lifetime. For all three technologies an additional billing cost of CFA 10,800 per customer is taken into account.

3.2 Geo-referenced data

A geo-referenced data library was created for Senegal. Appendix 7 lists each dataset, its type (e.g. points, polygons), its original source, year of production, and year acquired by the Earth Institute team. ASER was the original source of the electricity grid data. In many cases, data required extensive cleaning to remove repeat villages, inconsistencies between geo-referenced datasets and other datasets (e.g. information received from SENELEC), and improperly geo-referenced information.[37]

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have 3kW capacity. A 16hp or 12kW diesel MFP is assumed to meet the productive need of rural villages of less than 5000 people.

[37] Several aggregated datasets were developed for this project that combine information on population, electrification status and type, and access to institutions and roads. These aggregated datasets are now available with complete metadata. All data have been projected to WGS 1984 UTM 28N.

Key geo-referenced data obtained for use in the grid extension model include village locations and population as of 2002, existing MV distribution lines, and electrification status (including off-grid electrified villages) as of 2006. See Appendix 7 for data sources.

3.3 Limitations and proxies

The cost assumptions used in the models reflect the best available data. However, costs are constantly changing due to technological and economic factors. All the main aspects of the cost of each technology are included, but it is impossible to include every detail – this is left for the design phase of energy planning. Also, focusing on the main factors makes it easier to develop cost estimates for inputs when data are missing.

The grid extension model is kept as simple as possible to limit data requirements. Population is used as a proxy for demand. The model connects villages to the grid in straight lines ignoring most geographical and technical constraints. The capital cost may be up to 50% higher if these constraints – and particularly the need for the grid to follow major roads – are accounted for.[38] In general, the model is intended to provide a general picture of where grid extension is appropriate, not an exact prescription for how grid extension should be carried out.

One of the goals of this project was to understand the current situation with regard to institutional electricity coverage, particularly schools and health centers. Detailed village-level data on the location of institutions and their electrification status were not available. Therefore, information from a number of different datasets was integrated to develop a picture of current institutional coverage and electrification needs.

4 Electrification strategy and total costs

The cost of rural electrification depends on the chosen technologies and target coverage, among other factors. The target for ECOWAS member states is a 66% national electrification rate and a 36% rural electrification rate, with a 60% penetration rate for all electrified rural villages and a 100% penetration rate for urban centers.[39] In Senegal,

[38]A poorly developed road network is a major constraint to grid extension in Senegal. This has two main effects. First, the amount of line needed to connect villages may increase by a factor of 50% to follow winding roads. Second, since the cost of grid extension increases relative to decentralized options, the percentage of villages in which diesel or PV is the most cost-effective solution increases if roads are taken into account. Other constraints include rivers and protected areas. There are few large rivers in Senegal and most of the country is relatively flat, so these constraints are unlikely to have much of an effect on costs. Although some villages are located in protected areas where it may be more difficult to build grid lines, the small number of these villages and their location outside the main population centers in Senegal makes this too a small consideration. Further research could include the use of Network Analyst, an ArcGIS extension, to account for road, and other, constraints.

[39] The model assumes that all urban centers currently are electrified, either through a connection to the existing grid or with a diesel generator. ASER data show that up to 6 small urban areas (all with fewer than 15,000 people), 5 of which are within a few kilometers of the existing grid, may not be electrified. These

these targets are likely to be met primarily through extension of the existing grid using three-phase technology supplemented by diesel mini-grids and stand-alone photovoltaic systems in more remote rural areas.[40]

4.1 Total costs of electricity distribution scale-up

Scaling up electricity distribution to meet MDG and ECOWAS targets will require:

- All costs, capital and recurrent, including costs of electricity purchase, maintenance/replacement of equipment, capital replacement and billing/collection costs over a ten-year investment period to go from a national electrification rate of 47% to 66% are estimated to be $860 million (in 2007 dollars) (Table 8 and Figure11).
- Of the $860 million, the capital costs for increasing urban access to 100% (290,000 new households) is $88 million, whereas the capital cost of increasing rural access to 36% (190,000 new households) is $283 million. These costs include the cost of institutional access in these areas. An additional $48 million over the ten year investment is the capital cost of increasing the electrification rate of all rural institutions to 100%.
- The corresponding five year capital cost figures are $45 million for 120,000 new urban households and $145 million for 91,000 new rural households. (Table 10 and Figure 12). All the above costs are the 10 year discounted costs.
- Of the 480,000 households, urban and rural, to be electrified over the ten year period in the above scenario, 73% would be grid connected.
- Capital costs account for 73% of the cost of rural grid extension, 38% of the cost of diesel mini-grids, and 64% of the cost of PV-MFP systems.
- For small villages (< 500 people) far from the existing grid, PV-MFP (e.g. photovoltaics for household and a shared Multi-functional Platform for community productive use) is the most cost-effective option.
- For larger villages (500 – 5,000 people) far from the grid, a diesel mini-grid is the most cost-effective option.

