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Options for the Development of Liberia's Energy Sector

Africa Energy Unit (AFTEG) Energy Sector Policy Notes Series

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Africa Energy Unit (AFTEG)
Sustainable Development Department
Africa Region
The World Bank

"Traveler, your footsteps
are the road, nothing more;
traveler, there is no road,
you make the road by walking.
By walking you make the road,
and when you look back
you see the path that
you'll never walk again.
Traveler, there is no road,
only wakes in the sea."

«*Caminante, son tus huellas
el camino, y nada más;
caminante, no hay camino,
se hace camino al andar.
Al andar se hace camino,
y al volver la vista atrás
se ve la senda que nunca
se ha de volver a pisar.
Caminante, no hay camino,
sino estelas en la mar.*»

(By Antonio Machado)

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Abbreviations and Acronyms

AC	alternating current
ACRE	average coverage rural electrification
AGO	automotive gas oil
BAPA	Barangay Power Association (Philippines)
bcf	billion cubic feet
BMC	Bong Mining Company
BOM	Belgische Maatschappij N.V.
CFL	compact fluorescent lamp
CIF	cost, insurance, freight
COUF	Crude Offshore Unloading Facility
CSET	Center for Sustainable Energy Technologies
CLSG	Côte d'Ivoire, Liberia, Sierra Leone, and Guinea
CST	crude storage terminal
DC	direct current
DPC	decentralized power company
ECOWAS	Economic Community of West African States
EIA	U.S. Energy Information Administration
EPO	Equatorial Palm Oil
EPP	Emergency Power Program
ERB	Energy Regulatory Board
ESCO	energy service company
ESMAP	Energy Sector Management Assistance Program
FOB	free on board
GAMS	General Algebraic Modeling System
GDP	gross domestic product
GIS	geographic information systems
GOL	Government of Liberia
GWh	gigawatt-hours
HDI	human development index
HFO	heavy fuel oil
HV	high voltage
ICB	international competitive bidding
IDA	International Development Association
IEA	International Energy Agency
IFC	International Finance Corporation
IPP	independent power producer
JICA	Japan International Cooperation Agency
kV	kilovolt
kWh	kilowatt-hour
LEC	Liberia Electricity Corporation
LISGIS	Liberia Institute of Statistics and Geo-Information Services
LNOC	Liberia National Oil Corporation
LPG	liquefied petroleum gas
LPRC	Liberia Petroleum and Refinery Company
LV	low voltage
MCI	Ministry of Commerce and Industry
MLME	Ministry of Lands, Mines and Energy
MOTC	Monrovia Oil Trading Corp
MPA	Monrovia Power Authority
MSW	municipal solid waste
MUV	manufactures unit value
MV	medium voltage
MW	megawatts
NACUL	National Charcoal Union of Liberia
NEA	National Electrification Administration (Philippines)
NEC	National Energy Committee
NEP	National Energy Policy
NGO	nongovernmental organization

NOCAL	National Oil Company of Liberia
NORAD	Norwegian Agency for Development Cooperation
NPA	National Port Authority
NPV	net present value
NREL	U.S. National Renewable Energy Laboratory
O&M	operation and maintenance
PEA	Provincial Electricity Authority (Thailand)
PMS	premium motor spirit oil
PPA	purchasing power agreement
PRS	Poverty Reduction Strategy
PST	product storage terminal
PUA	Public Utility Authority
PV	solar photovoltaic
RE	rural electrification
REB	Rural Electrification Board (Bangladesh)
REC	rural electric cooperative
RESCO	rural energy services company
RREA	Rural and Renewable Energy Agency
SHS	solar home system
SIF	Société Nationale de Raffinage
SIR	Société Africaine de Raffinage
SME	small and medium enterprise
SNE	Servicio Nacional de Electricidad (Costa Rica)
SP-1B	St. Paul River 1B Hydropower Plant
SP-2	St. Paul River 2 Hydropower Plant
SPPAs	small power purchase agreements
SSMP	Sustainable Solar Market Packages
STEG	Société Tunisienne de l'Electricité et du Gaz
UN	United Nations
UNDP	United Nations Development Programme
UNIDO	United Nations Industrial Development Organization
UNMIL	United Nations Mission in Liberia
USAID	United States Agency for International Development
USTDA	U.S. Trade and Development Agency
WAPP	West African Power Pool
WFP	World Food Program

Scope of the Paper

The purpose of this paper is to present stakeholders in the Liberian energy sector—and the Liberian citizen in general—with options that might expand access and modernize energy services. To this end, the authors have attempted to analyze the data available and to bring international lessons to bear on the case of Liberia. There are several potential pathways to consider, though the aim is one: supporting the sustainable development of access to energy services for the people of Liberia.

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We thank Chris Neyor for drawing our attention to the poem by Antonio Machado that has guided our report.

Executive Summary

In mid-2011, Liberia has possibly the lowest rate of access to public electricity in the world. While the average rate of access to electricity in Sub-Saharan Africa is 28.5 percent, and in neighboring Sierra Leone and Côte d'Ivoire 6 percent and 43.7 percent, respectively, Liberia's rate of access to publicly provided electricity is close to zero. An urban access rate can only be derived for Monrovia: of an estimated 210,619 households, 1,217 are supplied with public electricity (as of late 2010), corresponding to 0.58 percent of Monrovia's population. With the exception of a very limited municipal mini-grid in Gbarnga, Bong County, no publicly supplied electricity service is available outside of Monrovia.

The root cause of this situation is Liberia's civil war. In 2003, at the end of 14 years of warfare, Liberia's power sector emerged seriously damaged. By 2005 what remained had been destroyed by looting. This included the complete destruction of the hydropower plant at Mt. Coffee and Liberia's entire transmission and distribution network. Operations of the Liberia Electricity Corporation (LEC) ceased completely. As a result, Liberia faces the challenging task of fully reconstructing its power system.

In early 2010 the high costs of electricity and low quality of energy services in general imposed a significant barrier to Liberia's long-term economic development. Over 80 percent of Liberia's household energy requirements are met using thermal energy for cooking, and both urban and rural households rely almost exclusively on charcoal and firewood. To maintain annual charcoal production levels of 36,500 tonnes, about 960,000 trees are being cut around Monrovia alone every year, which is fast depleting Liberia's rich forest stock. For lighting, households expend a significant amount of their income on inferior sources such as candles, flashlights, small battery-operated LED lamps, and kerosene or oil lanterns. Production activities, notably agriculture, rely primarily on human power. Some households have small generators of 500 to 900 watts to serve larger processing loads such as rice mills.

While the electricity services available in Liberia are poor, the cost of these services is nevertheless high in comparison with other Sub-Saharan African countries. In April 2010 the price of electricity from the grid was US$0.43 per kilowatt-hour (kWh), possibly the highest in Sub-Saharan Africa. People without access to public electricity pay even more: the use of dry-cell batteries costs US$74.01/kWh, car batteries US$8.43/kWh, candles US$8.27/kWh, generators US$3.96/kWh, and kerosene for lighting US$1.53/kWh.

Since elections in 2006, achievements are clearly visible in the energy sector. The Government of Liberia (GOL) has been working systematically toward the reconstruction of the electricity sector at the urban, rural, and regional levels. A National Energy Policy (NEP), endorsed in June 2009, set clear development goals for the short, medium, and long term. For the first time in Liberia's history, since early 2010, a Rural and Renewable Energy Agency (RREA) has dedicated its services solely to rural areas, including the rural poor.

By April 2010 the basic functions of LEC had been restored and the supply of electricity to about 2,500 customers in Monrovia established. In July 2010 a management contractor Manitoba Hydro International took over the operation and further build up of the LEC against clearly defined connection targets and timetables. While the LEC's overall financial situation is precarious, its operating revenue growth has been substantial, and it has developed a clientele with comparatively good payment discipline since its early days of operation. Following a complete decline in petroleum fuel use in the 1990s, demand for automotive gas oil and premium motor spirit oil again reached levels seen in the early '80s (during which the Liberian economy was at a high point) in early 2010. This marks the return of economic activity in Liberia.

Yet challenges remain. In the context of the NEP, clear timetables for the implementation of policy recommendations need to be established. These include translating the NEP into a national regulatory framework. The RREA and its Rural Electrification Fund (REFUND) need to become fully operational. At the LEC, average revenue falls well short of the average operating cost, which was US$0.63/kWh in 2009, even though average revenue rose from US$0.42/kWh in 2008 to US$0.45/kWh in 2009. While the LEC's tariff methodology appears appropriate, operating costs, including administrative costs, should be reduced. Customer connections need to increase if the target of 33,000 connections by 2015 is to be met. Under the policies now in place, the NEP targets of connecting 30 percent of Liberia's urban and peri-urban population and 15 percent of its rural population by 2015 seem out of reach.

In the context of petroleum fuels, Liberia does not have any official product specification standards. These are left to oil landing terminals, such as the Liberian Petroleum and Refinery Company's (LPRC's) product storage terminal, to specify. To ensure that safe fuel of satisfactory quality is landed, it is recommended that standards are enforced in accordance with international practices as follows.

Supplying adequate fuel for thermal power plants is a challenge in Liberia. In early 2010 there were no facilities to supply heavy fuel oil (HFO), and diesel fuel supply facilities were in need of repair or replacement. The prices of supplying fuel to Liberia are considerably above the regional average, as suppliers mark their prices up to account for any remaining perceived civil instability, the poor conditions of the receiving terminal at the Monrovia port, and the lack of acceptable international safety standards. The diesel fuel jetty, owned by the National Port Authority (NPA), and the HFO supply facilities have been slated for rehabilitation with World Bank financing, but this is not expected to be completed before 2012.

In an environment of high uncertainty, this paper attempts to lay out an optimal development pathway for Liberia's energy sector between now and 2040. To this end, two main demand scenarios were specified and a set of possible supply options analyzed. Using the linear general equilibrium model called General Algebraic Modeling System (GAMS), a least-cost expansion plan that meets the projected demand was derived. The plan indicates what power facilities should be constructed at what point in time to meet projected demand across five-year intervals until 2040 at least cost. To derive the optimal sector development plan for the medium term, until 2015, an additional bottom-up analysis was performed.

The electricity demand estimate for Liberia has been based on available data, including that collected during Liberia's 2008 census. According to the type of consumption (residential, commercial, public, or industrial), demand is projected using population growth, gross domestic product (GDP) growth, and industry-specific demand drivers. Conservative and high-demand scenarios are distinguished. In the high-demand scenario, economic growth is assumed to be more pronounced and to spur demand for electricity in the commercial and mining sectors. Demand reflects all demand, including suppressed demand.

The supply options under consideration cover all options that appear technically feasible for Liberia in 2010. Among the thermal options, diesel, HFO, and biomass power are considered. Further, construction of hydropower plants and the import of electricity are also considered and export of excess power is allowed for. Table ES1 provides an overview of all technologies that have been considered. Going forward it will be important for the GOL to update the studies on potential hydropower sites, most of which were prepared in the 1980s. It is also important to consider what additional energy technologies might be used in Liberia in the future.

The bottom-up analysis undertaken for the medium term indicates that in the time frame of 2009 to 2015 a gap in the supply-demand balance will occur starting from 2012. **Measures need to be taken to close this medium-term supply gap.** The emerging gap increases from about 4 megawatts (MW) in 2012 to about 13 MW in 2014. Only in 2015, when the West African Power Pool (WAPP) transmission interconnection for Côte d'Ivoire, Liberia, Sierra Leone, and Guinea (CLSG) is expected to become operational, will the gap be bridged. Assuming that financing is found, construction of an HFO-fired power plant presents a feasible and least-cost measure to close the medium-term gap between power demand and supply by installing 10 MW in 2013, and a further 5 MW in 2014. Further, an HFO plant would provide a stable thermal backup beyond 2015 to make up for the more intermittent hydropower. Due to the small size of the power addition, public financing would be preferred. Advantages of public financing include the flexibility of dispatching power without hampering the financial/economic development of the power system through fixed purchasing power contracts for which dispatch has to be maximized. Further, plant procurement is generally fast once financing is available.

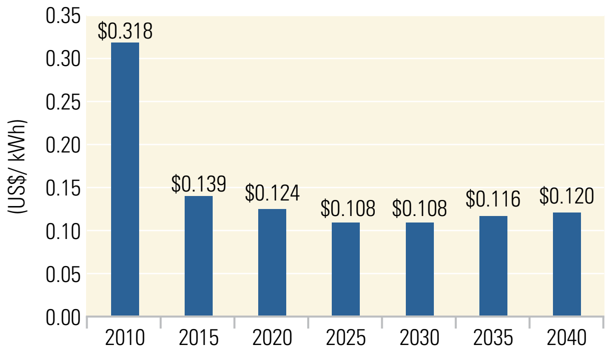
The least-cost modeling suggests that for both conservative and high-growth scenarios, a least-cost expansion plan for Liberia until 2040 would include the construction of a range of hydropower candidate plants, including rehabilitation of the Mt. Coffee hydropower plant by 2015 and construction of the St. Paul River development (SP-1B and SP-2) and Mano hydropower plants by 2020. In addition, the WAPP transmission interconnection of Côte d'Ivoire, Liberia, Sierra Leone,

Table ES1 | Supply Options to be Considered

Power Source	Earliest Possible Commissioning Date	MW Capacity	Total Levelized Cost (US$/kWh)
Diesel existing system	2010	13	0.32
Diesel system, learning curve	2012	1	0.29
Leasing diesel generation	2010	10	0.27
HFO	2012	10	0.16
Core biomass	2012	36	0.21
Biomass benchmarking	2012	31	0.11
WAPP phase 1 Low	2015	28	0.17
WAPP phase 2 Low	2020	23	0.11
WAPP phase 1 High	2015	50	0.17
WAPP phase 2 High	2020	47	0.11
Hydro 1: Mt. Coffee, phase 1	2015	66	0.10
Hydro 2: Mt. Coffee + Via Reservoir	2020	66	—
Hydro 4: SP – 1B + SP2 + Via Reservoir	2020	198	16–23 (11)
Hydro 3: Mano River	2025	90	16–23 (10)

Source: Authors' calculations.

Figure ES1 | Average Cost of Generation



Source: Authors' calculations.

and Guinea are part of the plan from 2015. Thermal complements include both HFO-fired and diesel plants. Diesel is selected due to the low capital cost required to provide for the operating margin of the system. The average cost of generation is expected to decrease significantly over time (as Figure ES1 indicates) for the low-demand scenario.

Power supply options for rural areas. As the interconnected system in Liberia increases, citizens—especially residents of Monrovia and the adjacent counties—will have increasing access to electricity. Larger cities located nearby the proposed WAPP transmission line would also gain access to the interconnected grid. Nonetheless this would still leave slightly more than half of Liberia's rural population (about 53 percent) without access to modern energy services. Given the limited range of the grid over the coming years and the relatively low load requirements of the current rural population, decentralized off-grid solutions (including mini grids and stand-alone systems designed for small loads and single applications) appear to be the best strategy for bringing modern energy services to rural areas. Renewable energy technologies are particularly well suited to an off-grid, distributed generation scenario, and Liberia is endowed with significant renewable energy resources such as solar, biomass, and hydropower. Based on international experience, private sector service delivery models, including dealer sales and fee-for-service models, are suitable for rural areas. Government policies and measures in support of these models need to be developed, which should build on independent institutions such as the RREA, involve highly reputed authorities or bodies, and include the broad participation of the rural population. The RREA needs to take clear leadership on these issues by developing a rural energy master plan.

With Liberia's limited financial resources and urgent needs for reconstruction (and not only in the energy sector), the question is how energy sector reconstruction can best be financed and investment priorities set. Modern electricity infrastructure is a key ingredient for economic growth, including job creation. **Since economic activity is concentrated in urban areas, large-scale infrastructure investments should be prioritized there. Where possible, enhancing the availability of lower-cost, off-grid applications in rural areas should be pursued in parallel with a social justice agenda.** It is often maintained that in an environment with few public resources, private financing of electricity services should be introduced. While this notion is generally valid, the rebuilding of Liberia's electricity sector will require substantial public and concessionary financing over the next 5 to 10 years. Private sector power suppliers require stringent payment conditions that will be difficult for LEC to meet as long as it remains a power utility under reconstruction. To rebuild the electricity grid, especially in Monrovia, initial investments should be based on public sector or concessionary financing until a solid and solvent customer base can be established. In parallel, a regulatory environment should be established that will facilitate future private sector interventions. The post-2015 involvement of private partners—such as the mining industry, for example, to provide part of the thermal load—should be investigated. Once big private sector off-takers become interconnected with the WAPP CLSG transmission line, leveraging their resources for the construction of large hydropower candidate plants may be considered.

To move forward with the above-mentioned options, it is important that Liberia, together with its government and multilateral partners, forge a path of strategic development with the aim of achieving concrete and visible results. Although the country's achievements in infrastructure rehabilitation, social services, and governance since 2006 have been commendable, in many areas of the country the evidence of these changes is small. While the development of sound policy frameworks and technical underpinnings is critical for a sustainable energy sector, it takes time. Similarly, the large-scale investments required to build the needed energy infrastructure will require time. It is therefore recommended that parallel activities be undertaken in the immediate term—such as outreach, education, and small interventions in urban and rural communities—so that the government's intentions for the development of the sector are known.

Part I

Fundamentals of Liberia's Energy Sector

The Beginning of the Road

1

Liberia suffered successive armed conflicts from 1989 to 2003 that devastated its economy, infrastructure, human capital, and institutions, including those of the energy sector. The Accra Peace Agreement of August 2003 marked a transition toward national reconciliation and stabilization that allowed the country to hold elections in 2005. The newly elected Government endorsed programs and policies aimed at improving governance, building capacity, and managing postconflict recovery through stabilizing the economy and supporting economic reconstruction.

Since President Sirleaf took office in 2006, reconstruction efforts have been substantial; increased price stability and structural reforms have reinforced public financial management. But the country still faces several challenges. The economy contracted by more than two-thirds in real terms between 1980 and 2003, and average per capita GDP is far from the prewar level of US$890. In 2008 per capita GDP was estimated at US$240, with almost two-thirds of the population living below the extreme poverty line, making Liberia one of the world's poorest countries (Republic of Liberia, 2008).

Investment in human capital and reconstruction of physical infrastructure are the central pillars of Liberia's government reform agenda, which aims to promote equitable economic development. A plan for recovery and reconstruction has been formulated for each sector, with a focus on both immediate needs and long-term development. Access to basic services such as health care, education, water and sanitation, roads, and telecommunications requires electricity, making it a crucial element of economic revival—and, as previously noted, one that will require significant investment.

International lessons learned from postconflict reconstruction indicate that developing countries face major financial challenges to increased access to basic services due to lack of investment during conflict and low income levels before conflict. While the poor in all developing countries suffer from lack of access to infrastructure services, those in postconflict countries suffer the most (Table 1.1).

The GOL further intensified its commitment to the provision of electricity through the adoption of the NEP in 2009, which calls for universal and sustainable access to affordable and reliable energy supplies to foster the economic, political, and social development of Liberia. The four pillars of the NEP are: (i) universal energy access, including the development of an energy master plan; (ii) least-cost production of energy and protection of the most vulnerable households; (iii) the adoption of international best practices in the electricity sector; and (iv) the acceleration of public and private partnership in the sector.

Before the war, the development and management of the energy sector was squarely in public hands. Until 1960 the provision of electricity services was the responsibility of the Department of Public Works.

Table 1.1 | Availability of Infrastructure Services

Infrastructure Services	Sub-Saharan Africa Liberia	Conflict-affected Countries[5]	Non-conflict-Affected Countries[5]	South Africa[5]	High-income Countries[5]
Electricity (kWh per capita)	87[1]	96	384	3,793	8,421
Telecommunications (fixed and mobile lines per 1,000 people)	193[2]	19	67	410	1,283
Roads (percentage paved)	7[3]	13	27	20	93
Water (percentage of population with access to improved sources)	25[4]	52	67	86	96

Sources: [1] Authors' calculations; [2] ICT At-a-Glance, World Bank, 2008; [3] World Bank, Database, 2008; [4] World Bank, Database, 2008; and [5] Schwartz and Halkyard, 2006.

In 1960 the GOL established the Monrovia Power Authority (MPA). After two years the responsibility of supplying electricity was transferred to the Public Utility Authority (PUA), which was also responsible for telecommunications, broadcasting, and water supply. On July 12, 1973, the PUA was transformed by a legislative act into three different corporations dedicated to communications, water and sewerage, and electricity. Among those, the LEC received the mandate to oversee the country's generation, transmission, and distribution of electricity.

From 1973 until late 1989 and before Liberia's civil war (1989–2003), electricity was mainly provided in the capital of Monrovia; around 35,000 customers—almost 13 percent of the population—were served by 1989. Total installed electricity capacity was 191 MW. The generation mix was composed of hydropower from the plant at Mt. Coffee—with a supply capacity of 63 MW during the wet season and 5 MW during the dry season (six months)—and 31 percent HFO and 21 percent diesel. LEC also handled the electricity supply of rural areas outside Monrovia through 10 small isolated power systems with a total installed capacity of 13 MW.

The unreliability of the LEC-provided system during the dry season stimulated the private sector (industries, mining, and commercial services) to secure its own generation, which equaled 216 MW. Of this 81 percent was based on HFO, 17 percent on diesel, and 4 percent on hydropower.

The LEC system was constrained from expanding due to financial difficulties that were largely caused by technical and commercial inefficiencies. Average combined technical and commercial losses from 1979 to 1984 were around 34.8 percent (UNDP and World Bank, 1987). While blackouts and load shedding were common, the LEC was unable to improve or maintain facilities due to lack of financial resources. For example, in the financial year 1983–84, the LEC supplied electricity valued at US$47.4 million while its revenue was only US$23.7 million.

Technical losses were primarily due to the lack of resources needed to conduct routine maintenance and improvement; the inadequate reactive power equipment needed to compensate for the low power factor from the industry, which ranged from 0.62 to 0.75 percent;[1] and the overloading of equipment due to unplanned extension of the distribution network. Technical losses were estimated at about 13 percent in 1984.

Commercial losses were also high and for the most part explained by illegal connections, lack of payment, the LEC's inability to enforce service disconnection, and tariffs that did not cover even short-run marginal costs. In 1984, for example, commercial losses were 22 percent.

[1] Best practices recommend a load factor of 0.90 percent.

Arrears by governmental departments and public facilities weighed most heavily on the LEC's commercial performance. Public entities were responsible for 27 percent of the electricity bills issued but only 50 percent of these were paid. Residential and commercial consumers represented 65 percent of the electricity bills issued and paid around 75 percent of the revenue received.

Liberia's tariff structure was divided into five levels differentiated by consumption and type of customer. Table 1.2 shows the evolution of the LEC's tariffs from 1974 to 1991. Because they lacked an automated tariff-adjustment mechanism, such as an index that adjusts tariffs to fuel prices changes, the LEC's operations have been continuously exposed to fuel price changes. A fuel adjustment charge of US$0.001/kWh was introduced in 1978, followed by an additional US$0.050/kWh adjustment charge in 1981. The LEC's financial situation became more complex between 1987 and 1991 when Liberia's currency was subjected to progressive devaluation. Tariff adjustments were not sufficient to cover even short-run marginal costs. As a result, the LEC did not have enough cash flow to buy fuel and spare parts, conduct maintenance, and pay and maintain experienced and qualified staff.

Tariffs were set and approved by the GOL based on the LEC's proposal, which was calculated on the basis of production costs, although reported costs in 1987 did not likely include depreciation and debt payment (Geoscience, 1998). For HFO, the LEC reported a generation cost of US$0.05/kWh, while for hydropower generation based on the Mt. Coffee plant it reported around US$0.025/kWh. Gas turbines fired with diesel fuel reached a generation cost of US$0.12/kWh.

Access to electricity in rural areas was very limited. The LEC was in charge of maintaining and operating 10 isolated HFO-fired generating units with a total installed capacity of 13 MW. Most rural households depended on the natural resources available to them, including charcoal and firewood for cooking and kerosene and candles for lighting. Generation costs in rural areas were higher than on the interconnected system due to the size of the system, the fuel source (diesel), and operational logistics. Rural operation costs were between US$0.10 to US$0.30/kWh (Geoscience, 1998), and few consumers had meters. The tariff in off-grid areas was subsidized at US$0.015/kWh. In 1982 around 75 percent of rural customers did not have meters and were charged either a flat tariff of US$10/month or according to usage, at a rate of US$0.08/kWh.

By the end of the civil war in 2003, the power sector had been seriously damaged. The remainder was destroyed by looting until 2005. The hydropower plant at Mt. Coffee and the entire transmission and distribution network were completely destroyed. LEC operations ceased. The new government elected in 2006 has been working toward the reconstruction of the electricity sector at the urban, rural, and regional levels.

With the help of an emergency program, LEC operations were resumed and basic electricity supply to government buildings, commercial operations, hospitals, schools, streets, and some private consumers in Monrovia

Table 1.2 | Evolution of LEC Tariff Brackets between 1974 and 1991

	Industrial	Commercial	Public Corporations	Government and Embassies	Residential
Consumption Levels	(>2,000 kWh)	(>1,500 kWh)	Not specified	Not specified	(<400 kWh)
1974	0.055				0.080
1979	0.081				0.101
1981	0.081	0.094	0.094	0.094	0.100
1987–91	0.114	0.093	0.064	0.064	0.043

Source: Geoscience, 1998.

was restored. The emergency program supported the construction of a small grid comprising four substations and distribution lines of 400 volts, 11 kilovolts (kV), 22 kV, and 9.6 MW of installed capacity run by high-speed diesel generators in four locations as follows: Kru Town, 5 MW; Paynesville, 0.64 MW; Congo Town, 2 MW; and Bushrod Island, 2 MW. This emergency assistance was financed by the European Union, the United States Agency for International Development (USAID), the Norwegian Agency for Development Cooperation (NORAD), and the World Bank through the Emergency Power Program (EPP I and EPP II).

As of end-year 2010, LEC's system provided electricity to 2,762 customers as follows: commercial, 50.5 percent; residential, 44 percent; government buildings, 4 percent; nongovernmental organizations (NGOs), 1 percent; and the LEC and other corporations, 0.50 percent. About 0.58 percent of Monrovia's households were covered in 2010. The remainder of the population depends on costly, inefficient, and polluting resources such as small gasoline and diesel generators, firewood, charcoal, candles, kerosene, and palm oil.

Limited distribution infrastructure, high tariffs, and lack of financing for new connections have constrained the LEC's ability to increase its customers and fully utilize all generation capacity. The system in place reached a peak load of 13.8 MW in February 2010. The most recent additions were 3 MW of NORAD-financed diesel generator and 10 MW of USAID financed diesel generator. To address the underutilization of capacity, NORAD and USAID are financing a 66 kV transmission line and a 22 kV distribution line.

In mid-2011, the LEC's board has set a single tariff of US$0.48/kWh. The tariff is determined according to a revenue requirement approach, which considers the total revenues required to meet all expenses and capital costs of the utility. The tariff is calculated on a quarterly basis taking into account the price of equipment, service schedule, cost of overhauls, 20 percent of technical and nontechnical losses, US$0.02/kWh for distribution operation and maintenance costs, the LEC's administrative costs, and a 93 percent efficiency in collections. The generation cost is estimated at US$0.32/kWh, which is high when compared with average historical generation costs in Africa of US$0.18/kWh (Foster and Briçeno-Garmendia, 2009). The high costs are explained by the small scale of the LEC's current operations and the use of high-cost diesel as the sole source of power supply.

To improve LEC operations, still in emergency mode, the GOL decided to bring in outside expertise. The decision was made to select a management contractor who would bring the LEC to a level of full functionality as a power utility with fully trained staff, and build up the customer base to a target level of approximately 33,000 customers within a 5-year horizon. To achieve this expansion of services, the management contractor would: (i) manage system expansion and connection of new loads expected to come on stream within 5 years; (ii) progress toward the GOL's objective of providing access to electricity to 30 percent of the population in Monrovia by end 2015, including middle- to low-income households; (iii) manage technical and commercial losses and operating and capital costs to minimize costs of service; and (iv) strengthen the LEC, enabling it to become a financially and operationally sustainable utility even after completion of the management contract. Competitive international bidding led to the selection of Manitoba Hydro International (MHI) as management contractor for LEC. MHI began operation in July 2010 and has been able to quickly improve LEC operations.

The GOL has committed itself to creating the conditions necessary for the successful operation of the management contract, which will be financed by NORAD. A grant-financed investment program is being put together to include overall financing of up to US$50 million and will be provided by NORAD, the World Bank, and USAID. The management contractor is expected to take full control of the LEC's operations and investment program.

This report seeks to identify options for the development of Liberia's energy sector, options that would enable the people of Liberia to gain access to modern energy services in a timely and cost-effective manner. In the first part, Liberia's underlying energy sector fundamentals will be delineated. The discussion will review the demand for electricity, assess possible energy supply options for Liberia, review the availability of petroleum fuels, and assess the state of the sector's financials. In the second part of the paper we review what options for development present themselves for Liberia's energy sector, based on the underlying power sector fundamentals that were established in the previous part of the paper. The options are selected based on least cost principles both for on-grid and off-grid technologies. We will consider what options are best suitable for closing the medium-term and long-term gap, and what measures would be helpful in closing the gap for supplying modern energy services to those rural areas that are likely to remain remote from the grid.

Liberia's Saint Paul River holds significant hydropower resources.

Liberia's Projected Electricity Demand 2010–2040

2

In early 2010, Liberia had possibly the lowest rate of access to public electricity among all world nations. While the average rate of access to electricity in Sub-Saharan Africa is 28.5 percent—and neighboring Sierra Leone and Côte d'Ivoire have electricity access rates of 6 percent and 43.7 percent, respectively—Liberia's rate of access to publicly provided electricity is close to zero (IEA, 2008). An urban access rate can be derived only for Monrovia: of the estimated 210,619 households, 1,217 are supplied with public electricity, corresponding to 0.58 percent of the city's population. No public electricity service is available outside of Monrovia with the exception of Gbarnga City in Bong County, which has a limited municipal mini-grid based on diesel generation.

Central to any projection of future energy systems is an understanding of demand. One can usually rely on long uninterrupted time series of demand for electricity, and project these trends into the future. In Liberia the case is different. While there are time series for demand preceding the nation's civil strife, the population changed in terms of geographical distribution, number and social stratification during the war years. Further, many sectors of the economy have been completely destroyed. As a result, data from the '80s cannot be used to project demand in 2011 or beyond. Moreover, due to the extremely low volumes of publicly supplied power—which are more a reflection of existing supply constraints than actual demand—even postwar figures cannot be used as a basis for projecting actual demand.

Although a number of demand assessments have been undertaken, most of them postwar, no comprehensive assessment has been undertaken that would cover Liberia as a whole. In this section an attempt is made to provide such an assessment based on available data sources. The assessment presents demand estimates for different geographical and sector segments that are aggregated using a bottom-up approach. Where applicable, it builds on the demand analyses conducted since civil strife ended. A summary of those analyses is presented in Annex I.

While the demand in Monrovia and its surrounding areas has been studied, including by the International Finance Corporation (IFC) and Liberia Electricity Corporation (LEC), the industrial, commercial, and household sectors outside Monrovia are for the most part unknown. For purpose of this assessment we aggregate from various data sources to produce a bottom-up forecast for both Monrovia and non-Monrovia demand. In what follows we distinguish among the following geographical and sectoral demand segments:

Segment 1: Monrovia electrical on-grid demand
Segment 2: Other anticipated on-grid demand
Segment 3: Urban and rural off-grid demand
Segment 4: Non-Monrovia industrial demand

Segment 1 will be broken down in the following sectoral categories for demand: governmental/public demand,[2] commercial demand, industry demand, and residential demand. It will be forecasted based on two cornerstone existing estimates: IFC (2008) representing the low-growth scenario, and LEC (2008) representing the high-growth scenario.

Segment 2 covers residential, public, commercial, and other sectors in towns benefiting from the following two projects: (i) the West African Power Pool (WAPP) low-voltage cross-border electrification project with Côte d'Ivoire, which covers Nimba, Grand Gedeh, and Maryland county in eastern Liberia; and (ii) the WAPP Côte d'Ivoire, Liberia, Sierra Leone, and Guinea (CLSG) transmission interconnection, which will enable access to power through four substations planned in Yekepa, Buchanan, Mt. Coffee/Monrovia, and Mano.

Segment 3 covers residential, commercial, public, and other sectors for those parts of the population that are not covered under segments 1 and 2. Segment 4 covers non-Monrovia-based industrial demand, including the mining (iron ore, gold), agriculture (rubber, oil palm, food production), and forestry (saw mills) sectors. In terms of urban areas it includes the city of Gbarnga.

For all of these segments a high- and a low-growth scenario are evaluated. The following sections provide more detail on the data sources, methodology, and assumptions by demand segment. More details on the methods used in this demand assessment are provided in Annex II.

While most sector categories are clearly understood, the "other sectors" category requires explaining. This category essentially captures structures that cannot be readily assigned to any other category. It includes ports, airports, houses of worship, radio stations, post offices, and cell-phone towers.

Except for Monrovia, where the report relied on the data gathered by IFC (2008) and LEC (2008), demand has been estimated on the basis of Liberia's 2008 census, based on which population figures were recorded and stratified by county, county capitals, and major towns (that is, towns with a population in excess of 5,000 persons). Subsequently, population estimates were aggregated into urban and rural areas. The census provides for the number of households, which is very useful, because we can estimate that one household is equivalent to one connection on the electricity grid.

Demand was then projected to 2040 on the basis of four drivers: (i) population growth; (ii) consumption of electricity per household; (iii) increased use of electricity among those who already have access to it; and (iv) the estimated increase of the rate of access to electricity. The percentage increase employed for the population was 2.8 percent per year, which in accordance with the Human Development Report (UNDP, 2009) was Liberia's average population growth from 2005–10.

For consumption of electricity per household, we use a figure of 444 kWh/year for urban areas, including Monrovia, which was provided by IFC (2008). For rural areas annual consumption is estimated at 173 kWh/year. This estimate was derived translating the annual use of basic lighting, a radio, and a cell-phone charger into kilowatt-hours.

The increased use of electricity among those who have already access to it is forecast using a 1.5 percent rate of increase per year. In the case of Liberia this corresponds to the rate of increase of 1 in every 10 households acquiring a television set in the first five years of access to electricity.[3]

If more data were available, the demand curve would be estimated using a willingness-to-pay analysis. While in mid-2011 a willingness to pay analysis for Liberian households is underway, this analysis comes too late for this report. Therefore the rate of increase of

[2] The public demand for electricity outside of Monrovia is aggregated on the basis of a bottom-up approach considering public government buildings, street lighting, and other public structures such as ports, airports, houses of worship, radio stations, post offices, and cell-phone towers.

[3] A television consumes about 185 kWh per year. Since the estimate for Liberian households assumes basic lighting, radios, and cell-phone charging, the addition of television is both a minimal and expected increase in energy intensity in the postconflict setting.

access to electricity is used as a proxy for deriving the number of people who can afford to pay for electricity. Access to electricity here is meant broadly, as access to both public and private electricity. Access to private electricity refers to those people who use their own generators at home to produce electricity because they cannot gain access to public electricity. Put differently, they reveal their preference/demand for electricity by actually accessing it themselves. Thus, implicitly, the rate of access to (public and private) electricity is a proxy for their willingness to pay.

There is no confirmed figure of the percentage of Liberia's population with access to public and private electricity, which reflects effective demand. The only figures available were provided by the Government of Liberia (GOL) as stated in the Poverty Reduction Strategy (PRS): "less than 2 percent of rural residents and 10 percent of urban residents have access to electricity." In the absence of any other data we use this as a starting point for our demand estimate.

Further it is conservatively assumed that effective demand for electricity will catch up with the average electricity access rate of Sub-Saharan Africa in 2011 by 2030, and then exceed those standards on a linear basis thereafter. The current average access rate for Sub-Saharan Africa is 28.5 percent, with 57.5 percent electrification in urban areas and 11.9 percent in rural areas (IEA, 2008). But in urban areas it is as high as 85 percent in Ghana and 78 percent in Côte d'Ivoire. Rural electrification rates are as high as 23 percent in Ghana and 18 percent in Côte d'Ivoire.

Assumed increases in household access to electricity is summarized in Table 2.1. For urban non-Monrovia household access, the figures for 2015 coincide with the electrification goal of 30 percent set by the GOL in its National Energy Policy (NEP). The 2015 figure for Monrovian households of 20 percent is based on an estimate by the IFC (2008). By 2040 Monrovia's population, with an 80 percent access rate, is expected to have reached levels of urban electrification that are on par with Ghana's and Côte d'Ivoire's access rate in early 2010.

Demand Segment Analysis

Segment 1: Monrovia electrical on-grid demand

The demand estimate for the Monrovian electrical on-grid demand aggregates estimates from the residential, commercial, public, and industrial sectors.

For the residential sector, estimates were derived taking into account both projected population growth, the increase of energy usage among those who already have access to electricity, and increase in access rates. The IFC's (2008) estimate of current use at 444 kWh/year per household is used for Monrovia.

For the commercial, public, and industrial sectors, two demand-growth scenarios are considered: a low- and high-growth scenario. These are based on forecasts provided by the IFC (2008) and LEC (2008), respectively.

Table 2.1 | Assumptions of Households' Increase in Electricity Access

	Percentage of Households with Access to Electricity						
	2010	2015	2020	2025	2030	2035	2040
Monrovia households	10	20	32	44	56	68	80
Urban non-Monrovia households (on-grid)	5	30	38	46	54	62	70
Urban non-Monrovia households (off-grid)	5	30	34	38	42	46	50
Rural households	5	15	22	29	36	43	50

Source: Author's calculations.

Both forecasts are based on thorough assessments of the commercial and industrial sectors in Monrovia and therefore are suitable for the purposes of our demand forecast (for more details see Annex I).

Separate estimates for street lighting were derived for this and the following segments.[4] Street lighting is assumed to be the same for both the low- and high-growth scenarios. Public institutions and those facilities included in the other category (for example, ports, airports, and so on) in Monrovia are included in the IFC and LEC estimates, and are therefore not separated out.

Table 2.6 shows the forecasted demand for the Monrovia electrical grid under the low-growth scenario, in megawatts (MW) and gigawatt-hours (GWh), and Table 2.7 shows the forecasted demand under the high-growth scenario.

Segment 2: Other anticipated on-grid demand

There are two key projects currently under way that promise to provide electricity to towns outside of Monrovia: the WAPP low-voltage cross-border electrification program, and the West African Power Pool Côte d'Ivoire, Liberia, Sierra Leone, and Guinea (WAPP CLSG) transmission interconnection.

- *WAPP low-voltage cross-border electrification program.* The low-voltage interconnections with Côte d'Ivoire's distribution network will benefit the counties of Nimba, Grand Gedeh, and Maryland in eastern Liberia. In Nimba, Sanniquellie, the county capital, will be connected, along with the towns of Logouato, Saclepea, Duoplay, Karnplay, and Ganta. In Grand Gedeh, the capital, Zwedru, will be connected, along with Toe Town, Blodiala, Zleh Town, and Tapeta. In Maryland, the capital, Harper, will be connected, along with Rock Town, Plebo, Fish Town, Fish Town City, Cavalla Town, Cavalla Rubber Concession, Kablaken, and Whole Graway.
- *WAPP CLSG transmission interconnection.* This project will interconnect Liberia, Guinea, Sierra Leone, and Côte d'Ivoire. From Côte d'Ivoire the transmission line will enter through Yekepa in the north, and will provide power to Yekepa. It will continue to Buchanan on the coast of Grand Bassa County, and then extend west near Monrovia, through the prewar hydropower plant at Mt. Coffee. From there it will cross through Bomi and Grand Cape Mount counties to Mano on the border, and then into Sierra Leone. The main load centers benefiting from the WAPP transmission line will therefore be where the transmission lines' substations are located in Yekepa, Buchanan, Mano, and Monrovia.
- The demand assessment for the non-Monrovia on-grid scenario includes a low- and high-growth scenario for the commercial sector, which is modeled based on the same range as Monrovia's commercial sector. This segment also includes the "other sectors" category. The low- and high-growth scenarios are shown in Tables 2.6 and 2.7 (in MW and GWh).

Segment 3: Urban and rural off-grid demand

The remaining off-grid areas include those counties and county capitals that will not gain access to a

[4] Currently no estimates are available for street lighting for Monrovia or Liberia's other urban centers. Therefore estimates for electricity usage from streetlights were derived. According to the Poverty Reduction Strategy (PRS), Liberia has 9,917 kilometers (km) of road, 734 km of which are paved; 100 km of paved roads are in Monrovia. The GOL has pledged to pave 241 km of roads in the county capitals during the PRS period. Based on these amounts, the study assumed that 341 km of paved county capital and Monrovia roads could be lined by streetlights by 2040. In addition, we assume an additional 50 km of paved roads in large non-county-capital urban centers such as Ganta.