The majority of electrification can be achieved through grid extension (three phase) rather than with decentralized options. For small villages (<500 people) that are far from the existing grid, PV is the most cost-effective option. For larger rural villages (500-5,000 people) that are far from the grid, a diesel mini-grid is the best option. Decentralized

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areas are not included in the urban calculations; however, their exclusion has a negligible effect on the results.

[40] Using single-phase technology can substantially increase the rural grid extension area and reduce the need for decentralized options, but is incompatible with SENELEC's standards and ASER's plans. In Senegal, the entire electricity grid currently uses three-phase technology – the SENELEC standard - regardless of village size, demand, or end-use. Single-phase lines may be a cost-effective choice for villages using electricity primarily for lighting, radio, and TV and can be combined with off-grid solutions (e.g. diesel-powered motors) for mechanical work.

electrification should be limited to areas with lower population densities where grid extension is unlikely, even in the long-term – e.g. in the region of Tambacounda.

Table 8. Investment needs to meet a 66% national electrification target over ten years. All the costs in this table are discounted aggregated costs over the period of investment. They are for both off-grid and on-grid as well as for both households and institutions.

	Total Cost, Years 1-5 ($mil)	Total Cost, Years 1-10 ($mil)
Urban and Peri-urban Electricity*		
Capital	**45**	**88**
System Maintenance Cost	8	32
Electricity / Fuel purchase	46	191
Billing/Collection Cost	6	25
Urban Total	**105**	**336**
Rural Electrification		
Capital	**145**	**283**
System Maintenance Cost	15	67
Electricity / Fuel purchase	35	96
Billing/Collection Cost	6	18
Capital Replacement	5	12
Rural Total	**206**	**476**
Additional Rural Institutions**	**11**	**48**
Grand Total	**322**	**860**
Capital Investment of Grand Total	**201**	**419**

*Costs to increase the penetration rate in urban areas from 80% to 100%. **Cost to electrify rural institutions that are outside of villages that will be covered by the main rural electrification program.

The breakdown of the above total capital costs by technology is given in the table 9. Urban costs are for grid only while rural costs are divided among grid, mini-grid, and PV-MFP. All the capital costs are discounted aggregated costs and represent costs for both households and institutions.

Table 9. Capital cost breakdown by technology.

	Capital Cost, Years 1-5 ($mil)	Capital Cost, Years 1-10 ($mil)
Urban and Peri-urban Electricity		
Urban Total	**45**	**88**
Rural Electrification		
Grid	72	141
Diesel mini-grid	48	60
PV-MFP	25	82
Rural Total	**145**	**283**

Table 10. Evolution of household electrification rates.

Household coverage	Current	Year 5	Year 10
Urban			
Electrification rate (%)	80%	89%	100%
# households (thousand)	506	634	795
Rural			
Electrification rate – grid	11%	16%	19%
Grid # households (thousand)	68	105	140
Electrification rate – Diesel mini-grid	1%	5%	6%
Diesel mini-grid # households (thousand)	3	38	43
Electrification rate – PV-MFP	1%	4%	11%
PV-MFP # households (thousand)	7	27	83
Rural coverage	**13%**	**25%**	**35%**
Rural households (thousand)	**78**	**170**	**266**
National Electrification Rate	**41%**	**54%**	**68%**
National Households (thousand)	**584**	**804**	**1,061**