Based on the assumption that one streetlight illuminates an area of 50 square meters, 143 streetlights would need to be installed per kilometer. Because many of these will not be grid connected in the near or medium term, the streetlight power demand estimate was based on the use of solar LED streetlights—currently the most efficient and cost-effective option. Such streetlights consume 17 watts of power per hour of use. Assuming 12 hours of operation per day, the total demand would be 4.15 GWh/year for all of Liberia. Street lighting for Monrovia is considered to be on-grid. One-third of the street lighting for county capitals and other large towns is considered on-grid and the remainder off-grid.

grid through the two above-mentioned WAPP projects. These areas include both urban centers and rural areas. They also include parts of Montserrado County that are just outside of Monrovia. Tables 2.6 and 2.7 show the estimated demand for segment 3 for both low- and high-growth scenarios.

Segment 4: Non-Monrovia industrial demand

The non-Monrovia industry scenario includes the following sectors: mining, agriculture, and forestry.

Mining. Liberia has considerable low-grade iron ore reserves remaining at the sites of the abandoned prewar iron ore mines. Deposits have also been found at Wologisi, Putu Range, Bea Mountains, and Goe Fantro, which have not yet been developed. Liberia's remaining reserves are estimated at almost 3 billion tonnes. The main deposits are found in the Western Cluster, Bong Range, Lofa County (Wologisi), Nimba County, and Grand Gedeh (Putu Range).

Table 2.2 shows the name and size of iron ore mining concessions under discussion. An assessment of the potential energy demand is derived based on the assumption that an expected production volume of 15 to 20 million tonnes per annum will need about 100 MW of power. The lifetime of the mines is assumed to be 25 to 30 years, which fits within the time frame of the analysis.

The estimate for the gold mines is based on information provided by AmLib, which is undertaking feasibility analysis in Bong County. There are also many small mining licenses under discussion that cover a range of minerals. Altogether, the potential mining demand is estimated to be 842 MW.

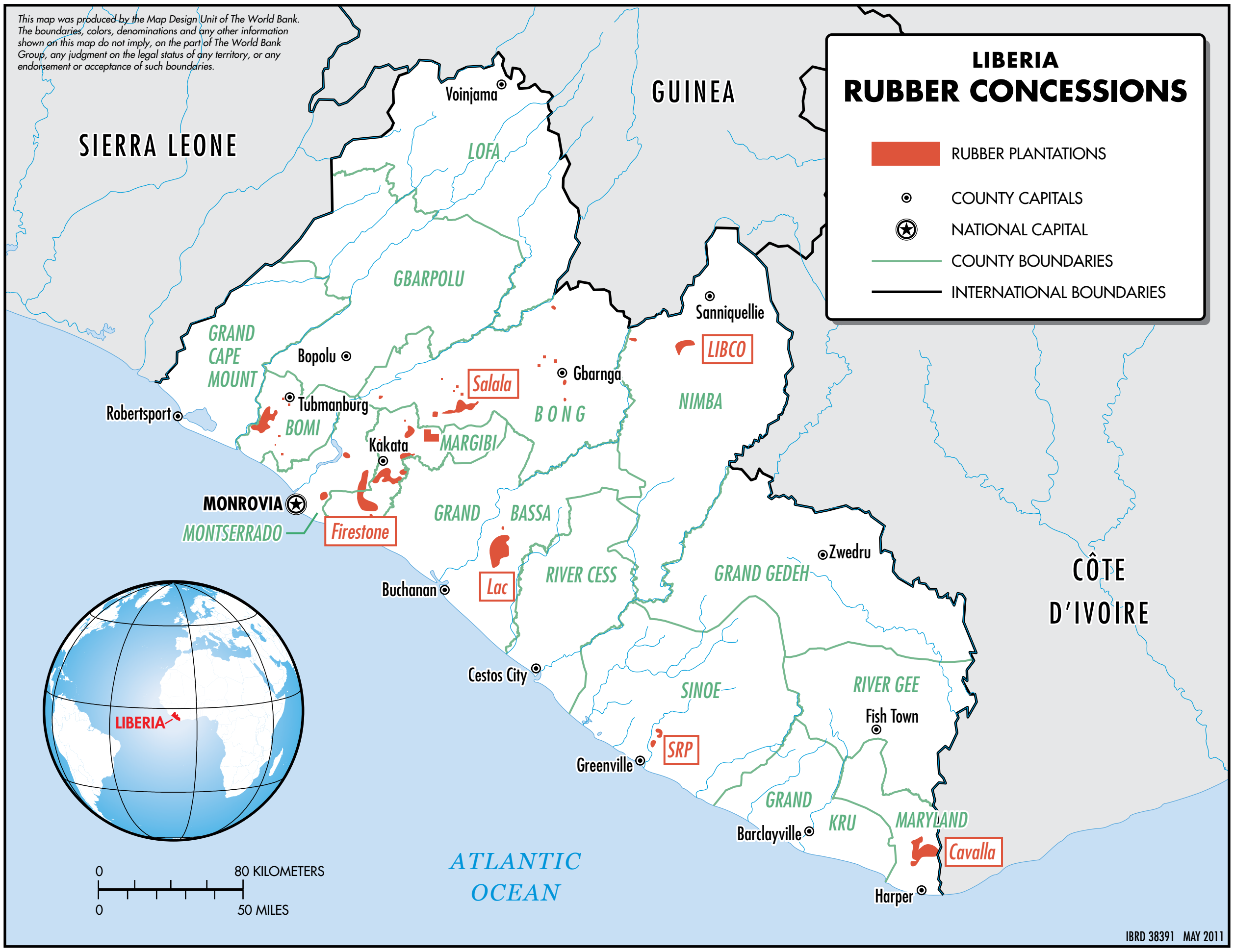
The potential demand estimate considers two scenarios to be forecast: low and high growth. Both scenarios

Table 2.2 | Estimated Energy Demand for Iron Ore and other Mining

Mine Type and Name	County	Production Volume (tonnes/annum)	Estimated Demand (MW)
Iron Ore			
Western Cluster	Cape Mount, Bomi, Gbarpolu (could be on-grid)	15,000,000	100
Putu Range	Grand Gedeh	20,000,000	100
Kitoma and Goe Fantro	Nimba	15,000,000	100
Nimba	Nimba	20,000,000	100
Wologisi	Lofa	20,000,000	100
Arcelor Mittal	Yekepa (could be on-grid)	15,000,000	132
China Union, Bong Mines	Bong (could be on-grid)	15,000,000	100
Gold			
Bea Mountain/New Liberty	Nimba	Gold	5
Cestos	River Cess	Gold	5
20 potential locations for gold, gems, and other minerals (that is, barite)	Various	Various	100
Total			**842**

Source: Author's calculations.

Figure 2.1 | Liberia's Rubber Concessions



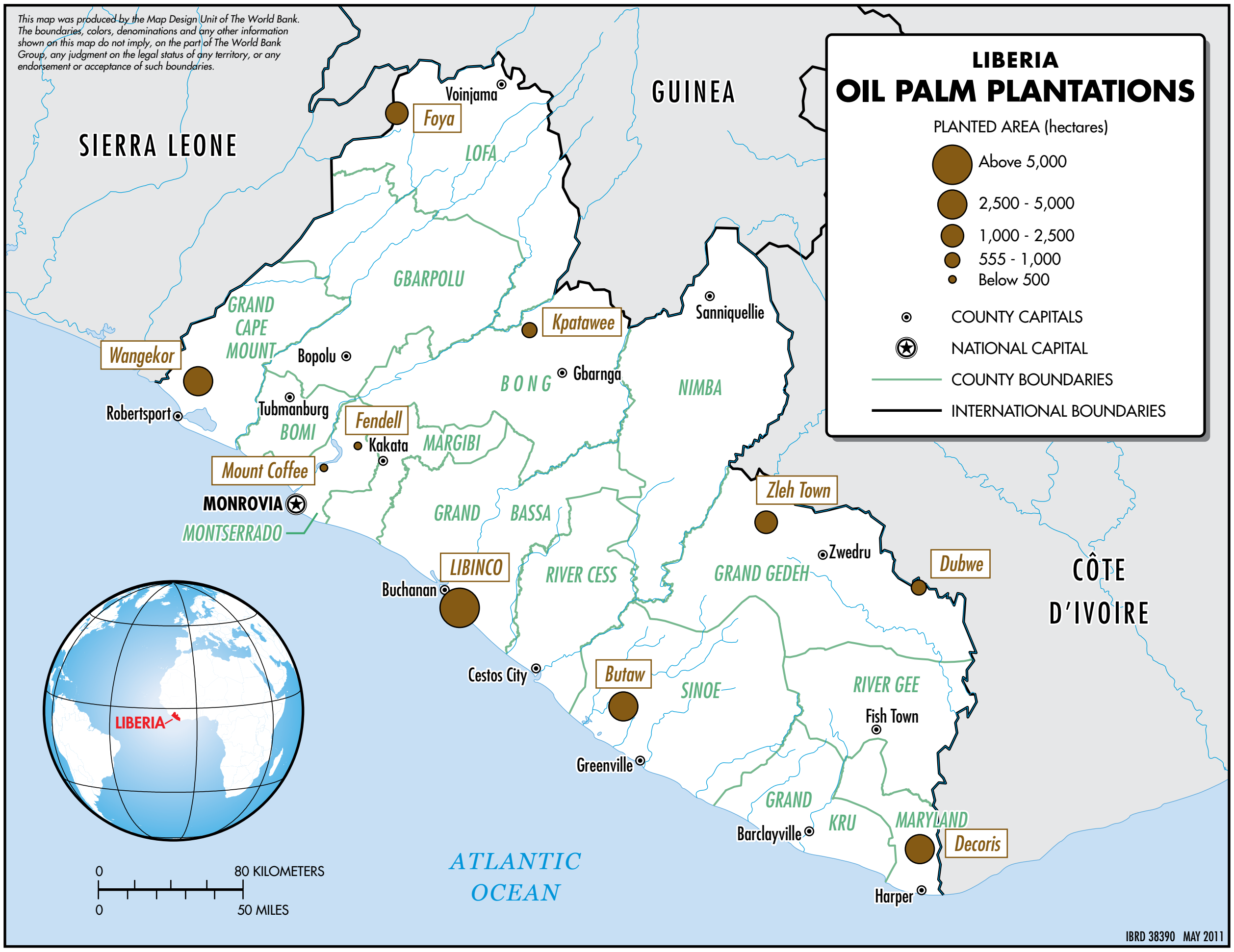
Source: Milbrandt, 2009; World Bank Map Unit, 2011.

assume a starting demand of 10 MW off-grid for 2010, based on the actual operations of ArcelorMittal. The conservative-growth scenario assumes that half of the potential demand is relaized by 2040; the high-growth scenario assumes that the full potential demand is practicable by 2040. The mines at Yekepa, Bong Mines, and the Western Cluster are considered potential on-grid locations, but neither estimate assumes the full load from those mines will be on grid by 2040.

Agriculture. Rubber concessions, oil palm concessions, and other agricultural farming operations such as for rice, cassava, and coffee are accounted for under this sector. Liberia's land is dominated by forest in the west and east, while the middle parts of Liberia, particularly through the Bong and Nimba corridor, are dominated by cropland.

In early 2010 seven rubber concessions were in operation in Liberia (Figure 2.1), ranging from about 2,200 to 25,000 hectares, and covering an area of approximately 58,000 hectares in total (Milbrandt, 2009). Firestone, with 25,000 hectares, has a current energy demand of about 4.8 MW, which is supplied by a 4 MW hydropower plant on the Margibi plantation, along with additional supply from diesel generation. Firestone also practices load shedding, especially during the dry season when the production from

Figure 2.2 | Liberia's Oil Palm Concessions



Source: Milbrandt, 2009; World Bank Map Unit, 2011.

Firestone's hydropower plant is reduced to about 1 MW. Based on the known production volume of Firestone and a few other concessions, and the energy demand of Firestone, an estimated demand of about 30 MW is assumed to be the potential demand from the rubber sector, which is assumed to be reached by 2040 with a gradual increase from the current 5 MW.

As shown in Figure 2.2, Liberia has 10 oil palm concessions, of which most are not operating. Equatorial Palm Oil (EPO) in mid-2011 was rehabilitating its concessions in Grand Bassa and Sinoe counties, and had a tentative plan to produce crude palm oil at the Grand Bassa location. EPO estimates based on prewar operations and current operations elsewhere, that a 5-ton oil mill requires between 750 kW and 1 MW of power. For lack of data, this study assumes that the eventual potential of the oil palm sector is 10 MW, allowing one mill per current concession by 2040. For the near-term forecast only EPO's plans are accounted for.

Most of Liberia's agricultural activities are carried out by small farmers, but the production of some crops is significant, as shown in Table 2.3. Not much information, however, exists on the potential energy needs of such operations. Currently almost all agricultural production is done by hand, with some small farmers utilizing diesel-powered rice mills in rural areas, and one large

Table 2.3 | Liberia's Agricultural Production

Commodity	Production Volume (tonnes)
Rice	110,000
Coffee (green)	3,200
Cassava	490,000
Other root and tuber crops	64,500
Groundnuts	4,800
Maize	15,000
Cacao (beans)	3,000
Oil palm (fruit)	183,000
Coconuts	81,000
Bananas and plantains	152,000
Sugarcane	255,000

Source: Milbrandt, 2009.

rice production project recently instigated in Lofa County with donor support.

Due to lack of information regarding the power needs of these agricultural activities (rice, cassava, coffee, cacao, and other farming and associated milling activities), the study assumes the agricultural load to be approximately half the load of oil-palm-processing activities, resulting in 5 MW by 2040.

It is assumed that the majority of the agricultural demand will be off-grid due to its distance from the interconnected grid that will be constructed. One-fifth of agricultural demand is assumed to be on-grid post-2015 (Table 2.4).

Forestry. Liberia has significant forest cover. As shown in Figure 2.3, a large share of Liberia's forest cover is available for logging under forest management contracts and timber sales contracts. In 2009, 13 logging contracts were active or pending in Liberia, with a total of over 1 million hectares, as shown in Table 2.5 (Milbrandt, 2009). Prior to the war, there were 70 logging companies operating in Liberia, but at present only a few logging companies are active. Immediately prior to the civil conflict, however, there were 22 sawmills operating in Liberia. Because data on current operations is not known, this assessment takes the prewar sawmilling activities as the potential energy demand from the forestry sector in Liberia.

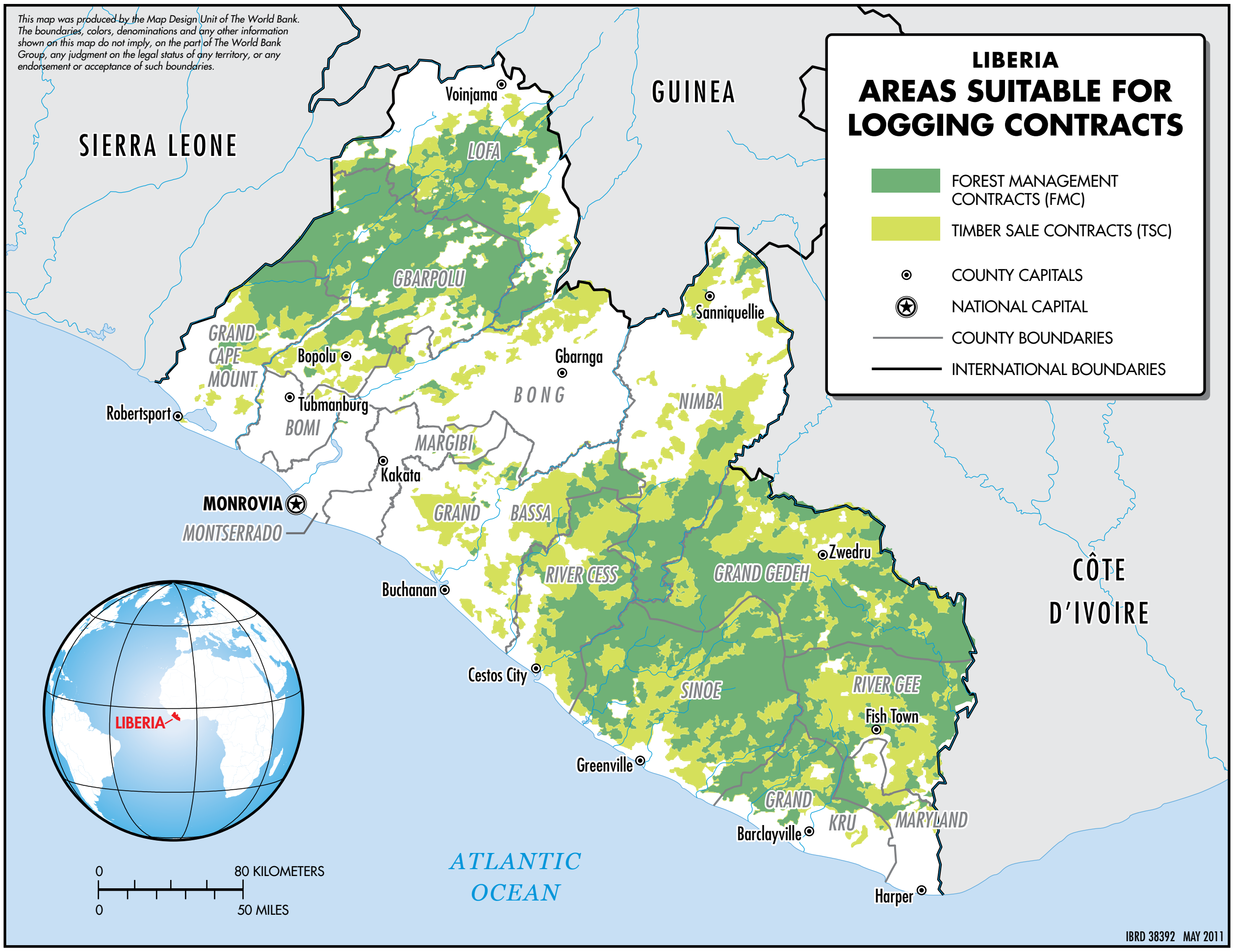
An average mid-sized sawmill has an output of 1,300 cubic meters (m^3) of logs per day, which would equal 474,500 m^3 per year for one sawmill. If all 22 prewar sawmills were producing at this rate, the output would have equaled over 10 million m^3 per year. A study conducted by TechnoServe (2008) that investigated sawmilling opportunities in Liberia estimates that energy use in sawmills varies from 97 to 1,304 kWh per cubic meter of timber production. Kiln drying has the biggest effect on this variation, and most kiln-drying techniques in Liberia have historically been conventional, based on combustion of wood. Therefore, the assessment is at the low end of the potential range. Assuming that all 22 sawmills operational prior to the war were to become operational again, and assuming they were mid-sized sawmills, the potential

Table 2.4 | Aggregated Electricity Demand from Agriculture

Sector	Estimated Energy Demand (MW)				
Year	**2010**	**2015**	**2020**	**2030**	**2040**
Rubber	5	8	15	20	30
Oil palm	1	2	3	6	10
Food agriculture	0	1	2	4	5
Total	**6**	**11**	**20**	**30**	**45**

Source: Author's calculations.

Figure 2.3 | Areas Considered Suitable for Logging Concessions



Source: Milbrandt, 2009; World Bank Map Unit, 2011.

eventual demand for power would be about 116 MW. The demand assessment assumes that this demand level of 116 MW will be reached in 2040 but that due to the location of logging contracts, very few would be on-grid. The assumption is that one-fifth of the area will eventually be grid accessible. Given current logging activities and the expected timeline of grid expansion, the near- and medium-term demand for logging is expected to be low.

But it should be noted that Liberia's timber resources are located largely in the southeast, including in areas that will benefit from the low-voltage interconnection with Côte d'Ivoire's distribution network under the auspices of the WAPP in the near term. Though the feasibility study for the interconnection did not include logging activities in its demand profile, the potential for near-term demand from the sector in these on-grid areas should be considered.

Tables 2.6 and 2.7 show the demand estimate for both the low- and high-growth scenarios for this segment. Only mining is assumed to be subject to different growth rates across the two scenarios. As previously described, a portion of these sectors is assumed to be grid accessible in the medium to long term. Therefore, each scenario includes an on-grid and off-grid estimate.

Table 2.5 | Logging Contracts in Liberia

County	Ownership	Area (hectares)
Gbarpolu and Lofa	Alpha Logging and Wood Processing, Inc.	119,240
River Cess	EJ and J Investment Corporation	57,262
River Cess	Liberia Tree and Trade Company	59,374
Grand Gedeh and River Gee	Pending	253,670
Grand Gedeh and Sinoe	Pending	131,466
Nimba, Grand Gedeh and River Cess	Pending	266,910
Grand Kru, Maryland and River Gee	Pending	119,344
Grand Bassa	Tarpeh Timber Corporation, Inc.	5,000
Grand Bassa	Tarpeh Timber Corporation, Inc.	5,000
Bong and Gbarpolu	B&V Timber Company, Inc.	5,000
Gbarpolu	Bargor & Bargor Enterprise, Inc.	5,000
Grand Cape Mount	B&V Timber Company, Inc.	5,000
Grand Cape Mount	B&V Timber Company, Inc.	5,000
Total		**1,037,266**

Source: Milbrandt, 2009.

Tables 2.6 and 2.7 also display the aggregate demand across all sectors. Under the low-growth scenario, total demand is expected to increase from 36.51 MW in 2010 to 740.02 MW. Under the high-growth scenario, total demand is expected to increase from 37.79 MW to 1,519.62 MW, which is double the demand in the lower-growth scenario. This indicates that demand estimates are sensitive to the underlying assumptions.

Over the time period of the modeling exercise, which spans 30 years, it is remarkable that a significant share of the demand may not be readily met through the interconnected grid due to the remote location of this demand. In the low-growth scenario about 60 percent of the 2040 demand is in areas that are considered off-grid, while in the high-growth scenario about 55 percent of the total demand is considered off-grid. Future studies will no doubt better assess whether it is not economical to connect at least some of the industrial load centers to the grid.

In absolute terms, the overall demand increase still appears modest. For example, countries such as Benin and Togo, which have about double Liberia's population, in mid-2011 have a level of power peak load that corresponds to Liberia's peak load under the slow-growth scenario in 2040.

Table 2.6 | Total Estimated Electricity Demand in Liberia, 2010–40, Slow Growth Scenario

Liberia Electricity Demand (MW) Slow Growth	2010	2015	2020	2030	2040
Monrovia Electrical Grid	**18.66**	**34.30**	**41.98**	**63.15**	**127.28**
Household	1.13	2.43	4.19	8.51	14.11
Commercial and public	3.60	6.50	10.00	15.97	36.45
Industrial	13.90	25.30	27.70	38.50	76.45
Street lighting	0.03	0.07	0.09	0.16	0.27
Other On-grid (WAPP, Côte d'Ivoire Interconnection)	**0.37**	**1.70**	**2.51**	**5.00**	**9.54**
Household	0.13	0.81	1.11	1.83	2.76
Commercial	0.04	0.61	0.93	2.13	4.86
Public	0.10	0.08	0.15	0.36	0.77
Street lighting	0.03	0.07	0.09	0.16	0.27
Other (ports, airports, cell towers, radio stations, post, churches)	0.07	0.13	0.22	0.51	0.89
Urban and Rural Off-grid	**0.98**	**4.84**	**7.26**	**14.61**	**27.62**
Household	0.54	2.36	3.29	5.58	8.50
Commercial	0.08	1.37	2.10	4.79	10.93
Public	0.17	0.76	1.23	2.76	5.54
Street lighting	0.01	0.04	0.09	0.21	0.42
Other (ports, airports, cell towers, radio stations, post, churches)	0.18	0.32	0.55	1.28	2.22
Non-Monrovia Industrial: Off-grid	**16.50**	**71.00**	**191.00**	**324.00**	**443.47**
Mining	10.00	50.00	150.00	250.00	315.00
Agriculture (rubber, oil palm, food production)	6.00	11.00	16.00	24.00	36.00
Forestry	0.50	10.00	25.00	50.00	92.47
Non-Monrovia Industrial: Potential On-grid	**0.00**	**0.00**	**59.00**	**91.00**	**132.12**
Mining	0.00	0.00	50.00	75.00	100.00
Agriculture (rubber, oil palm, food production)	0.00	0.00	4.00	6.00	9.00
Forestry	0.00	0.00	5.00	10.00	23.12
Total On-grid	***19.02***	***36.00***	***103.49***	***159.15***	***268.93***
Total Off-grid	***17.48***	***75.84***	***198.26***	***338.61***	***471.09***
Total eEectricity Demand	**36.51**	**111.84**	**301.75**	**497.76**	**740.02**
Liberia Electricity Demand (GWh) Slow-Growth Scenario	**2010**	**2015**	**2020**	**2030**	**2040**
Monrovia Electrical Grid	**117.46**	**216.89**	**268.70**	**553.18**	**1,114.95**
Household	9.88	21.29	36.70	74.54	123.58
Commercial and public	22.08	39.86	61.32	139.93	319.30
Industrial	85.23	155.14	169.86	337.27	669.69
Street lighting	0.27	0.60	0.82	1.45	2.38

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Table 2.6 | Total Estimated Electricity Demand in Liberia, 2010–40, Slow Growth Scenario *(continued)*

Liberia Electricity Demand (GWh) Slow-Growth Scenario	2010	2015	2020	2030	2040
Other on-grid (WAPP, Côte d'Ivoire Interconnection)	**2.98**	**14.46**	**21.51**	**43.29**	**82.99**
Household	1.10	7.13	9.73	16.04	24.14
Commercial	0.37	5.31	8.18	18.66	42.57
Public	0.85	0.73	1.30	3.19	6.70
Street lighting	0.04	0.18	0.37	0.94	1.82
Other (ports, airports, cell towers, radio stations, post, churches)	0.61	1.10	1.93	4.46	7.76
Urban and Rural Off-grid	**8.62**	**42.41**	**63.62**	**128.02**	**241.91**
Household	4.77	20.66	28.86	48.84	74.48
Commercial	0.74	11.96	18.40	41.98	95.79
Public	1.50	6.68	10.78	24.15	48.57
Street lighting	0.09	0.36	0.75	1.88	3.64
Other (ports, airports, cell towers, radio stations, post, churches)	1.54	2.76	4.83	11.17	19.42
Non-Monrovia Industrial: Off-grid	**101.18**	**435.37**	**1,171.21**	**1,986.77**	**2,719.38**
Mining	61.32	306.60	919.80	1533.00	1931.58
Agriculture (rubber, oil palm, food production)	36.79	67.45	98.11	147.17	220.75
Forestry	3.07	61.32	153.30	306.60	567.05
Non-Monrovia Industrial: Potential on-grid	**0.00**	**0.00**	**361.79**	**558.01**	**810.15**
Mining	0.00	0.00	306.60	459.90	613.20
Agriculture (rubber, oil palm, food production)	0.00	0.00	24.53	36.79	55.19
Forestry	0.00	0.00	30.66	61.32	141.76
Total On-grid	***120.44***	***231.35***	***652.00***	***1,154.48***	***2,008.09***
Total Off-grid	***109.80***	***477.79***	***1,234.83***	***2,114.79***	***2,961.29***
Total Electricity Demand (GWh)	**230.24**	**709.13**	**1,886.83**	**3,269.27**	**4,969.37**

Source: Author's calculations.

Table 2.7 | Total Estimated Demand for Liberia, 2010–40, High-Growth Scenario

Liberia Electricity Demand (MW) High Growth	2010	2015	2020	2030	2040
Monrovia Electrical Grid	**19.66**	**54.50**	**75.58**	**149.99**	**417.78**
Household	1.13	2.43	4.19	8.51	14.11
Commercial and public	12.50	31.40	38.20	69.36	179.89
Industrial	6.00	20.60	33.10	71.96	223.50
Street lighting	0.03	0.07	0.09	0.16	0.27
Other On-grid (WAPP, Côte d'Ivoire Interconnection)	**0.44**	**3.97**	**5.09**	**12.06**	**28.60**
Household	0.13	0.81	1.11	1.83	2.76
Commercial	0.15	2.93	3.57	9.25	23.99
Public	0.10	0.08	0.15	0.36	0.77
Street lighting	0.00	0.02	0.04	0.11	0.21
Other (ports, airports, cell towers, radio stations, post, churches)	0.07	0.13	0.22	0.51	0.89
Urban and Rural Off-grid	**1.19**	**10.07**	**13.18**	**30.63**	**70.65**
Household	0.54	2.36	3.29	5.58	8.50
Commercial	0.29	6.59	8.02	20.81	53.97
Public	0.17	0.76	1.23	2.76	5.54
Street lighting	0.01	0.04	0.09	0.21	0.42
Other (ports, airports, cell towers, radio stations, post, churches)	0.18	0.32	0.55	1.28	2.22
Non-Monrovia Industrial: Off-grid	**16.50**	**121.00**	**341.00**	**574.00**	**770.47**
Mining	10.00	100.00	300.00	500.00	642.00
Agriculture (rubber, oil palm, food production)	6.00	11.00	16.00	24.00	36.00
Forestry	0.50	10.00	25.00	50.00	92.47
Non-Monrovia Industrial: Potential On-grid	**0.00**	**50.00**	**109.00**	**216.00**	**232.12**
Mining	0.00	50.00	100.00	200.00	200.00
Agriculture (rubber, oil palm, food production)	0.00	0.00	4.00	6.00	9.00
Forestry	0.00	0.00	5.00	10.00	23.12
Total On-grid	***20.10***	***108.47***	***189.67***	***378.05***	***678.50***
Total Off-grid	***17.69***	***131.07***	***354.18***	***604.63***	***841.12***
Total Electricity Demand (MW)	**37.79**	**239.54**	**543.86**	**982.68**	**1,519.62**
Liberia Electricity Demand (GWh) High-Growth Scenario	**2010**	**2015**	**2020**	**2030**	**2040**
Monrovia Electrical Grid	**123.59**	**340.75**	**474.74**	**1,313.94**	**3,659.73**
Household	9.88	21.29	36.70	74.54	123.58
Commercial and public	76.65	192.54	234.24	607.56	1,575.87
Industrial	36.79	126.32	202.97	630.39	1,957.90
Street lighting	0.27	0.60	0.82	1.45	2.38

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Table 2.7 | Total Estimated Demand for Liberia, 2010–40, High-Growth Scenario *(continued)*

Liberia Electricity Demand (GWh) High-Growth Scenario	2010	2015	2020	2030	2040
Other On-grid (WAPP, Côte d'Ivoire Interconnection)	**3.89**	**34.82**	**44.56**	**105.64**	**250.53**
Household	1.10	7.13	9.73	16.04	24.14
Commercial	1.28	25.67	31.23	81.01	210.12
Public	0.85	0.73	1.30	3.19	6.70
Street lighting	0.04	0.18	0.37	0.94	1.82
Other (ports, airports, cell towers, radio stations, post, churches)	0.61	1.10	1.93	4.46	7.76
Urban and Rural Off-grid	**10.44**	**88.22**	**115.50**	**268.31**	**618.88**
Household	4.77	20.66	28.86	48.84	74.48
Commercial	2.56	57.76	70.27	182.27	472.76
Public	1.50	6.68	10.78	24.15	48.57
Street lighting	0.09	0.36	0.75	1.88	3.64
Other (ports, airports, cell towers, radio stations, post, churches)	1.54	2.76	4.83	11.17	19.42
Non-Monrovia Industrial: Off-grid	**101.18**	**741.97**	**2,091.01**	**3,519.77**	**4,724.54**
Mining	61.32	613.20	1,839.60	3,066.00	3,936.74
Agriculture (rubber, oil palm, food production)	36.79	67.45	98.11	147.17	220.75
Forestry	3.07	61.32	153.30	306.60	567.05
Non-Monrovia Industrial: Potential On-grid	**0.00**	**306.60**	**668.39**	**1,324.51**	**1,423.35**
Mining	0.00	306.60	613.20	1,226.40	1,226.40
Agriculture (rubber, oil palm, food production)	0.00	0.00	24.53	36.79	55.19
Forestry	0.00	0.00	30.66	61.32	141.76
Total On-grid	***127.48***	***682.17***	***1,187.69***	***2,744.10***	***5,333.61***
Total Off-grid	***111.62***	***830.19***	***2,206.51***	***3,788.08***	***5,343.42***
Total Electricity Demand (GWh)	**239.10**	**1,512.36**	**3,394.20**	**6,532.17**	**10,677.03**

Source: Author's calculations.

Liberia's Energy Supply Options 2010–2040

3

As Liberia's energy sector develops, the GOL needs to consider the options available to it for meeting the population's demand for modern energy services in a sustainable manner. While the debate in recent years has focused on meeting Liberia's short-term power supply needs, in this chapter we will review options that are available to Liberia for the medium and long term, as well as the capacity to feed into an interconnected grid. We consider the time period until 2015 the medium term, and until 2040 the long term. In general, the selected supply alternatives presented here are based on potential or actual projects that have been previously analyzed in feasibility studies, and that in principle appear feasible in Liberia. Further below, we will use the generic supply data presented in this section to project least-cost supply-side development paths for Liberia.

Diesel Generation

The existing generation system in the base year for our analysis–2010—is composed of high-speed diesel generation units with an installed capacity of 9.7 MW. The system was implemented in two phases through the Emergency Power Program. An additional capacity of 3 MW has been put in place in early 2011 and financed by the Norwegian Agency for Development Cooperation (NORAD). Diesel generation was the most immediately available option for Liberia, especially given that heavy fuel oil (HFO) cannot currently be delivered. Liberia's power utility, the LEC, is expected to maintain diesel as the principle source of power supply during the short term to respond to immediate electricity needs while other supply options are developed. The generation cost of producing electricity with these diesel units is high, at US$0.32/kWh, due to high fuel costs and the small size and decentralized structure of the system, which prevents the units from being fully dispatched.

General experience in Africa shows that the costs of temporary diesel power generation units typically range between US$0.20 and $0.30/kWh (Foster and Briçeno-Garmendia, 2009). In the case of Liberia, any additional capacity expansion for diesel generation is likely to provide power at lower costs than the system currently installed for the following reasons: (i) the implementation of a management contract is expected to substantially improve the LEC's operational performance; and (ii) the improved dispatch of the diesel generation units will follow an increase in load. For the modeling exercise, the generation cost is conservatively estimated at US$0.29/kWh, and no capacity constraint is given for any additional capacity based on diesel generation.

Leasing Diesel Generation

Numerous countries in Africa have responded to the power crises experienced over the past several years by leasing power plants to avert the social and economic impacts engendered by frequent and persisting power blackouts and load shedding. Postconflict requirements for emergency power, supply-constrained systems, unanticipated shortages of generation capacity, weather-related damage to existing facilities, and droughts (resulting in diminished hydropower production) have forced power utilities to lease diesel generation on a temporary basis.

Emergency power supply, through a leasing contract, temporarily helps power utilities to stabilize their systems to cope with unanticipated shortages of supply capacity in the short term. The leasing units are commonly in place within 6 to 12 months, taking into account the process of procurement, mobilization, and interconnection to the electricity power network. Most of the emergency supply alternatives are based on diesel generators (sometimes with the option to run on HFO). Electricity prices vary widely depending on commercial agreements.

Procurement of leased power is commonly undertaken in emergency situations and leads, in many cases, to significant financial consequences for the electricity utilities. First, these utilities' lack of capacity and limited experience in emergency procurement—and the short time horizons within which they require power—have frequently led to unfavorable commercial agreements involving above-market rates for the emergency power procured. Second, an emergency crisis often induces partial or full suspension of normal procurement procedures, leaving more opportunity for the mishandling of funds. Third, high variable costs impose higher cash flow requirements to ensure the running of leased generation units. Therefore, leasing emergency generation is not advisable for periods in excess of two years, since, for longer periods, the fixed costs can usually cover the costs of procuring equipment on a permanent basis.

For the purposes of our modeling exercise, Uganda's recent experience was taken into account. In 2003–06 Uganda suffered serious power shortages due to delays in developing additional generation capacity, drought in the region, and significant technical losses in the distribution system. The World Bank supported an emergency power supply program based on leasing diesel generation units of 50 MW. For the purpose of this analysis, a fuel price escalation was applied since the Uganda project was developed in 2006.[5] The generation cost is therefore assumed at US$0.27/kWh (2009).

Environmental Considerations

Among the different supply options, diesel generators are arguably the most problematic in terms of environmental consequences, mainly due to the limited possibility of mitigating potential impacts. The main problems of diesel combustion are noise and air pollution. Diesel generators release particulate matter and exhaust gases, which are often associated with an increase in morbidity relating to respiratory diseases among local populations. In addition, diesel generators produce large amounts of greenhouse gas emissions that contribute to global warming. The environmental risks associated with diesel generators also include potential leaking from storage tanks and the consequent contamination of land and waterways, which may last well after decommissioning unless proper mitigating and cleaning measures are put in place. Social impacts may include potential resettlement of communities living on or near a plant's construction site and loss of access to land. But in Monrovia, site(s) for the setting up of a few futher diesel generators are available. The design of proper environmental and social management plans help ensure that these mitigating measures are identified early in project design.

Heavy-Fuel-Oil-Fired Generation

HFO-fired generation is also commonly used for emergency power situations or as base load power. HFO-fired generation units generally reduce fuel costs by about 50 percent when compared with diesel fuel. We have benchmarked HFO power plant costs using data from the literature and from a recently finalized HFO-fired generation independent power producer (IPP) in Sub-Saharan Africa. We use an estimate for the average generation cost based on HFO of US$0.16/kWh.

[5] In 2006 oil prices were US$57 per barrel. In January 2010 the oil price stood at US$75.2/per barrel. The leasing generation cost in Uganda was about US$0.23/kWh in 2006.

In mid-2011 HFO can neither be landed nor stored in Liberia. Before the war, HFO was imported and handled by the Liberian Petroleum Refinery Corporation (LPRC) at the product storage terminal (PST) close to the Free Port of Monrovia. As a result of the war, the facilities were destroyed and partly dismantled and now require rehabilitation and expansion work. Part II of this report will discuss the issue of fuel supply in more detail.

Environmental Considerations

HFO-fired power plants share most of the environmental risks associated with those that use fossil fuels. The most problematic issue is air pollution. Similar to diesel generators, HFO-fired power plants emit greenhouse and by-product gases and particulate matter, which cause climate change and potentially harm to the health of local communities. In addition, waste management should be carefully considered in the design, construction, operation, and decommissioning of such plants. Environmental risks associated with HFO-fired power also include potential spills during transportation and storage of the fuel. In general, however, there is a large spectrum of mitigating measures that may be put in place to significantly reduce the potential impacts of HFO-fired power plants. Social impacts may include potential resettlement of communities living on or near a plant's construction site and loss of access to land. But in Monrovia, the site for the potential construction of an HFO-fired power plant and associated facilities is already devoted to industrial use and resettlement is not envisaged. The design of proper environmental and social management plans help ensure that these mitigating measures are identified early in project design.

Biomass Power Generation

Another option for providing power to Liberia's grid is through the combustion of biomass energy. In Milbrandt (2009) Liberia's biomass resources and their potential for power generation and as fuel for transportation have been analyzed. The study estimated that if only 10 percent of the available cropland were dedicated to oil palm, coconut, or sugarcane, 27,452 GWh could be generated for electricity consumption. Liberia has a significant agriculture potential, estimated at 3.7 million hectares of arable land, which represent 38 percent of the total land area. Also, according to independent reports (Aah-Kee, 2009; Krishnan, 2009), a scoping study has identified five sites for rubber plantations, with a power generation potential to support 80 MW of biomass-fired power, which represent around 2,500 hectares of rubber trees per year. But the economic and financial feasibility of biomass power options depends on the type of technology used, the size of the power plant, and the transportation cost of the fuel (Wiltsee, 2000).

In terms of technology, there are two main options for combustion boilers: pile-burner-utilizing stationary or travelling grate combustors, and fluidized-bed combustors. For size, a biomass-steam electric power plant from 30 to 100 MW is recommended (ESMAP, 2007). The impact of fuel transportation costs on the feasibility of a power plant becomes significant at distances greater than 32 km, and usually becomes restrictive beyond the 160–320 km range (Wiltsee, 2000). For the purpose of the long-term least-cost expansion model, three potential biomass power plant scenarios were considered, of which two were retained as modeling options. Further analysis of the adequacy and supply security of the main feed stocks would be needed to evaluate the power production potential. Some feed stocks require a long rotation period to harvest and replant. For example, in the case of rubber plantations, rotation periods of 25–30 years are needed.

Core Biomass Power Plant Scenario

Under this scenario we assume that the plant would, at full dispatch, result in a tariff of US$0.185/kWh, fixed for 3 years, which could subsequently escalate to US$0.225/kWh over 25 years. The unit capital costs of the project are assumed to be US$4,167 per megawatt installed, with an installed capacity of 31 MW. Construction of a biomass plant is estimated to take between 30 and 36 months. As the least-cost simulation is based on 5-year steps from 2010, the model allows for commissioning the biomass plant in the period 2015 to 2040.