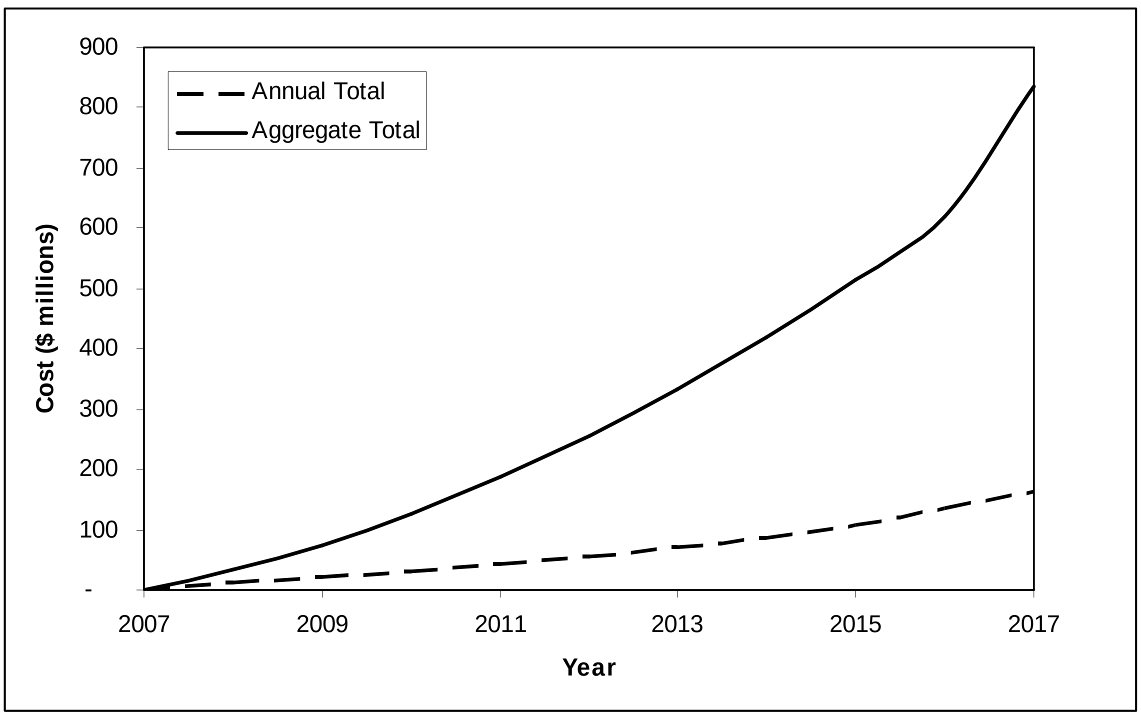

Figure 11. Annual and aggregate investment needs to meet rural electrification target.

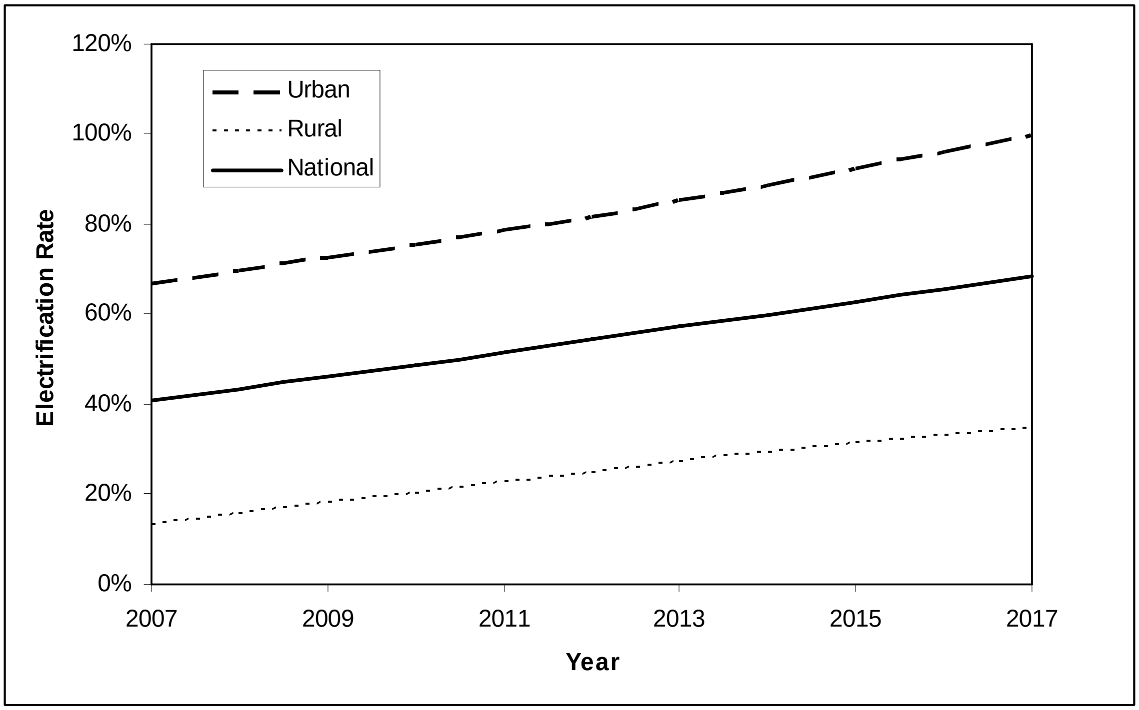

Figure 12. Evolution of household coverage to meet 66% national electrification target