The biomass project would provide a less expensive generation option than the existing high-speed diesel generation units, and the electricity production cost would be less dependent on fuel price fluctuations. Under this scenario biomass is priced conservatively.

Benchmark Biomass Power Plant Scenario

Two independent studies commissioned by the NORAD and the United States Agency for International Development (USAID) indicate that based on international experience the price per kilowatt-hour of biomass plants could be as low as half the price of the proposed core biomass scenario (Aah-Kee, 2009; Krishnan, 2009). In these studies, typical unit capital costs for biomass-fired power plants are quoted as between US$1,600–$2,400/MW (Aah-Kee, 2009; ESMAP 2007).[6] All cost estimates provided by the Energy Sector Management Assistance Program (ESMAP) study were developed for a single reference location in India with the purpose of avoiding any site-specific discrepancies when comparing technologies. A conservative approach was taken into account for this indicative planning. Thus, an upper-bound capital unit cost of US$2,419 per installed megawatt and an installed capacity of 31 MW were assumed. We use this as an alternate biomass scenario for the project discussed above.

Biomass Power Generation Benchmarking Based on Wood Chips in International Markets

This scenario assumes that biomass power generation in Liberia is not restricted by the availability of local fuel resources and that wood chips can be imported. But fuel availability is contingent on wood chip prices in international markets. Aah-Kee (2009) prices costs for affordable wood chips at US$35 to US$39 per ton from the United States, using a U.S. port. When adding transportation costs, the price at the Monrovia port would be around US$95 per ton. This price is higher than the price range for domestic biomass, which has been quoted as US$37–US$60 per ton, and which is assumed for the core biomass scenario. The actual market price in Liberia could be even lower than this. Therefore, this possible scenario was not considered.

Environmental Considerations

Managing the environmental and social impacts associated with biomass projects is not trivial. For example, a 36 MW biomass project will need around 380,000 tonnes of wood chips per year, requiring the harvesting of about 910 hectares of rubber trees per year. Therefore, postharvest operations to rehabilitate the land and to replant new rubber trees are essential to avoid the risks associated with logging operations, which can lead to soil erosion. However, if biomass is grown sustainably, the greenhouse gas balance of biomass-fired power plant could be neutral.

Hydropower Generation

Historic studies, conducted over the period 1976 to 1983, have assessed Liberia's hydropower resources for both large and small hydropower plants (Norconsult, 2008). Recent studies do not exist, and there is a great need to update the findings from these earlier studies and to evaluate data and data measurement for Liberia's hydrology to confirm the earlier findings, especially for those sites where no hydropower plants were built. The historic studies indicate that Liberia is endowed with significant hydrological resources. Due to the absence of elevated hinterland, the preferred technological option for large-scale hydropower would be run-of-river plants. Run-of-river hydropower plants are typically built on rivers with a consistent and steady flow that is either natural or maintained by an upstream reservoir that serves to compensate for seasonal fluctuations. Liberia's hydrological resources for power generation

[6] Aah-Kee (2009) refers to six projects implemented in Brazil, Chile, Guyana, India, Mali, Mauritius, and Uganda. The ESMAP (2007) report gives US$1,700/MW as the reference value. Detailed cost estimates for the biomass-steam electric power plant in India were: a levelized capital cost of US$2.59/kWh, a fixed operation and maintenance (O&M) cost of US$0.45/kWh, a variable O&M cost of US$0.41/kWh, and a fuel cost of US$2.50/kWh.

Powerhouse of Mount Coffee Hydropower plant in July 2010.

View of St. Paul River from the powerhouse of Mount Coffee hydropower plant in July 2010.

vary greatly between the wet season (July to November) and the dry season (December to June). Thus, proposals for a hydropower plant for Liberia include a combination of dams and storage in upstream reservoirs. For the purpose of the least-cost expansion model, we are considering three potential scenarios for the build-up of hydropower potential in Liberia.

The Mt. Coffee hydropower plant was the only large-scale hydropower plant constructed before the war, and was conveniently located on the Saint Paul River approximately 27 km northeast of Monrovia. The plant was commissioned in 1966 with an installed capacity of 30 MW, and its capacity was increased to 64 MW in 1972. This plant was the main source of power supply in Liberia, and was managed by the LEC. Because of the seasonal fluctuations of the Saint Paul River, however, the plant could only supply about 5 MW of electric capacity during the dry season. Under civil unrest, the plant was shut down and the pool gradually rose until August 1990, when the Forebay Dam 1 was breached, rendering the power plant inoperable. Since 1990 the powerhouse and substation of Mt. Coffee have been looted, and the hydropower plant is in need of full reconstruction.

In 2008 the U.S. Trade and Development Agency (USTDA) commissioned a study by Stanley Consultants, the firm that developed the original design of Mt. Coffee, to assess the technical feasibility of the reconstruction of the Mt. Coffee hydropower plant and the construction of a storage reservoir near the confluence of the Via and Saint Paul rivers. For Mt. Coffee, the study recommended the installation of four Francis turbines, with an individual capacity of 16.5 MW, into the existing turbine pits, and the reconstruction of the powerhouse, intake structure, and substation. The idea of the proposed reservoir was to increase the availability of the plant and to offset the impacts of the dry season. The study also reviewed the hydropower development potential upstream of the Saint Paul River to identify opportunities for exporting power to the proposed regional WAPP CLSG interconnection transmission line.

For modeling purposes, one supply scenario envisages a reconstructed Mt. Coffee hydropower plant operating at prewar levels with a total installed capacity of 66 MW. On its own, Mt. Coffee is estimated to generate a minimum annual energy production of 255 GWh, a maximum annual energy production of 425 GWh, and an average annual production of 342 GWh. The estimated cost of electricity generation is US$0.11/kWh (Stanley Consultants, 2008). For the purpose of modeling, it is assumed that the plant will be operational in 2015. It is more realistic to assume that Mt. Coffee will be available from 2016, but the model allows for 5-year intervals only. Moreover, Mt. Coffee's low cost of electricity generation relative to other operations in Liberia, its proximity to Monrovia, Liberia's main load center, its favorable geology, and the low environmental and social impacts expected indicate that this project is a suitable candidate for meeting Liberia's demand in the long term (Ciampitti, 2009).

Mt. Coffee Hydropower Plant and Construction of Via Reservoir

Since the hydrological conditions of the Saint Paul River vary by season, several alternatives have been analyzed to offset this high seasonal variability. As indicated, the construction of a new storage reservoir near the confluence of the Via and Saint Paul rivers was analyzed as a second phase (Stanley Consultants, 2008). The construction of the Via Reservoir is designed to support electricity production with better distribution across the wet and dry seasons. As a result of the Via reservoir construction, the Mt. Coffee power plant supply would increase its average energy production from 342 GWh/year to 435 GWh/year.

The optimum location for the Via storage project is approximately 3.5 km upstream of the confluence of the Via and Saint Paul rivers and about 150 km north of Monrovia, where it would maximize the storage potential of the reservoir while minimizing the earthen embankment sections. This location would require an in-depth analysis to assess the potential impact on the environment and the people affected, which is likely to be complex.

The parallel construction of the Mt. Coffee hydropower plant and the Via reservoir is considered as a long-term alternative to rebuilding the Mt. Coffee hydropower plant alone. When compared with only rebuilding the plant, the unit capital investment costs increase by about 57 percent and the plant availability increases by about 25 percent.

Saint Paul River Hydropower Development

Stanley Consultants suggest a sequential implementation of two hydropower projects along the Saint Paul River. The first plant is Saint Paul-2 (SP-2), which is located 60 km downstream of the Via storage project, and would provide an estimated annual average energy production of 1,330 GWh assuming the Via reservoir is constructed. The second plant is Saint Paul-1B (SP-1B), located 40 km downstream of SP-2. SP-1B would provide an estimated annual average energy production of 630 GWh, assuming the Via reservoir is constructed.

Given the project's complexity and the need for further research, it is assumed that these power plants will be constructed post-2015. For the purpose of the least-cost expansion plan this means that they are available options in the power mix from 2020, as the model is in 5-year steps. To consider this option we assume that the SP-1B, SP-2, and Via reservoir are built and operated jointly, as is shown in Table 3.1. The costs and energy gains associated with the Via reservoir are thus imbedded in the SP1-B and SP2.

Mano Hydropower Plant

This plant would be located on the Mano River, which delineates the border between Liberia and Sierra Leone. Its construction would require high levels

Table 3.1 | Potential Availability of Hydropower in Liberia and Timeline for Earliest Plant Commissioning

	Mt. Coffee	SP-1B	SP-2	Mano	Total Cumulative Hydropower Capacity
2015	66 MW	—	—	—	66 MW
2020	—	78 MW	120 MW	—	264 MW
2025	—	—	—	50 MW	314 MW

Source: Ciampitti, F.; Stanley Consultants; Main; and Geoscience.

of coordination between both countries and could conceivably be developed under the auspices of the WAPP. Several studies indicate that hydropower generation can be economically attractive, although the lack of transmission interconnection has been the main deterrent for its development. But once the proposed WAPP CLSG interconnection transmission line has been built, the site can be directly connected to the grid.

Analyses regarding the optimal level of installed capacity vary from 37 MW to 143 MW, suggesting the need for further study of this hydropower option. To be consistent with the feasibility study for the WAPP CLSG regional transmission line, it is assumed that the optimal installed capacity for the Mano River is 90 MW, with an annual average energy production of 397 GWh. As this is a cross-border hydropower power plant, it is further assumed that of the 90 MW a maximum of 50 MW would be available to Liberia, with the remainder being available to Sierra Leone.

Environmental Considerations

Several factors influence the potential environmental and social impacts of hydropower projects that are highly site specific. Characteristics affecting these impacts include the size of the dam, the size of the associated power plant, and the presence of a reservoir. But independent from the characteristics of the specific project, the main gain in terms of the environment is the total absence of air pollution. Environmental impacts may include changes in river ecosystems, erosion patterns, river flows, and vegetation clearings. When a reservoir is needed, hydropower projects may often cause the inundation of portions of land, which include wildlife habitats, farmland, forests, cultural heritage monuments, and villages. Hydropower has also some inherently benign features, which include the lack of air pollution such as by-product gases or particulate matter. Greenhouse gas emissions are limited to methane and vary with the size and type of the plant's reservoir. In general, it is fundamental to manage the potential impacts early in the project cycle by designing proper environmental and social management plans and a resettlement action plan. Further due diligence such as advisory expert panels are commonly also required.

West African Power Pool Transmission Interconnection for Côte d'Ivoire, Liberia, Sierra Leone, and Guinea (WAPP CLSG)

The goal of the WAPP is to establish a well-functioning, cooperative power-pooling mechanism for West Africa as a means of increasing access to stable and reliable electricity at affordable costs to the citizens of the Economic Community of West African States (ECOWAS). To reach this goal, the WAPP is promoting regional priority projects. Among these is the transmission line interconnection between Côte d'Ivoire, Liberia, Sierra Leone, and Guinea, (CLSG). The objective of this project is to provide access to least-cost (hydro) power options for the subregion and to enable the pooling of power resources across these four countries. Project preparation is well advanced, with feasibility and environmental studies in draft form. The World Bank, European Investment Bank, African Development Bank, Kreditanstalt fuer Wiederaufbau, and ECOWAS Bank have all indicated their interest in financing this transmission line. The main obstacle remaining is the establishment of a special purpose company that would own and operate the transmission line on behalf of the four countries.

The WAPP CLSG project is proposed as a regional transmission line of 220 kilovolts (kV) double circuit with a power capacity of 300 MW. To avoid the implementation of an oversized solution and to reduce the initial investment costs, a two-stage implementation plan has been adopted. In the first phase, a single circuit will be strung with a power transmission capacity of 150 MW by 2015. In the second phase an additional circuit providing a total power transmission capacity of 300 MW will be strung in 2020.

The implementation arrangements are being studied and indicate two main phases for generation supplied through the transmission line. First, energy surplus from Côte d'Ivoire will supply the CLSG transmission line in 2015 at an expected cost of US$0.17/kWh.

Second, hydropower potential in Guinea is foreseen to be developed to the point that an energy surplus will supply the WAPP CLSG with an expected generating cost of US$0.11/kWh after 2020. These two alternatives are explored in the indicative plan with sensitivity scenarios for power capacity available for Liberia through the CLSG transmission line.

Because of the significant uncertainties related to the pricing of electricity on the WAPP CLSG transmission line and the availability of power to Liberia, the least-cost modeling includes a number of sensitivity analyses. Power availability can be divided into two phases depending on how much power can be supplied from the neighboring countries to Liberia, as is shown in Table 3.2. A conservative scenario implies that only 28 MW would be available for the Liberia power system in 2015. The capacity would increase over time and reach a maximum of 50 MW by 2020, when the transmission line is strung with double circuits. An optimistic scenario would set initial capacity of 50 MW in 2015, which would increase to a maximum of 97 MW available from 2020.

Transmission and Distribution Beyond the WAPP CLSG Transmission Line

As stated earlier, Liberia's transmission and distribution network has to be reconstructed to ensure that power can be adequately distributed to potential customers. A basic system is expected to be built for Monrovia under the leadership of LEC's management contractor. Donor financing of US$50 million has been identified for the construction of a distribution network and the connection of about 33,000 new customers up until 2015. Beyond 2015, more transmission and distribution investments become necessary. For the sake of simplicity, these investments have not been considered in this report. A benchmarking analysis indicates that the investments requirements for transmission are in the order of US$15/MWh.

Environmental Considerations

Transmission lines have limited environmental and social impacts that are often transitory. The main issues are related to the resettlement of local communities living within the right of way, the clearing of vegetation, the optimization of line routing to avoid protected areas and cultural heritage monuments, aesthetic impacts, and the potential leaking of chemical products used in electrical equipment. The proper design and implementation of mitigating measures early in the project cycle would easily ensure the minimization of such impacts. In addition, a large environmental benefit of transmission lines is a reduction in greenhouse gas emissions due to the optimization of power generation along an interconnected network, which allows for a reduction in the use of the most polluting supply options.

Costing of Supply Options

Investment and operational costs for different generation technologies are based on international references and benchmarking of projects implemented

Table 3.2 I WAPP CLSG Pricing and Capacity Scenarios

Scenarios	2015	2020–40
Estimated cost	Energy surplus from Côte d'Ivoire mainly based on gas-fired power plants Estimated energy price: US$0.17/kWh	Energy surplus from Guinea based on hydropower development Estimated energy price: US$0.11/kWh
Low capacity available for Liberia	27.6 MW (total: 83 MW)	50.6 MW (total: 152 MW)
High capacity available for Liberia	50 MW (total: 150 MW)	96.7 MW (total: 290 MW)

Source: AETS-SOGREAH, 2009.

Table 3.3 | Power Supply Alternatives and Cost Estimates for Liberia

Power Source	Expected Earliest Possible Commissioning Date	MW Capacity	Capital Cost (US$ Million)	Unit Cost (US$/kW)	Expected Availability (%)	Total Variable Cost (fuel + O&M) (US$/kWh)	Total Levelized Cost (US$/kWh)
Diesel (existing system)	2010	13	12	934	70	0.28	0.32
Diesel (learning curve)	2012	1	1	934	70	0.26	0.29
Diesel (leasing)	2010	10	24	2,388	80	0.24	0.27
HFO	2012	10	15	1,470	80	0.12	0.16
Biomass	2012	36	150	4,167	85	0.08	0.21
Biomass benchmarking	2012	31	75	2,419	85	0.06	0.11
WAPP phase 1 Low	2015	28	160	1,659	85	0.15	0.17
WAPP phase 2 Low	2020	23	160	1,659	85	0.09	0.11
WAPP phase 1 High	2015	50	160	1,659	85	0.15	0.17
WAPP phase 2 High	2020	47	160	1,659	85	0.09	0.11
Hydro 1: Mt. Coffee phase 1	2015	66	162	2,455	59	0.01	0.10
Hydro 2: Mt. Coffee + Via Reservoir	2020	66	383	5,803	75	0.01	—
Hydro 4: SP-1B + SP-2 + Via Reservoir	2020	198	879	4,438	75	0.01	16–23 (11)
Hydro 3: Mano River	2025	90	257	2,856	50	0.01	16–23 (10)

Source: Based on Geoscience (1998); Ciampitti (2009); Stanley Consultants (2008); ESMAP (2007); and personal communications.
Note: — Not available.

in Africa. This assessment does not model technological change over the period analyzed but it does assume ongoing improvements in operational performance. The latter corresponds to an operational learning curve and to the ability of the system to dispatch the supply alternatives under normal conditions (and without any load shedding) as the demand increases. This assumption leads to an operational cost reduction. The supply alternatives were computed on the basis of capital investment cost, variable generating and fuel costs, maximum net power, and plant availability. Table 3.3 summarizes all supply options and their associated cost considered in this report.

An argument could be made that this report does not consider significant power supply options for Liberia's future such as a liquid natural gas (LNG) power plant, on-grid wind power, or on-grid solar photovoltaics. The reason for this is that, to date, there has been no analysis undertaken as to whether these options could be sensibly deployed in Liberia. Using them as part of a possible power mix even for a scenario post-2030 would therefore amount to mere speculation. Certainly further work is needed to explore supply options beyond the ones that have been analyzed here.

Wroto town, Monrovia.

Petroleum Fuel Supply for Power Generation

4

Key energy supply options depend on the availability of reasonably priced petroleum fuels in sufficient quantities. In this chapter we analyze the availability of petroleum fuels in Liberia with a focus on power generation.

Upstream Petroleum Sector

There are no known hydrocarbon reserves in Liberia. Potential petroleum resources have, however, been identified in small sedimentary basins onshore and in the extension of this sedimentary sequence offshore. Exploration for hydrocarbons offshore first took place in the early 1970s and ended in 1985 when the seventh and last offshore well was drilled. No further exploration was carried out until 2000–01, when the TGS-NOPEC Geophysical Company of Norway acquired approximately 9,500 km of new geophysical data. It is this database that forms the foundation for the exploration of offshore Liberia in mid-2011.

Downstream Petroleum Product Supply and Consumption

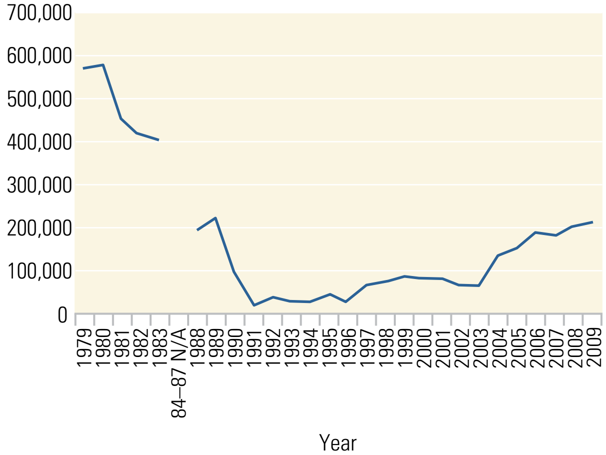
The most important factor determining Liberia's petroleum consumption pattern is the performance of the mining sector, which accounted for about 49 percent of petroleum demand in 1983. The 30 percent decline in petroleum product consumption since 1980–83 was due mainly to reduced iron ore production.

Until 1982 petroleum products were produced at the government's refinery in Monrovia under the management of its wholly owned Liberia Petroleum and Refinery Company (LPRC). The refinery was closed at the beginning of 1983 due to the LPRC's inability to make major payments for crude oil. Subsequently the GOL decided not to reopen the refinery because further evaluation indicated that it was cheaper to import petroleum products than to refine them locally. But LPRC staff had little experience in product procurement and frequently bought too late and paid above-market rates.

From 1990 through mid-2003 the country's demand diminished almost to the point of collapse due to ongoing conflict. After 2003 demand picked up, but the economy and attendant oil product consumption are still a long way from complete recovery. Figure 4.1 shows the official import/consumption figures from preconflict years through the first two years of the civil war.[7] It shows total oil product consumption over the three historical periods since 1979. The preconflict peak and all-time high was in 1980 at some 579,000 tonnes, when the mining sector was thriving. The mining sector then declined such that preconflict, in 1989, the consumption was 226,000 tonnes. During the conflict years total

[7] Data for 1979 through 1983 were obtained from World Bank (1988). The years 1988 onward were obtained from LPRC. The four years 1984 through 1987 are missing from these data series.

Figure 4.1 | Historical Oil Product Consumption (in tonnes)



Source: World Bank, 1988 and personal communication from LPRC, 2010.
Note: Liberia's conflict period lasted from about 1989 to 2003. No data were available for the period of 1984 to 1987.

apparent[8] consumption declined to as low as 20,000 tonnes in 1991. Following the end of the conflict in mid-2003, in the "recovery" phase, total consumption increased to some 215,000 tonnes by 2009.

Most of the fuel oil was consumed in power generation by slow-speed generating units at the public utility, the LEC, or at the three mining operations that operated at the time. The LEC also consumed a significant amount of diesel-using gas turbines or high-speed diesel sets.

Sector Organization

The Ministry of Lands, Mines and Energy (MLME) controls upstream, resource-related areas such as petroleum exploration and development while the Ministry of Commerce and Industry (MCI) is the controlling ministry for downstream petroleum, including the import, storage, and distribution of oil products.

Upstream Sector Organization

In its capacity of overseeing upstream activity, the Ministry of Lands, Mines and Energy (MLME) supervises petroleum exploration and development activities through the state-owned National Oil Company of Liberia (NOCAL). The NOCAL has been charged with managing the nation's petroleum resources since 2000. It has wide-ranging powers that enable it to both manage these resources while hiring others to perform the actual exploration activities. Even though it can theoretically engage in those exploration activities itself, it has no technical or financial capacity to conduct oil exploration, especially in deep water. Figure 4.2 illustrates the Liberian offshore exploration blocks that have been delineated. Exploration commitments have been agreed on by the following companies on twelve of these blocks, as shown:

- Hong Kong Tongtai — 6, 7
- European Hydrocarbon Ltd — 8, 9
- Anadarko — 10, 15, 16, 17
- Chevron — 11, 12, 14
- Broadway Consolidated Plc — 13

In addition, a third bidding round with submissions for blocks 1, 2, 3, 4, and 5 on January 31, 2010, and bid opening February 19, 2010, resulted in bids on all the blocks.

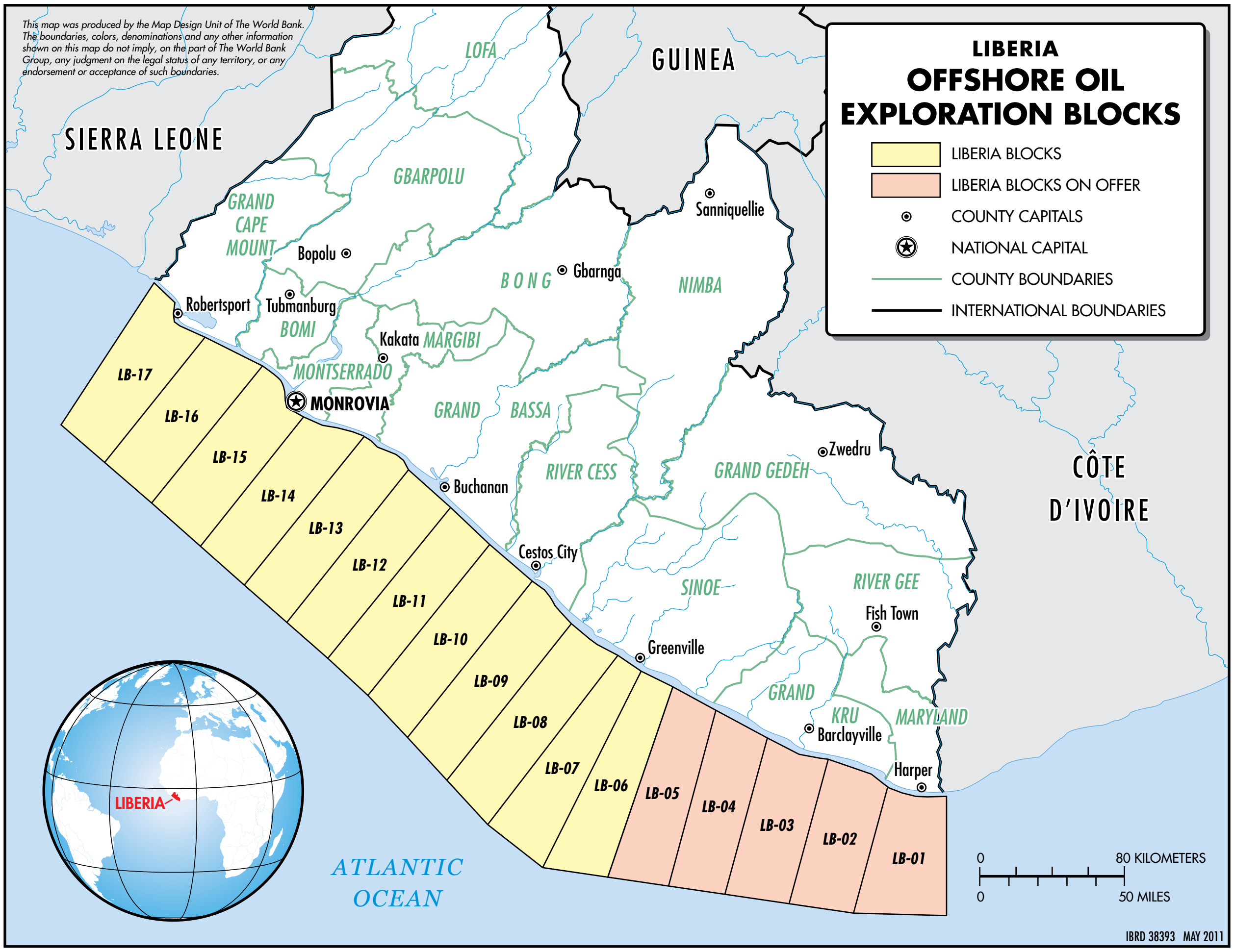
Downstream Sector Organization

In its capacity as the overseer of downstream activity, the Ministry of Commerce and Industry (MCI) registers companies and issues commercial operating licenses. The LPRC, a parastatal company, has the only legal right to import oil products into Liberia and distribute them. It is the owner and operator of the only marine receiving storage terminal for oil products in Monrovia. It does not import any products directly at the moment, nor distribute, but in early 2010 franchised its right to import to eight companies who have met the franchising criteria:

- Aminata & Sons, Inc.
- Conex Petroleum

[8] These conflict-era figures represent "supply" through formal (mostly LPRC) channels. There was undoubtedly some informal supply through other channels, but the volumes were not significant in the large picture.

Figure 4.2 | Liberia's Offshore Exploration Blocks



Source: National Oil Company of Liberia (www.nocal-lr.com); World Bank Map Unit, 2011.

- LibAfric
- Monrovia Oil Trading Corp (MOTC)
- Oando
- Srimex
- TOTAL Liberia Inc.
- Westoil Developments

The requirements that must be met by a franchisee include: (i) a capacity to import at least 3,000 tonnes per shipment and sell 7,000 tonnes per quarter, (ii) the payment of a one-time application fee of US$5,000, (iii) the payment of an annual franchise fee of US$25,000, and (iv) the maintenance of a minimum strategic stock of 500 tonnes of total products. There are some six distributors authorized by the LPRC to sell through service stations and to bulk clients in Liberia. All service stations must, by law, be owned by Liberian nationals. The MCI, in collaboration with the LPRC, also establishes regular ceiling prices for oil products.

Petroleum Market

Over the past several years—because of conflicts, disruptions, and ongoing recovery efforts—the Liberian petroleum product market has not been that of a normally functioning economy. Figure 2.3 and Table 4.1 summarize the evolution of the total import

Table 4.1 | Liberia Preconflict Oil Production Consumption (in tonnes)

Type of Fuel	1978	1980	1981	1982	1983	84–87	1988	1989	1990	1991
PMS	89,450	83,211	71,193	69,358	65,780	N/A	56,000	64,929	43,428	8,023
AGO	198,224	171,028	133,645	115,607	123,271		61,034	53,238	29,729	8,280
KEROSENE	9,174	8,349	7,064	4,771	4,954		8,000	8,048	3,242	1,673
JET A-1	42,202	30,000	26,697	26,881	27,890		21,000	45,445	15,843	
FUEL OIL	231,683	286,634	210,891	200,396	179,109		49,718	54,475	3,018	2,410
Total	**570,733**	**579,221**	**449,490**	**417,013**	**401,004**	**N/A**	**195,752**	**226,135**	**95,259**	**20,386**

Source: World Bank, 1988; and Personal communication from LPRC, 2010.

and consumption of oil products from 1979 through 2009, though data are missing for 1984–87.

Figure 4.3 provides individual product detail for this same data series. It shows some 579,000 tonnes of total consumption in 1980, the peak year preconflict, with roughly half of the consumption being HFO. This bottomed out in 1991 at some 20,000 tonnes. The Figure also illustrates the complete disappearance of HFO consumption in the absence of centrally generated power and the collapse of mining activity. The almost complete disappearance of Jet A-1 consumption during the conflict years is also highlighted.

It is interesting to note that the total consumption of two products—premium motor spirit oil (PMS) and automotive gasoil (AGO)—of some 200,000 tonnes in 2009, exceeds the immediate preconflict volumes and roughly equals the demand volumes for these fuels in the early ’80s, when the Liberian economy was strong.

Infrastructure

Monrovia’s bulk-handling infrastructure for oil products consists of an oil jetty connected by receiving lines to a product storage terminal (PST) on Bushrod Island in Monrovia. Both the LPRC PST and the refined products jetty owned by the port of Monrovia suffered from a severe lack of maintenance during the conflict years. Since the conflict ended in 2003, the LPRC has performed some basic maintenance, but both facilities have deteriorated to the extent that they are unsafe and represent a serious risk to the country’s fuel supply. Options for alternative fuel supply to Liberia in any significant volume are limited.

Oil Jetty

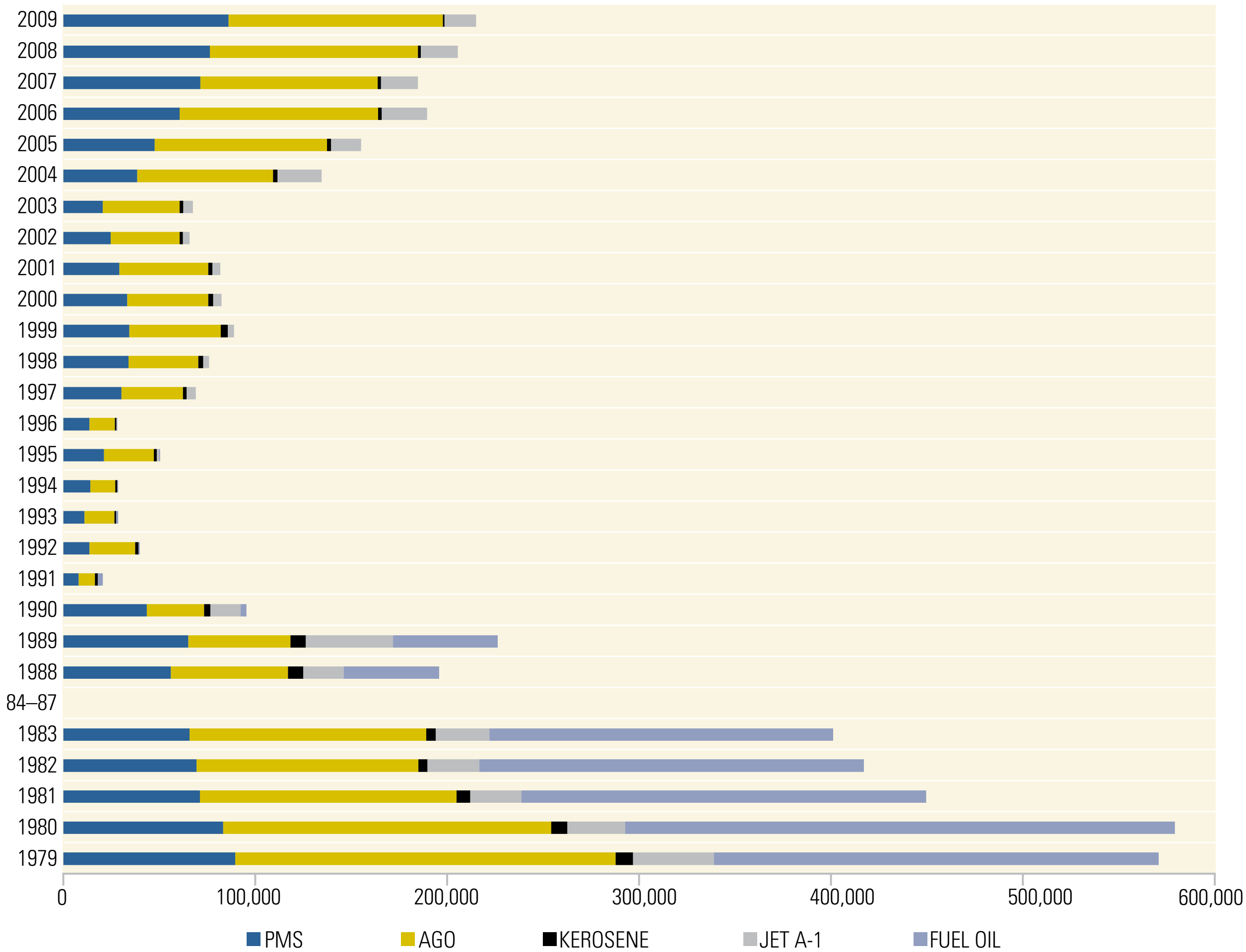
The oil jetty has the following characteristics: two mooring dolphins and an island berthing pier connected to shore by a piling causeway upon which there is a personnel access walkway and product receiving lines. The port specifications/limitations are:

- » Dead weight maximum 25, 000 MT
- » Maximum tanker length 160 meters
- » Maximum tanker width 25 meters
- » Draft 9.5 meters

There are two 8-inch receiving lines in service. One is used exclusively for jet fuel and the other for PMS and AGO. The latter is flushed with seawater between pumpings of the two different products and at the completion of tanker unloading.

The existing pipelines are corroded to the extent that operating pressures have to be reduced to prevent leakage and product losses. This results in excessive discharge delivery times, so that excessive ship demurrage costs are incurred. In addition, the pipe supports are deeply corroded while the walkway grating and railings are largely absent due to pilferage. The oil jetty is owned by Liberia’s National Port Authority (NPA) and will be replaced by a new oil jetty, which is being financed by the World Bank.

Figure 4.3 | Oil Product Import and Consumption 1979–2009 (tonnes by Product)



Source: World Bank, 1988; and Personal communication from LPRC, 2010.

Monrovia Product Storage Terminal (PST)

The storage terminal potential capacity is 16 tanks with a total capacity of some 44,000 tonnes. Although the LPRC has been engaged in a rehabilitation program since the end of the conflict, there are still several tanks out of service with bad foundations, deteriorated floors and roof plates, and multiple bullet holes. An estimate of the present serviceable capacity is given in Table 4.2. In mid-2011 no HFO can be landed.

Table 4.2 | Product Storage Terminal (PST) Capacity, September 2004

	Number of Tanks	Total Capacity, tonnes
PMS	4	10,200
Jet/kerosene	3	5,600
AGO	4	18,400
Total	**11**	**34,200**

Source: Personal communication from LPRC.
Note: PMS = premium motor spirit; AGO = automotive gas oil.

Besides the storage tanks, there are major deficiencies in all the elements necessary for the proper working of an oil storage terminal, such as:

- Supply pipelines from the jetty
- Piping networks within the terminal
- Truck-loading racks
- Environmental protection
- Fire protection
- Power generation
- Safety and security
- Product laboratory

In 2007 a detailed study of the terminal was performed. This included an estimate of the physical requirements and capital costs of the rehabilitation of the PST. It also included a product demand study to identify the additional storage capacity and other elements that will be required to meet a 2013 time horizon. The study recommended the construction of three new fuel storage tanks to increase the terminal's capacity from 45,000 to 60,000 tonnes to meet projected 2013 volumes, one new slop tank, the rehabilitation of 14 existing storage tanks, the installation of new piping throughout the terminal and along the shoreline to a new oil jetty, the construction of a water tank and installation of a sprinkler system and other fire-fighting equipment throughout the terminal, the modernizing of the loading rack, the installation of modern environmental protection systems, the installation of lighting and security surveillance equipment, and the construction and equipping of a new laboratory to test products. When completed, the terminal would comply with applicable international standards. In mid-2006 the estimated cost for these measures was US$14 million.

Crude Oil Jetty and Shore Tankage

There is another large jetty in Monrovia located on Bushrod Island. It is known as the Bong Mine pier. This very solid, impressive dock served as an ore shipment facility but also has two crude oil lines connected from the dock to a nearby tankage. The lines appear to be out of service, and the two crude oil tanks are surrounded by black oil sludge within their firewalls. Apparently they were damaged during the conflict, and oil leaked out. The three tanks have a total capacity of some 46,000 tonnes.

Main Refinery Site

There are some 50,000 tonnes of crude and product storage at the site of the former refinery near Monrovia. The tanks are not in good condition and would require extensive rehabilitation and cleaning to be returned to serviceable condition. The pipeline connecting the PST to the refinery tankage is out of service and would also require an expensive repair program to be brought back into service.

Ganta Storage Terminal

The LPRC owns a PST in Ganta near the Guinea border about 300 km northeast of Monrovia. This was built in 1989 and has 13 horizontal tanks of 1,136 barrels capacity each, for a total of 14,768 barrels, and has never been used. The tanks appear to be in reasonable working order. Supporting infrastructure such as loading racks, pumps, and electrical and other equipment has, however, been looted and vandalized. A complete detailed inspection and rehabilitation of this equipment would be required to render the PST serviceable. An investigation should be made into possible commercial exploitation of the terminal, preparatory to privatization.

Buchanan

There is a marine storage terminal on the south coast at Buchanan, previously owned by the Liminco Mining Company. The original configuration was 13 tanks with a total capacity of 218,000 barrels, but much of this was heavily damaged during the conflict.

Aviation Storage Sites

The Robertsfield International Airport, some 45 miles from Monrovia, is served by a total storage facility of some 16,000 U.S. gallons. Jet fuel is brought by road tanker from the LPRC PST from Monrovia. There is also an old U.S. military storage facility at Robertsfield. Information on the condition and capacity of this tankage was not available. TOTAL also operates an aviation fuelling facility at the small Spriggsfield airport near Monrovia, which is used by United Nations Mission in Liberia (UNMIL) helicopters and World Food Program (WFP) air services.

Liberia Electricity Corporation (LEC)

At the old LEC central power station site located on Bushrod Island, about 1.5 km north along the shore from the Bong Mines pier, there are eight storage tanks that were used for HFO and AGO service. Their capacities and services are summarized in Table 4.3. The total HFO capacity in three tanks is 37,120 barrels.

Table 4.3 | Liberia Electricity Corporation Storage Tank Capacities, Bushrod Island (barrels)

HFO	13,670
HFO	13,670
HFO	9,780
Total HFO	**37,120**
AGO	20,570
AGO	1,190
AGO	1,190
AGO	240
AGO	240
Total AGO	**23,430**

Source: Personal communication LEC, 2010.
Note: HFO = heavy fuel oil; AGO = automotive gas oil.

There also appears to be the remains of a receiving jetty on the shoreline near these tanks. It is not known what relationship this pier had to the supply of oil products to these tanks.

Supply and Procurement

Since the Monrovia oil refinery shut down in 1983 and since then all petroleum fuels for the country have been imported as finished products from the international market. The LPRC has the exclusive right to import, which it now cedes on a franchise basis to some seven importers who have met franchising criteria. The importers deal with traders on a CIF (cost, insurance, freight) basis in Monrovia, and the traders generally obtain supplies in the Gulf of Guinea area—most commonly from the Société Africaine de Raffinage (SIR) refinery (Abidjan, Côte d'Ivoire) or Société Nationale de Raffinage (SNR) refinery (Limbe, Cameroon). The Port Gentil refinery (Gabon) has also been a source for Liberia in the past.

Monrovia Oil Trading Corp (MOTC,) a Liberian company with Belgian owners, purchases through a large Belgian trading group, Belgische Olie Maatschappij N.V (BOM) which arranges the free on board (FOB) purchase through another trader (usually Addax); BOM also arranges the small tanker affreightment. MOTC takes custody on a CIF Monrovia arrangement with BOM. In 2005, for example, a cargo of 3,500 tonnes of AGO came from Limbe, Cameroon. The usual cargo size for MOTC is in the 3,000 to 5,000 ton range, arranged on a cargo-by-cargo spot basis approximately once per month. BOM supports MOTC in the opening of a letter of credit for each cargo, but there is no ownership relationship between BOM and MOTC.