The total grid compatible area is shown in Figure 13. 72% of Senegal's population lives in the grid compatible area. The estimated amount of MV line needed to cover the entire grid compatible area is 5,057 km.[41] The estimated amount of MV line needed to meet the 5- and 10-year targets is 1,194 km and 3,275 km respectively.

[41] This figure includes a road factor of 1.5 to account for additional line that may be needed if roads are followed.

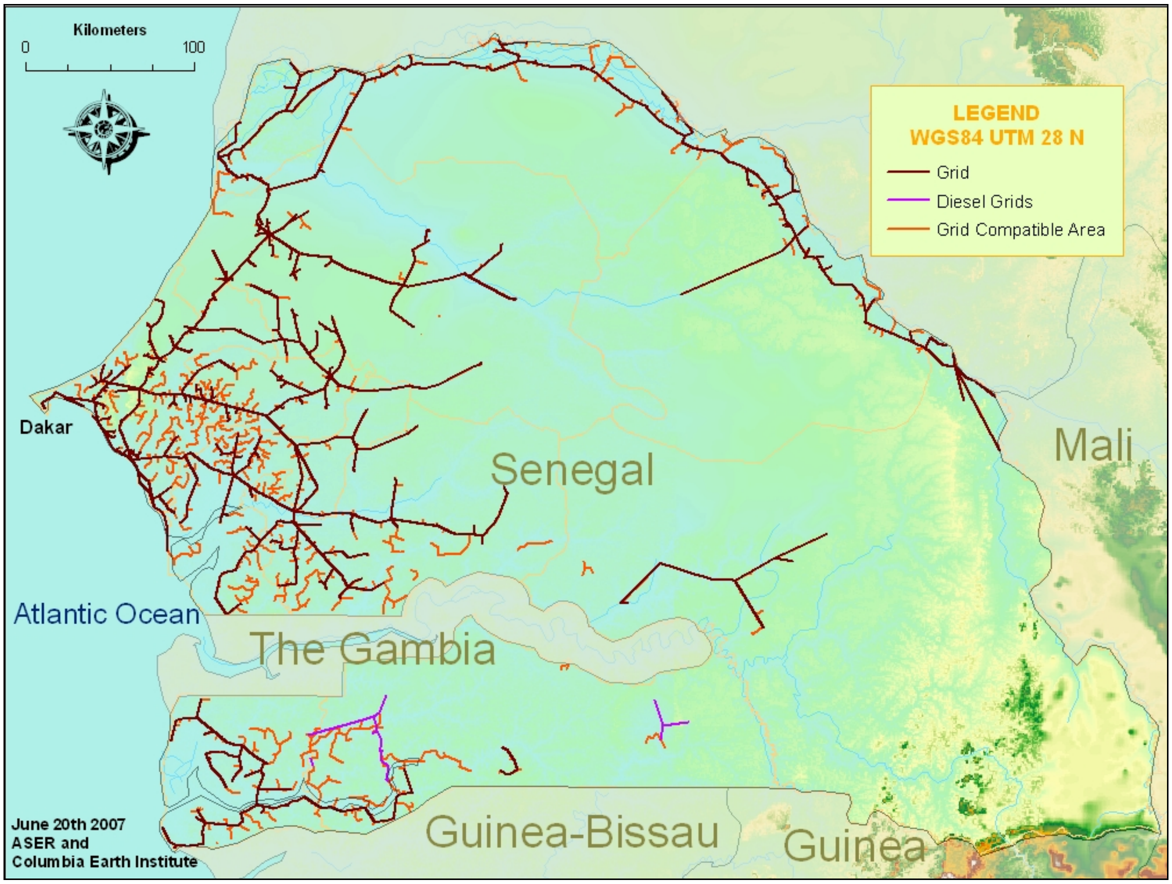

Figure 13. Grid compatible area given three-phase technology and demand assumptions. Note that diesel mini-grids shown are existing multi-village diesel mini-grids, not new grids.

4.2 Costs per household[42]

Costs per household vary depending on the technology, the location of the village, and projected household-level demand.