West Oil, a Liberian company, purchases through TOTAL Trading on a delivered "in-tank" arrangement. They import a 5,000 to 7,000 ton mixed cargo of PMS and AGO roughly every month. Supplies have come from Limbe, Cameroon, and prior to that from SIR, Abidjan. They open a letter of credit outside Liberia, which can cost them from 3–7 percent of the cargo amount, depending on whether it is through a bank or a quasi-bank (for example, a forfaiting house). In 2005 prices paid for the delivered product were Platt's FOB Med[9] (0.2 percent S gasoil) plus US$72 per ton for AGO and Platt's FOB Med (premium unleaded) plus US$63

[9] The SPOT Reference FOB product price for the Mediterranean region as provided by the Platt's European product price assessment service on a daily basis.

per ton for PMS. Compared with the pricing in the subregion, this total CIF differential of US$60 to US$70 per ton above Platt's FOB Med is unusually high, even for these small 3,000 to 7,000 ton cargo sizes.

The Liberian importers attribute the high costs to two factors:

- The high risk premiums for Liberia charged on FOB price, marine freight, and cargo insurance. For example, cargo insurance charges of 2 percent of total CIF cargo value have been observed. Normal cargo insurance rates average about 0.15 percent. Freight premiums to compensate risk are common on all goods arriving in Liberia. Apart from perceived security risks, the deteriorated condition of the receiving terminal and lack of acceptable international safety standards contributes to risk premiums.
- An extremely tight market for oil products prevails in the Gulf of Guinea region at the moment. It appears that high Nigerian demand combined with a nonperforming refining sector in Nigeria has caused the market to soak up all products in the region. For example, there is no surplus supply to be had out of the SIR refinery, Abidjan, which would be the most logical, shortest haul source for Liberia. The marine freight from Limbe, Cameroon, is more costly than that from Abidjan by some US$15 to US$20 per ton.

Product Quality and Specifications

There are no official national product specifications in Liberia. It is common for a terminal (such as the LPRC PST) with commingled, fungible products from several through-putters to establish its own specifications. The LPRC states that such standards are in place, but from a few examples it appears that ambiguities remain to be clarified:

- *Premium motor spirit (PMS).* Essentially the SIR, Abidjan, specification (that is, max. 0.013 g/l) is used, but it seems that a 0.8 g/l maximum lead content is still permitted. Most cargos received have a very low lead content or are practically unleaded. It is recommended that an unleaded criterion be clearly established (for example, maximum 0.001 grams Pb/USG per ASTM D526).
- *Automotive gas oil (AGO).* The only content-related specification is for sulfur. Specifications with both 1.0 percent maximum and 0.5 percent maximum sulfur content have been observed as the governing limits. It is recommended that the 0.5 percent be clearly established (maximum sulfur content percent with 0.5 per ASTM D1551).

Pricing and Taxation

In broad terms, a ceiling price for each product sold to wholesale and retail consumers is established in a collaborative process between the MCI and LPRC. It is roughly based on Platt's FOB Med reference price for the product at a given time plus allowances for FOB premium, freight and insurance, onshore costs such as the LPRC storage and handling, maintenance, operator margins, and applicable taxes and government levies. The structure and adjustment process lacks transparency, however, and suffers from a lack of predetermined, regular adjustment procedures. The final price is maintained at the same level through political intervention for lengthy periods, even as international prices fluctuate. Approved pump prices for products as published on the MCI website effective as of June 26, 2009 are summarized in Table 4.4.

Table 4.4 | Price Ceiling for Petroleum Products (US$/gallon, effective June 26, 2009)

	PMS	AGO	Kerosene/Jet A-1
Wholesale/distribution	3.07	2.92	2.97
Retail	3.25	3.10	3.15

Source: MCI Website.
Note: PMS = premium motor spirit; AGO = automotive gas oil.

Future of the Sector

The progress of the sector, particularly downstream, over the next few years is inexorably tied to the economic recovery now under way. The assumptions presented for downstream sector activity depend on this as well as on certain policy measures as found in Liberia's National Energy Policy (NEP). Upstream activity will depend on the results of exploration now under way on several offshore blocks.

Institutional Developments

The NEP recommends that the GOL establish the Liberia National Oil Corporation (LNOC) as the government's implementing agency for both upstream and downstream operations. The LNOC would be created from a merger of the operations of the NOCAL and LPRC and would oversee activities not transferred to the MLME or an also-recommended Energy Regulatory Board (ERB). For upstream operations, the policy of the GOL is to bring the country's investment climate in line with international best practices so that the extraction of petroleum resources will benefit all Liberians, and exploration and development will be conducted in an environment-friendly manner. The GOL, with technical and operational assistance from LNOC's upstream operations department, would establish a fully transparent and accountable process for petroleum exploration and commercial development, with regulatory oversight by the ERB.

For downstream operations, the NEP recommends that the GOL, with technical and operational assistance from LNOC's downstream operations department, support competitive private sector investment or participation in new storage depot management or ownership, port management, off-loading facilities for petroleum products, up-country storage depots, tankers moving petroleum products around the country, and construction and operation of a refinery primarily devoted to exports.

It is recommended that the GOL's involvement in the downstream sector be minimized. It is important to recognize that upstream and downstream petroleum are completely different. The upstream resource-related area requires more involvement, including some intervention in operations, while the downstream activities involving the commercial trading of commodities should be left to the private sector—but with strong oversight, regulation, and enforcement, particularly in areas of health, safety, and environmental and consumer protection.

As is common practice in most countries, the activity of receiving, storing, and shipping products at Monrovia's PST should be privatized, but with open access provisos built into legislation, such that the entry fee for import and distribution operators is minimized. The privatization exercise would be conducted, *inter alia,* with an eye toward initializing the significant investment required to bring the receiving and storage facilities up to international standards.

Any suggestion about renewed oil refining in Liberia should be treated with great caution. Small-scale refining that serves a small market exposed on the coast to international trade simply cannot compete with the import of finished products from spot markets served by large, efficient, complex refineries. Larger-scale refining involving a major export business is questionable. What advantage would Liberia have in this regard when compared with the huge refining complexes in the Mediterranean and the medium-sized plants in the West African region such as SIR, Abidjan?

Upstream Expectations

Although the geological and geophysical information on the Liberian offshore is sketchy at the moment, regional successes indicate that the future of Liberia as an oil producer may be a bright one. What actual opportunities exist should become much clearer in two or three years as results of the first exploration and drilling activities start to come in from the awarded blocks.

Downstream Developments

Based on the trend seen during the brief recovery period 2003–09 and the demands seen preconflict, it is not inconceivable that Liberia's market could reach 500,000 tonnes/year by 2015. This assumes that major components of the economy recover, such as mining, regulated timber exploitation, and rubber as well as a significant amount of centralized power generation.

As previously stated, above the jetty, the receiving pipelines and main PST in Monrovia are in a dangerously run-down condition and jeopardize the health and safety of Liberians as well as the viability of the economy as there are no reasonable alternatives for importing oil products in bulk if the jetty/PST goes down. This must be addressed. The World Bank–financed intervention to build a new oil jetty is expected to be completed by 2012.

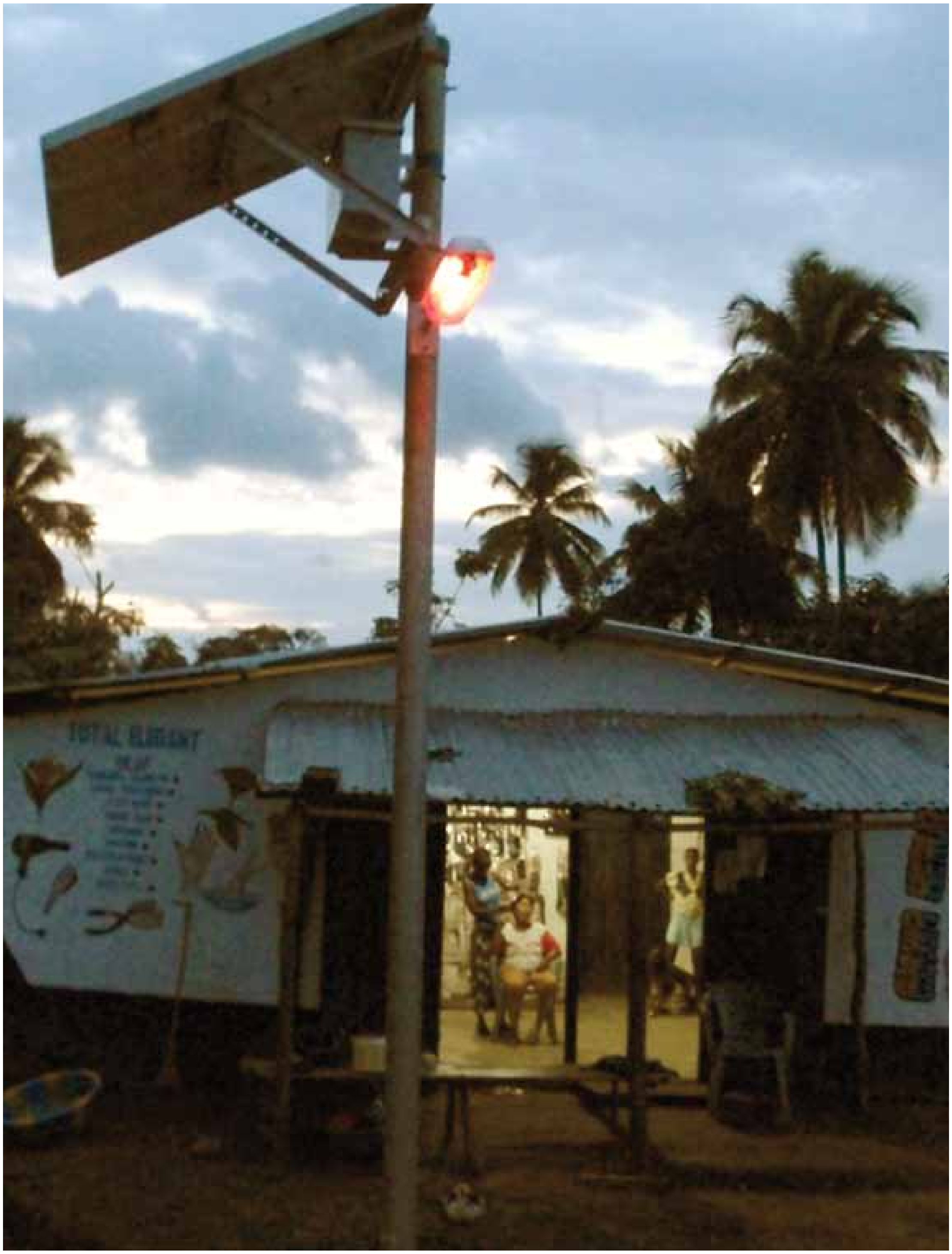
Import of Heavy Fuel Oil

Currently there is no possibility of supplying HFO to Liberia. There are several technical, commercial, and supply issues that must be resolved to make the supply of HFO and related equipment possible:

- *The grade and specifications of HFO* to be used (for example, viscosity, sulfur content, and so on). This issue relates to the utilization equipment (for example, low- or medium-speed diesel) as well as environmental emissions. It can also relate to supply economics—what is available in the region?
- *Quantity.* For example, 12 MW of power at an 80 percent load factor and 35 percent efficiency would require about 20,000 tonnes per year of HFO or about 3,300 tonnes of cargo every 2 months. The basis for such decisions would have to be defined.
- *Procurement modality.* Would there be a local agency capable of procuring HFO using international competitive bidding (ICB), say, on a yearly multicargo contract or an equivalent negotiated contract with an international supplier/trader? Or should procurement be put in the hands of a local multinational through an "all-in" supply contract to handle all the details, including scheduling, letters of credit, and possibly even some involvement in the receiving and handling of installation investment. In the latter case, the multinational would take appropriate significant margins. That said, if there is no agency to handle these decisions, they may be left to chance. Since the volumes are small, it would be difficult to justify seeking expert help in procurement.
- *Storage facilities.* There are approximately 37,000 barrels (5,700 tonnes) of old HFO tankage at the LEC site on Bushrod Island. This is sufficient for the procurement quantities mentioned above. In addition, there is more tankage at this site identified as AGO tankage. One tank in particular, with a capacity of 20,570 barrels (3,100 tonnes), could be used for HFO.
- *Receiving and transfer*. The possibility of mooring HFO vessels of appropriate size at the shoreline near LEC or further away at Bong Mine pier would have to be investigated. The appropriate receiving and transfer pipelines, with requisite controls and pumping, would have to be verified and designed (tanker pumps may be adequate for discharging to shore tanks).
- *Security for products and facilities*. Securing products against pilferage and facilities against vandalism must be a concern at the outset. The LPRC's experience has shown the high cost of looting and the difficulty of overcoming the tacit acceptance of malevolent activities that benefit far too many people (including shippers) to be easily abandoned. It is best that strict measures be imposed from the start of operations even if they seem costly and superfluous.

These comments relate to fairly modest volumes of HFO corresponding to limited central power generation facilities, say 20 to 30 thousand tonnes per year. For this purpose a feasibility study is under way, financed by the World Bank, to examine how HFO pipelines and storage could be rehabilitated. The study, to be completed in mid-2011, will consider alternatives for fuel-handling facilities and piping that will enable HFO to be supplied to a future HFO-fired power plant on Bushrod Island, Monrovia. This analysis includes technical and operational feasibility, environmental assessment and environmental management plans, rehabilitation costs, and review of the legal agreements needed for each alternative. The unloading options contemplated in this analysis are: the existing crude storage terminal (CST), the Bong Mining Company (BMC) pier, and the former crude offshore unloading facility (COUF). A combination of storage fuel facilities are also included with the consideration of the following options: two tanks in the CST and a large HFO tank in the BMC yard, both located about 1.5 km from the Bushrod power plant; existing tanks at LEC's Bushrod Island; and a new HFO tank to be constructed near the BMC-CST site in a joint venture with the LPRC.

If Liberia really wants to import HFO in preconflict volumes for both, central power generation and mining activities (around 100,000 to 200,000 tonnes per year), a much more ambitious project must be developed. Professional companies such as TOTAL or Addax would definitely have a place in such a scheme, as would perhaps mining companies with the procurement and handling expertise necessary for these import volumes.



Beauty salon in Greenville, Sinoe County, Monrovia.

Sector Financials

5

Financial Background

When generating electricity, at a minimum, costs should be fully recovered in order for the operation to remain viable. The financial situation of any power sector is therefore crucial to assess before deciding its sustainability. This chapter presents an overview of the financial situation of Liberia's energy sector just preceding the conclusion of LEC's management contract.

The LEC is responsible for the major public electricity supply throughout Liberia. It was established in July 1973 as a subsidiary of the Public Utility Authority (PUA), but became autonomous when the authority was dissolved in February 1976.

Before the civil war in Liberia (1989–2003), the LEC was in serious financial difficulties due to high nontechnical losses and poor collections. In the mid-1980s the LEC supplied energy worth US$47.4 million, but its revenue was only about half that amount (US$23.7 million). Its acute financial difficulties had five fundamental causes: (i) a lack of autonomy; (ii) the seriously depressed state of the Liberian economy; (iii) poor payment of bills by government institutions and public corporations; (iv) an extremely poor public image; and (v) a breakdown of management systems.

The fundamental challenges faced by Liberia's energy sector were never fully solved due to the civil war. To complicate matters further, almost all energy infrastructure—such as power plants, substations, and transmission lines—was damaged or destroyed during the civil war, and LEC's operations ceased.

The GOL started a program to revive the Liberian electricity sector in 2006. Subsequently LEC began to generate revenue again. The LEC's operating revenue growth has been substantial, from US$4.9 million in 2007 to US$8.8 million in 2009 as can be seen in Table 5.1.

The operating ratio, defined as the ratio of operating expenses to operating revenues, improved in 2007, but due to the increase in plant fuel costs and administration expenses, deteriorated in 2008. As can be seen in Table 5.2, cash operating expenses exceeded operating incomes in 2008 and 2009. Accordingly, operating expenses also increased to US$9.1 million in 2009 from US$4.6 million in 2007. To close the LEC's operating gap, the government contributed US$1.9 million both in 2007 and 2008, and US$2.2 million in 2009. Plant fuel costs significantly increased from 2007 to 2008 due to an increase in the fuel price. Salaries also increased marginally from 2007 to 2009.

Electricity Tariff Calculation

The electricity tariff has been set at a level to cover operating costs, including streetlights. The current tariff is based on full operation and maintenance (O&M) cost recovery with direct full cost of generation

Table 5.1 | Operating Revenues (US$ thousands)

	2007		2008		2009	
	(US$)	% of Operating Income	(US$)	% of Operating Income	(US$)	% of Operating Income
Energy Sales	2,988.60	60.3	3,859.90	65.8	6,385.50	72.3
Government Contribution	1,903.20	38.4	1,949.50	33.2	2,201.90	24.9
Prepaid Meter Sales	15	0.3	15	0.3	12.6	0.1
Power Connection Fee	18.6	0.4	6.4	0.1	66.9	0.8
Reconnection Fee	1	0.0	0.1	0.0	21.1	0.2
Sales of Fixed Assets	1.6	0.0	1.6	0.0	0	0.0
Other Income	30.5	0.6	32.5	0.6	149	1.7
Total Operating Revenues	**4,958.80**	**100**	**5,865.40**	**100**	**8,837.30**	**100**

Source: Annual reports of Liberia Electricity Corporation.

Table 5.2 | Cash Operating Expenses As a Percentage of Operating Revenues (%)

	2007	2008	2009
Plant Fuel Cost	45	70	68
Salaries	3	4	5
Maintenance Cost	7	4	6
Administration Expense	27	29	22
Other Operating Cost	11	8	3
Total Operating Costs	93	116	104

Source: Annual reports of Liberia Electricity Corporation.

passed through and applied uniformly to all customers. Since LEC is operating on a cost-recovery basis, all customers are required to prepay a month's estimated electricity usage in advance, and delinquent customers are disconnected.

Although only set at levels to cover O&M costs, the current electricity prices are high and in the range of US$0.40–US$0.50/kWh, mainly due to fuel costs. But this is lower than the cost of self-generation, which is estimated at not less than US$0.75/kWh. The GOL subsidizes the balance of the LEC's costs and is expected to continue doing so during the transition.

The retail tariffs are set by the LEC Board since Liberia does not have a regulatory agency. The methodology used to determine the retail tariff is based on revenue requirements, which are normally assessed on a quarterly basis, and consists of dividing the actual costs for a quarter by the projected sales of electricity (in kWh) for the following quarter (for example, quarterly costs/quarterly kWh). Diesel is purchased from total under three-month contracts at the full retail price set by the LPRC.

The calculation of the Liberian tariff takes into consideration the following:

» Generation cost (77 percent)—fixed cost of the equipment (10 percent of generation cost), fuel cost (80 percent of generation cost), and O&M cost (10 percent generation cost).
» Transmission and distribution cost (5 percent) under 20 percent technical and commercial losses (including theft)—US$0.02/kWh.
» LEC costs, including administration expenses (23 percent)—US$0.09/kWh (which is offset by the GOL subsidy of US$0.02/kWh for salary).
» 93 percent collections efficiency.

Table 5.3 | Evolution of the Liberia Electricity Corporation Tariff Since July 2006

Date	Tariff (cts/kWh)
July–Oct 2006	43
Nov 2006–Feb 2008	34
Mar–July 2008	43
Aug–Sept 2008	53
Oct–Nov 2008	57
Dec 2008–Apr 2009	42
May–Oct 2009	45

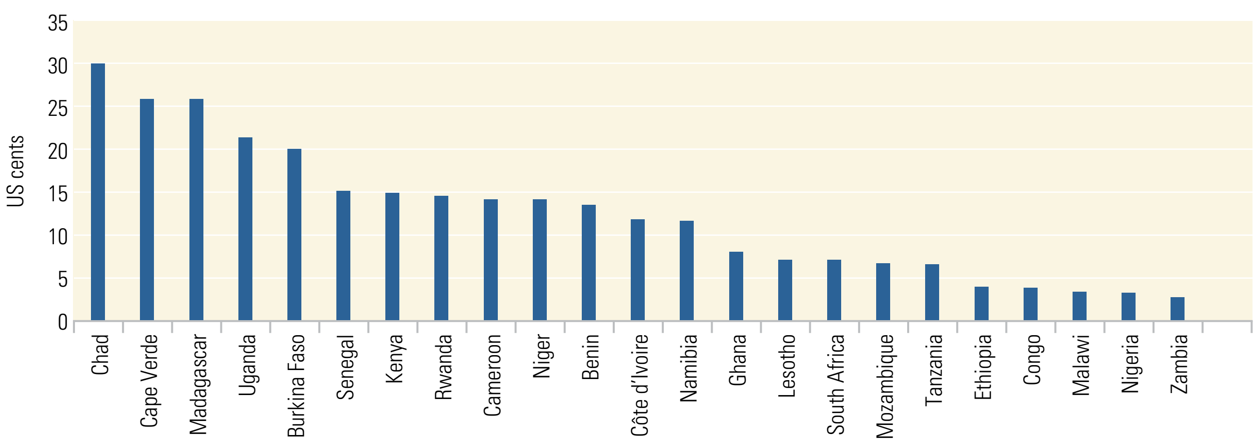
Source: Annual reports of Liberia Electricity Corporation.