The discounted per-household average grid connection cost in urban settlements is $305 for raising the urban penetration rate to 100% over a 10 year period. This includes the LV line to connect the household to the grid and the equipment needed for the household installation. Transformer and MV line capacity is assumed to be sufficient to reach a 100% penetration rate and is thus not taken into account.

The $305 connection cost per household takes into account the time dimension of the investment plan. This means that the capital cost of household connections in later years is discounted to their present value. The undiscounted urban per-household average grid

[42] These costs per households are averaged over the number of connections by technology to meet the targets. They should not be interpreted as basis for selecting the most cost effective technology. For example the cost per household of US$716 for PV and US$965 for diesel does not suggest that PV is the cheapest technology and that policy options should push for more PV systems. The difference is due to the fact that most PV systems are selected for small villages with very low demand which makes the average to come out low.

connection cost, i.e. the average cost of connecting these households today, is therefore higher and totals $409 per household.

For rural grid connections, the undiscounted per-household average cost for LV connections and household installations is $502. The difference between the urban and rural per-household cost can be explained by the greater inter-household distance in rural settings, which is, however, slightly offset by the higher cost of more complex equipment in urban households to reflect the more extensive use of electricity there.

When including the MV line extension to connect the village to the national grid and transformers for sub-stations in per-household connection costs, the undiscounted average rises from $502 to $1,140. The discounted average per household connection cost rises from $385 for LV line and household connection equipment only to $875 when also including MV line and transformer costs.

Table 11. Average capital costs (per household) for grid connections.

Average Grid Capital Costs (per household)	Undiscounted	Discounted
Urban household	409	305
Rural household (LV line + HH installation)	502	385
Rural household (including MV line and transformers)	1,140	875

For off-grid villages that will be supplied by a diesel mini-grid, the undiscounted per-household average cost for LV connections and household installations is $470 (discounted $409). As the investment needed is very similar to that of villages that are to be connected to the grid, their cost structure is also very similar. The $32 undiscounted gap can be explained by slight differences in the structure of villages (e.g. size) supplied by grid and supplied by a diesel mini-grid.

When including the diesel generator supplying the electricity in per-household average costs, the undiscounted average sums up to $965. The discounted per-household average cost is $840.

Table 12. Average capital costs (per household) for diesel mini-grid connections.

Average Mini-Grid Capital Costs (per household)	Undiscounted	Discounted
Rural household (LV line + HH installation)	470	409
Rural household (including diesel generator)	965	840

For villages supplied by PV-MFP, the undiscounted average per-household installation cost of the solar system is $716. The discounted average cost is $522.

Since in the case of PV, mechanical power is provided by a separate technology, i.e. the MFP, the PV household costs refer only to installations on individual homes. The costs do not take into account the investments needed at the community level, i.e. for making available mechanical power for productive use and street lighting.

Table 13. Average capital costs (per household) for PV-MFP systems.

Average Capital Costs (per household)	Undiscounted	Discounted
Rural household PV only	716	522
Rural Household PV and MFP	1,155	842

Table 14. Average annual recurring costs (per household). Costs include system maintenance, electricity/fuel purchase, billing/collection, and capital replacement. All the costs are discounted.

Average Recurring Costs (per household)	Grid	Diesel	PV
Urban household	160	N/A	N/A
Rural household	122	300	140

4.3 Institutional coverage

Currently, less than 20% of rural social institutions (schools, health clinics, market/community centers) have access to electricity. Reaching 100% of these institutions carries a capital cost of $8.23 million (Table 15) and an additional $48 million capital cost for institutions located in communities not electrified.

The average undiscounted capital cost of basic electrification of a rural school is $825 and for a health clinic is $726. Costs may be substantially higher for larger institutions with many rooms and more intensive electricity requirements (e.g. for computers and laboratory equipment in schools or sterilization equipment in health clinics).

Table 15. Total capital costs and electrification rates for health clinics and schools.

Capital Costs for Institutions (million $)	Current	5 years	10 years
Health		0.70	3.66
Education		0.88	4.57
Total		1.58	8.23
Electrification Rates (%)			
Health	7%	26%	100%
Education	5%	23%	100%

4.4 Generation scale-up

Current generation capacity in Senegal is approximately 500 MW, and energy demand was 1.74 million MWh in 2003. Needed generation capacity to meet the scale-up in distribution is about 100 MW depending on the type of power plant. Economic growth may require a substantial increase in generation capacity. If the elasticity of electricity demand growth is 1.5 and economic growth is assumed to occur at 5% per year, and if this demand is assumed to be decoupled from the demand estimated here, an additional generation capacity of 500 MW will be needed. Note that investments to scale up generation capacity are not included in cost estimates made in this report.

5 Other considerations

The cost estimates made here give a general sense of needed investments in the electricity sector to meet MDG-related goals in Senegal. The total cost over the 10-year investment period is an aggregate of the annual costs after discounting.

The specific technologies considered – grid extension, diesel mini-grids, and stand-alone photovoltaic systems – were selected because they currently are in use in Senegal so costs and applications are well understood. Other technologies, including wind power and hybrid systems, may become more competitive and widely applied in Senegal in the future and should not necessarily be excluded from planned investments.

The computed costs consider population growth, and associated growth in the number of households and institutions. They do not consider associated economic growth or population movements, which may affect technology choices, distribution costs, and generation scale-up.

Many rural villages do not have adequate access to institutions – more than a thousand schools and health clinics are needed, particularly in the eastern and southern regions of the country. Costs of electrifying institutions are included in the total cost estimates only insofar as those institutions exist, and only certain kinds of institutions (schools, health clinics, community center/markets, and streetlights) are considered. The cost of creating and electrifying additional institutions is not included.

6 Conclusions and recommendations

The estimated cost of reaching Senegal's target electrification rate within 10 years is approximately $860 million, more than 60% of which is for rural electrification. Non-electrified villages in western Senegal that are host to schools and/or health clinics should be prioritized for grid extension. The proximity of these villages to the existing electricity grid reduces the capital cost of connection. Villages that are far from the existing grid (e.g. villages in Tambacounda) are unlikely to be included in a grid roll-out in the near future. Villages in these regions that have a school, health clinic and/or market center should be prioritized for decentralized technologies such as a diesel mini-grid or stand-alone PV system.

Connecting a large number of new households to the grid likely will require reinforcement of the existing transmission and distribution network. The amount of reinforcement can be estimated by analyzing projected increases in peak demand for each part of the extended network and determining likely points of stress in the existing network. Reinforcement of the existing network should be accounted for as part of rural electrification planning.

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Appendix 1. Technology comparison model assumptions.

Currency (USD or Sh)					
Currency choice (USD or FCFA)	FCFA				
Exchange rate	1	USD	=	500	FCFA
Reverse exchange rate	1	FCFA	=	0.00200	USD
Time horizon	10	years			
Discount rate	10%		DCFF =	6.1	

Location Density	**Low Density**		**High Density**	
Village Size	**<500**	**500-1000**	**1000-5000**	**5000-10000**
Household data				
Distance between hh (meters)	30	24	24	8
Rural household size	9.6	9.6	9.6	7.5
Domestic use	Lighting, radio, cell phone charging etc.			
Penetration rate (% of hh in the village)	60%	60%	60%	80%
Consumption (kWh/hh/yr)	73	110	450	1398
Productive use	Mechanical power etc.			
Penetration rate (% of hh in the village)	100%	100%	100%	100%
Consumption (kWh/hh/yr)	20	60	70	100
Institutions data				
# of institutions per community				
Health Centers	0.2	0.4	0.5	2.0
Schools	0.2	0.6	1.5	2.5
Community Centers / Markets	0.1	0.7	2.4	12.8
Public Lighting points (1 point per 25 hh)	1.0	2.8	7.3	25.5
Institutions data				
Consumption (kWh/institution/yr)				
Health Center	223	335	502	753
School	438	657	986	1478
Community Center / Market	365	548	821	1232
Public Lighting (kWh/yr)	102	102	102	102

Fuel / Electricity purchase			
MV electricity cost per kWh	83.40	FCFA	Price of March 2007
Diesel cost per Liter	540.0	FCFA	
Distribution losses for Grid	15%		
Distribution losses for Diesel Mini-Grid	5%		

% of Total Demand during peak hours	40%	Urban population growth rate	2.3%
% of total productive demand during peak	80%	Rural population growth rate	2.3%
Number of peak hours in a year	1460	Time Horizon for Investment Program	10 years

Appendix 2. Domestic service levels.

Services	Components	Usage	Power and Energy
Level 1	*03 light bulbs of 11 watt* *01 radio of 15 watt*	4 hours/day on average	48 W or 192Wh/day
Level 2	*05 light bulbs of 11 W* *01 radio of 15 W*	4 hours/day on average	70 W or 280Wh/day
Level 3	*08 light bulbs of 11 W* *01 radio of 15 W* *01 TV of 50 W*	4 hours/day on average	153W or 612Wh/day

Source: ASER First Concession Study, 2005

Appendix 3. Characteristics of SENELEC equipment.

Type of Network	Size of Conductors	Type of conductors
High voltage 225kV	288 mm² et 2 x 228 mm²	Almelec et ACSR
Medium Voltage 30 kV		
Main Line	148 mm², 75.5 mm² et 54.6 mm²	
Derivation	54.6 mm² et 34.4 mm²	
Distribution Network		
Distribution	3*70+54+25 mm²	Three phase for main lines
	3*35+54+16 mm²	Three phase for main and derivation lines
	4*16 mm²	Three phase for derivation lines
Connection	4*16 mm²	Three phase
	2*16 mm²	Single Phase

Source: ASER

Apparent Power [KVA]	Primary Voltage [KV]	Operation Losses [W]
25	30	500
50	30	1100
100	30	1750

Source: ASER

Appendix 4. Inter-household distance assumptions.

Assumptions on inter-household distances were derived from a study on rural electrification in Togo but adjusted with ASER to the case of Senegal (ASER, 2004). For Senegal, 30m was taken for localities of less than 500 people, 24m for areas between 500 and 5000 people, and 8m for areas of population greater than 5000.

Topology and size of localities	Inter-household distances (m)
Small dispersed villages	**45.1**
Small threadlike villages of less than 2,000	**22.7**
Medium threadlike villages 2,000-5,000	**14.3**
Medium concentric villages 2,000 – 5,000	**8.4**
Large concentric villages > 5,000	**5.4**

Source: ASER, 2004.

Appendix 5. Grid extension algorithm.

The grid extension algorithm is based on Kruskal's minimum spanning tree algorithm and runs in Java on GIS data (converted to text files using an AML script). The algorithm requires a digitized version of the existing electricity grid (straight lines connecting villages, densified to allow new connections from points in between villages), the population of each village, and *MVmax* per capita output from the Technology comparison tool. The basic principle is:

Connect if: MVmax(meters/person)*Pop>=Distance(meters)

This problem is solved using Kruskal's algorithm for solving a minimum spanning tree problem. The general problem is stated as:

Given a connected G=(V,E) and a weight d:E->R+, find a minimum spanning tree T.

Kruskal's algorithm:

1. Set i=1 and let $E_0 = \{\}$.
2. Select an edge e_i of minimum value not in E_{i-1} such that $T_i=E_{i-1}$ if $U\{e_i\}$ is acyclic (i.e. not creating a loop) and define $E_i=E_{i-1}$ U $\{e_i\}$. If no such edge exists, let $T=<E_i>$ and stop.
3. Replace I by i+1. Return to step 2.

Kruskal's algorithm applied to the grid extension problem:

Input connected graph (E: grid), edge weight (d: distances between villages), vertex weight (V: population)

1. Set i=1 and let $E_0 = \{\}$.
2. Select an edge e_i of minimum value not in E_0 U…U E_{i-1} such that

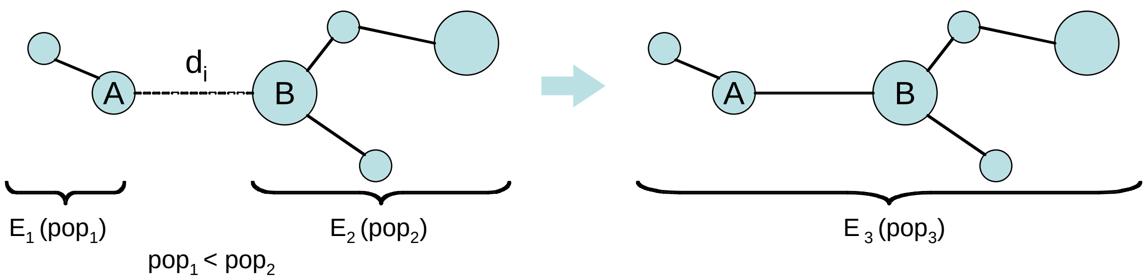
$T_i = E_0 \cup \ldots \cup E_{i-1} \cup \{e_i\}$ is acyclic

If $d_i < pop_1 * MVmax$ (i.e. it is cost effective to connect A to B)

Then define $E_3 = E_1 \cup E_2$ and $pop_3 = pop_1 + pop_2 - d_i / MVmax$

3. Replace I by i+1. Return to step 2.

Note that $d_i/MVmax$ is the population that is "used" to connect A to B and therefore should not be accounted for in future cost-effectiveness calculations for new connections.



The algorithm begins by looking for the shortest possible connections and then continues making connections until all grid-compatible villages have been connected. Since the search begins with the shortest possible connections, regardless of their location in space, small villages can become grouped together into larger demand hubs, ultimately connecting a greater number of villages that are small and/or far from the existing grid. On the other hand, this means algorithm will generate mini-grids (sets of connected villages that are not connected to the main electricity grid and that may not have a source of electricity), but there is an option to clean out all mini-grids. The final output is an extended electricity grid, with the original grid as a backbone.

For more information about Kruskal's minimum spanning tree algorithm, see: http://www-b2.is.tokushima-u.ac.jp/~ikeda/suuri/kruskal/KruskalApp.shtml?demo2.

Appendix 6: Assumptions and cost breakdown for MFP

This Electricity Costing Model assumes that mechanical power for productive uses in all urban areas is met through access to grid electricity. It assumes also the existence in theses areas of equipment such as mills and electric motors for the provision of those services. However, in Senegal, most villages with fewer than 500 people do not have access to such equipment. In order to meet the 100% penetration rate for productive use, this model assumes that every rural village where grid extension or a diesel mini-grid is not the most cost-effective technology will have access to an MFP. In certain cases, adjacent communities could share the same MFP. In cases where this is not possible, the cost for productive use may be underestimated.

Investment	CFA	US$
Small house	700,000	1400
Engine (16-HP)	650,500	885
Alternator (7.5 kVA) & belt pulley	365,000	730
Lighting , cooler and Meters	335,000	670
Peanut’s paste presses	340,000	680
Mill	394,500	789
De–husker	373,000	746
Battery charger	156,000	312
Total	**3,106,000**	**6,211**
Installation	**CFA**	**US$**
Frame and track	269,000	538
Accessories	28,000	56
Installation cost	73,500	147
Transportation cost	69,000	138
Total	**439,500**	**879**
Total MFP cost	**3,545,500**	**7,090**

Source:UNDP—Columbia University Workshop, May 2007.
Enhancing the Profitability and Sustainability of the MFP in Senegal

Appendix 7. Geo-referenced data library for Senegal.

Dataset	Description	Type	Source
Senegal villages	Contains 14,282 villages with 2005 population data (projected forward from 2002 census). Data were cleaned to remove repeat villages, etc.	point	Acquired from ASER in 2006. Population data from 2002 census.
Senegal electrification	A set of 4 files listing villages electrified by SENELEC before 2000, by SENELEC since 2000, by ASER since 2000, and containing solar home systems. Other than solar home systems, does not specify the type of electrification. Does not always match SENELEC information. Proprietary.	point	Produced by a consulting firm in Senegal and acquired from ASER in January 2007.
DPS villages	Contains 13,434 villages (most urban centers are not included) and whether each village has access to a primary school, a health post, water, markets, and roads. Population data were projected forward from 1988 census to 2000. Village names do not always match Senegal_villages.	point	Produced by DPS in 2000. Acquired from DPS in November 2006.
DPS rural communities	Aggregates DPS_villages to 322 rural communities (smallest administrative unit in Senegal).	polygon	Produced by DPS in 2000; acquired 2006.
DPS districts	Aggregates DPS_villages to 31 departments.	polygon	Produced by DPS in 2000; acquired 2006.
DPS regions	Aggregates DPS_villages to 10 regions (Matam and Saint Louis are incorrectly combined).	polygon	Produced by DPS in 2000; acquired 2006.
Regions	Outline of Senegal's 11 regions.	polygon	Original source unknown. Acquired in Spring 2006.
Topography	A set of files containing rivers, lakes, ocean, protected zones, roads, and elevation. The road files includes information about type of road.	Polygo n& line	Original source unknown. Acquired from ASER in November 2006.
Electricity grid raw	A set of 2 files that include 90kv high-voltage transmission and 33kv medium-voltage distribution lines. Many lines are curved to follow roads. Does not connect villages to grid.	line	Source: ASER. Acquired from ASER in November 2006.
Electricity grid clean	Electricity grid digitized by the Earth Institute team. Straight lines that connect villages. Digitization based on paper maps received from ASER and SENELEC as well as information on village electrification status.	line	Created by Columbia Earth Institute team. Last updated February 2007.

Note: All data projected to WGS 1984 UTM 28N.