Current Tariff Levels

Table 5.3 summarizes recent electricity tariffs in Liberia. Tariff levels have been kept in the range of US$0.34–0.43/kWh, but remained at high levels during the second half of 2008 in response to the rapid increases in world oil prices.

Figure 5.1 shows average tariff levels for a wide range of countries in Sub-Saharan Africa. Even the rates in Chad, Cape Verde, and Uganda—otherwise among the highest tariff levels in Sub-Saharan Africa—are below the rates charged in Liberia. For several reasons, including exchange rate distortions and differing electricity resource bases, a detailed comparison of rates would not be meaningful. Nevertheless, we conclude that Liberian power tariffs seem to be much higher than those in any other Sub-Saharan African country. This indicates that over time tariffs in Liberian business have to come down if Liberian businesses are to become competitive in the African context.

Figure 5.1 | Power Tariffs in Sub-Saharan Africa



Source: Foster and Briceño-Garmendia, 2009.

Part II

Options for the Development of Liberia's Energy Sector

Least-Cost Energy System Expansion in the Medium-Term

6

The aim of this section is to derive an optimal energy system expansion path for Liberia's supply options in the medium term, between 2010 and 2015. A potential gap between power supply and demand is expected over this period of time. Clarifying how this gap will be filled is critical to support the reconstruction of the electricity system in Monrovia in the medium term, and the entire country in the long term.

A bottom-up approach has been used to forecast the supply-demand balance for the medium term. This approach reflects the supply options currently available on the ground or envisaged to be accessible and economically viable over the next five years. The available options include: (i) diesel generation—existing system; (ii) diesel generation—additional capacity of 3 megawatts (MW) financed by the Norwegian Agency for Development Cooperation (NORAD); (iii) diesel generation—an additional capacity of 10 MW financed by the United States Agency for International Development (USAID); and (iv) the West African Power Pool (WAPP) Côte d'Ivoire, Liberia, Sierra Leone, and Guinea (CLSG) transmission interconnection from 2015.[10]

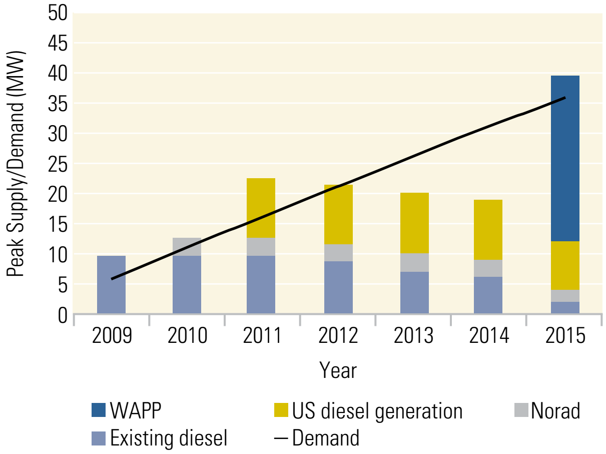
The demand is based on the analysis presented in the earlier chapter on Liberia's energy demand. For the purpose of the medium-term analysis, we assume that only part of the total demand—that is, only commercial and residential demand in Monrovia—will be required to be met by the Liberia Electricity Corporation (LEC) grid. Demand from residential rural areas is excluded from the current analysis, and large private projects (for example, in the mining sector) are assumed to generate enough power to meet their own needs in the medium term.

The system is assumed to absorb the suppressed demand incrementally year by year. Suppressed demand in Monrovia is large and currently met mainly through the use of private generators. But once tariffs are lowered due to increased generation capacity and distribution efficiency, a large part of this suppressed demand will be quickly absorbed by the system, creating jumps in the demand curve. To simplify the analysis but capture suppressed demand, the demand values have been obtained by linear interpolation between the reference points in 2009 and 2015, whereby the figure for 2009 reflects actual demand for public electricity during that year, and the figure for 2015 reflects the projected demand in accordance with the chapter on electricity demand.

Figure 6.1 and Table 6.1 show the supply-demand balance between 2009 and 2015. For this analysis, only power supply options that are certain of being implemented, as reflected in available funding, are considered. This implies that only the existing and the NORAD- and USAID-financed diesel power plants are dispatched. Additional power is envisaged to be

[10] Detailed capacity, availability, units, and variable and total levelized costs for the different generation options are outlined in the chapter describing the supply options.

Figure 6.1 | Supply-Demand Forecast for the Medium Term, 2010–15



Source: Authors' calculations.

available through the WAPP CLSG transmission project for which preparation is under way, and which is estimated to come online in 2015.[11] At the same time it has to be assumed that the installed diesel generators will wear out in advance of their expected lifetime due to their heavy usage, and thus supply from available units would slowly decline by 2015.

Figure 6.1 depicts clearly that the committed power in the time frame 2009–15 would leave a gap in the supply-demand balance starting from 2012. The emerging gap increases from about 4 MW in 2012 to about 13 MW in 2014. Only in 2015, when the WAPP CLSG comes online, can the gap be bridged. Table 3.1 suggests that among the options available by 2012, heavy fuel oil (HFO) is least cost.

Assuming an HFO-fired power plant can be financed, the gap between the power demand and the supply can be filled, as shown in Figure 6.2 and Table 7.1. In the supply balance it is assumed that 10 MW would be dispatched in 2013, and increased to a total of 15 MW in 2014. Such additional capacity will allow the phasing out and decommissioning of some of the oldest and more costly diesel generators and will also guarantee additional capacity during peak hours, thus avoiding load shedding. Further, the HFO plant would provide a stable thermal backup for more intermittent hydropower beyond 2015. Because of the small size of the power addition, public financing is recommended. Advantages of public financing include the flexibility of dispatching power without hampering the financial/economic development of the power system through fixed purchasing power contracts for which dispatch has to be maximized. Further, plant procurement is generally fast once financing is available.

The addition of HFO to the supply mix in the medium term will also allow power to be generated at a lower cost within a shorter time frame compared with existing

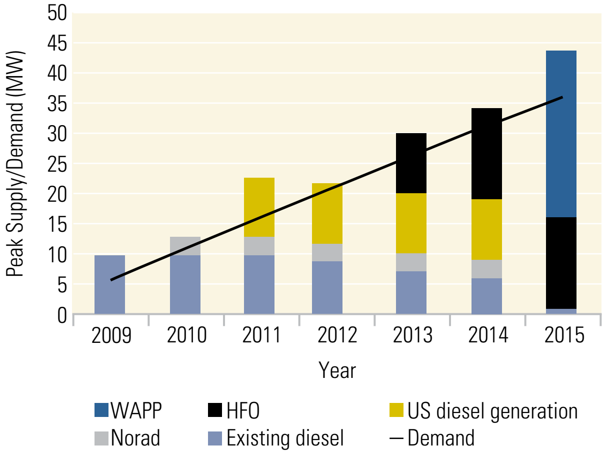
[11] For the medium-term analysis, the WAPP Phase 1 (low-capacity) scenario is considered.

Table 6.1 | Supply-Demand Balance and Generation Options by Year (MW)

	Total Demand (MW)	Total Supply	Balance	Diesel – Existing System	Diesel – NORAD	Diesel – USAID	WAPP
2009	5.82	9.7	3.88	9.7	0		
2010	19.02	12.7	–6.32	9.7	3		
2011	22.456	22.7	0.244	9.7	3	10	
2012	25.852	21.7	–4.152	8.7	3	10	
2013	29.248	20.06	–9.188	7.06	3	10	
2014	32.644	19.06	–13.584	6.06	3	10	
2015	36	39.76	3.76	2.06	2	8	27.7

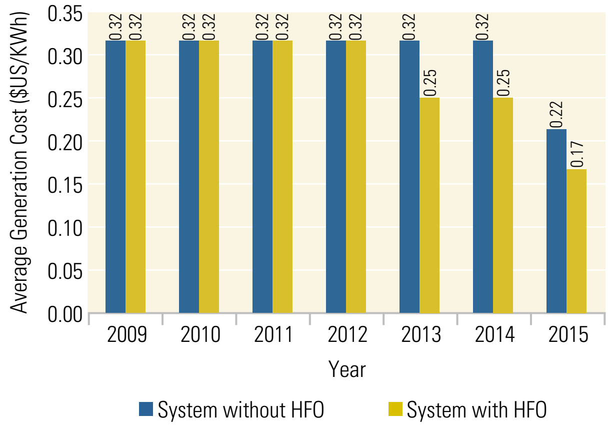
Source: Authors' calculations.

Figure 6.2 | Supply-Demand Forecast for the Medium Term, 2010–15, with HFO (MW)



Source: Authors' calculations.

Figure 6.3 | Average Generation Cost with and Without HFO



Source: Authors' calculations.

diesel generation. The phasing out of older diesel generators will create additional savings opportunities for the Government of Liberia (GOL) and lower tariffs for consumers. Figure 6.3 shows the average generation costs with and without HFO power plant addition.[12] Opting for a HFO-fired power plant will reduce the generation cost from US$0.32/kilowatt-hours (kWh) to US$0.25/kWh in 2013 and to US$0.17/kWh in 2015, compared with US$0.32/kWh until 2014 and US$0.22/kWh in 2015 for a system based solely on diesel generation.

[12] The average generation cost for each year is calculated by considering the sum of the total levelized costs for each supply option and the relative power dispatched for that year, weighted by the total capacity for that specific year.

Neighborhoods such as these have benefitted from the recent efforts to extend the electricity grid. West Point, Monrovia.

Least Cost Energy System Expansion in the Long-Term

7

Beyond 2015 choices become more complex. Despite the significant uncertainties involved in making such projections, especially against the postconflict background of Liberia, they may provide important information for the development of the energy sector. As will be shown, this information not only relates to suggestions for concrete projects to be prioritized, but rather to understanding what questions to ask as the country moves forward.

Methodology Used

In planning power expansion the main objective is to define which generation options should be added to the system while minimizing the capital investment cost and the electricity production cost of the alternatives considered at any point in time. This optimization is subject to meeting electricity demand within acceptable reliability levels and subject to supply constraints.

For reconstruction of the electricity sector in Liberia, consistent long-term planning is required to prioritize the best development options. In this case, planning needs to incorporate the specific characteristics of Liberia's electricity sector, such as seasonal dependence on hydropower generation, the need for full sector reconstruction postconflict, the small size of the sector (which does not allow for economics of scale), the high uncertainty of demand and supply, and the need for and availability of donor community support.

Table 7.1 I Supply-Demand Balance and Generation Options Per Year, with HFO (MW)

	Total Demand	Total Supply	Balance	Diesel – Existing System	Diesel – NORAD	Diesel – USAID	HFO	WAPP
2009	5.82	9.7	3.88	9.7	0			
2010	19.02	12.7	–6.32	9.7	3			
2011	22.456	22.7	0.244	9.7	3	10		
2012	25.852	21.7	–4.152	8.7	3	10		
2013	29.248	30.06	0.812	7.06	3	10	10	
2014	32.644	34.06	1.416	6.06	3	10	15	
2015	36	43.7	7.7	1	0	0	15	27.7

Source: Authors' calculations.

For the purpose of simulating a least-cost expansion plan, a General Algebraic Modeling System (GAMS) has been chosen (Turvey and Anderson, 1977). The GAMS provides a linear programming approach to the economic planning of power systems. It solicits a least-cost power supply expansion plan subject to meeting Liberia's demand. The calendar year 2010 was chosen as the base year for modeling periods of five-year intervals through calendar year 2040.

The costs of the supply alternatives that are specified include both fixed and variable costs: the capital investment cost, operation and maintenance cost, and fuel cost. These cost parameters are subject to local conditions and affect the annual levelized cost, which in turn determines the merit order of the plants. The cost parameters included in this modeling exercise are based on feasibility studies, benchmarking reflecting conditions similar to the Liberian context, and a sensitivity analysis. The feasibility studies for hydropower generation need to be updated to reflect more accurate costs.

Considering a long-term horizon of 30 years, the modeling objective function is a cost function that is minimized subject to the overall electricity demand and formulates an investment program by searching for the least-cost solution. As previously stated, the search for an optimum (least-cost) investment program is subject to a number of technical conditions particular to Liberia's power system.

First, sufficient available installed capacity needs to be operating at all times to meet the instantaneous peak demand. This will require a specific level of operating marginal reserves that ensures that enough electricity will be available to meet the real-time demand in the event of any generation failure or unexpected increase in peak demand. This will be reflected in the reliability of the system provided by a specific level of operating marginal reserves but also represents an increase in the least-cost generation expansion of the system. In more developed systems, regulatory bodies usually require producers to maintain a constant operating reserve margin of within 10–15 percent of normal capacity to prevent supply disruptions due to breakdowns in the system or sudden increases in energy demand. But this implies a high capital investment cost that many systems, especially in West Africa, have not been able to afford. Best practices recommend 15 percent. To strike a balance between what is technically necessary and what can realistically be expected in the context of Liberia, we assume a 10 percent operating reserve margin.[13]

Second, no plant can be operated above its maximum availability factor. The availability factor is defined as the ratio of actual power available (excluding any downtime due to plan failure, maintenance, and so on) divided by the maximum power output if the plant were to run continuously. The availability factor is specific to each technology alternative and reflects the rationing of its capacity due to overhaul and routine maintenance.

Third, hydrological conditions in Liberia need to be captured in the least-cost analysis since they vary greatly from season to season. As described in the chapter discussing Liberia's energy supply options. Several studies looking at the hydropower potential in Liberia point out that the dry season is from December to June and the wet season from July to November. Therefore, seasonal shortages of water inflow or possible requirements for irrigation and flood control will restrict the amount of energy to be produced. The modeling captures this seasonality through the load factor of the plant, which is the average energy produced divided by the theoretical maximum energy over a period of time.

Fourth, seasonal fluctuations need to be compensated by thermal power generation. The modeling exercise captures this compensation by limiting the amount of hydropower that can be allowed in the system. This is set as a fraction of the peak demand that the hydrocapacity will represent in the energy capacity mix. For the purpose of modeling, it is assumed that hydropower generation can contribute as much as hydrological conditions and storage capacity allow.

[13] A standard practice is around 15 percent of operating margin reserve, for example, the Electricity Reliability Council of Texas, Texas (2008 summer) reported 12.5 percent, and the Pennsylvania, Jersey, Maryland Power Pool (2008 summer) reported 26 percent. In the case of Liberia, 10 percent was assumed.

Fifth, a constraint is imposed for the maximum capacity available for each technology over the 30-year time frame. Supply alternatives are to be implemented in phases to avoid an oversized power plant when compared to demand. Therefore, the power capacity of some supply alternatives increases over time depending on the expected demand. In the case of the regional transmission line and hydropower generation, installed capacity also depends on construction scheduling. For example, due to an expected expansion of the WAPP CLSG transmission line in 2020, capacity will increase from the originally installed level. For the operation of any HFO-fired power plant, an operational fuel unloading and storage facility is required. On the other hand, some alternatives are not expected to increase their capacity, and these will provide the same capacity over the complete scenario. Table 7.2 shows the upper bounds of capacity for each supply alternative.

Fifth, decommissioning of plants is also considered in the modeling exercise, subject to the life span of each technology. (The life span is the average length of time that the power plant can be in operation.)

The model determines the overall production cost for any additional capacity installed over time, subject to meeting growing demand, power plant constraints, and required reliability levels. The capital and operating cost of each supply alternative are combined and discounted to obtain a net present value (NPV) of the total capital investment required for each least-cost generation expansion scenario.

Macroeconomic Assumptions

All costs incurred in the expansion of the system are stated in 2009 U.S. dollars. Price escalation is based on the manufactures unit value (MUV) index, which is generally accepted as a proxy for the price of developing country imports of manufactured goods in U.S. dollar terms. For example, World Bank procurement also utilizes MUV in assessing prospective cost escalation for imported goods for World Bank–financed infrastructure. Another important assumption is the interest rate for capital investment, which is applied to past and future costs to determine the NPV. In this regard, the interest rate will depend on the risk of lending to a national utility, and the possibility of obtaining soft government loans or guarantees for investments; in the case of Liberia 12 percent was taken into account.

Table 7.2 | Upper Bound of Supply Alternatives' Capacity

Plant	2010	2015	2020	2025	2030	2035	2040
Diesel existing system	9.64	9.64					
NORAD diesel	3	3					
New diesel		inf	inf	inf	inf	inf	inf
HFO		inf	inf	inf	inf	inf	inf
Biomass—core scenario		30	30	30	30	30	30
WAPP (CI-L) low capacity		27.7	50.7	50.7	50.7	50.7	50.7
WAPP (CI-L) high capacity		50	90.6	90.6	90.6	90.6	90.6
Hydro 1: Mt. Coffee, phase 1		66	66	66	66	66	66
Hydro 2: Mt. Coffee–Via			66	66	66	66	66
Hydro 4: SP – 1B + SP – 2+ Via reservoir			198	198	198	198	198
Hydro 3: Mano River				90	90	90	90

Source: Authors' calculations.
Note: inf = infinite expansion possible, CI-L = Côte d'Ivoire – Liberia, Mt. = Mount

Scenarios Analyzed, and Findings

The analysis of future supply requirements to meet demand is based on two scenarios of high and low demand growth. A sensitivity analysis was carried out to determine the effects of different capital investment costs for HFO and the cost of electricity associated with the WAPP CLSG transmission line.

Scenario 1: Conservative Demand Growth

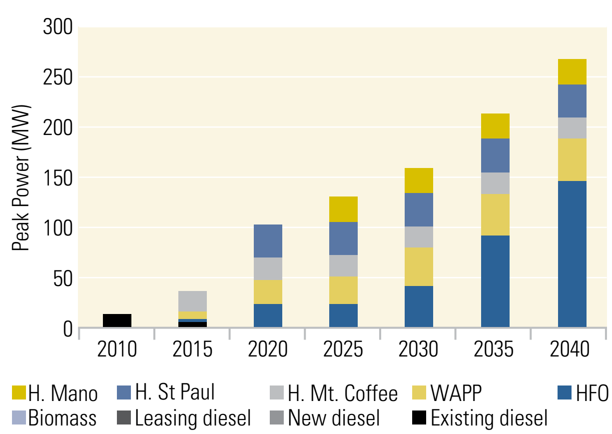
This scenario presents the most conservative assumptions in terms of demand growth and supply alternatives. The investment costs taken into consideration represent the upper value of the benchmarking supply analysis conducted. In the case of the regional WAPP CLSG transmission line, this scenario assumes low capacity due to the limited surplus that the neighboring countries interconnected to the line can contribute in terms of electricity. The cost of electricity for the WAPP CLSG line in this scenario is considered at the highest value, assuming that the initial cost of power, which is based on gas-fired power plants in Côte d'Ivoire, would prevail over the lifetime of the transmission line.

The model results indicate that the most economic options for expanding the interconnected power system is a mixture of hydropower generation composed of the rehabilitation of the Mt. Coffee hydropower plant, Saint Paul River development, and Mano hydropower project, and an addition of thermal power provided by diesel power generation, HFO, and the WAPP CLSG transmission line. The modeling exercise suggests the use of Mt. Coffee capacity of 36 MW, Saint Paul River capacity of 45 MW, and Mano capacity of 50 MW as the optimum solution for hydropower generation. The low-demand scenario does not create conditions sufficient to achieve the economics of scale needed for full dispatch of these hydropower plans. Therefore, the model proposes that the capacity and energy surplus, which the original project can provide, be supplied into the WAPP transmission line, which is capable of absorbing the excess demand. The costs associated with the investments and the generation of this surplus will thus be covered through tariff payments from consumers outside of Liberia.

The capacity available from the WAPP CLSG project will be fully used, even with the conservative assumptions underlying this scenario. As far as thermal power is concerned, the use of HFO and diesel increase over time when the capacity limits of the WAPP CLSG transmission line are reached. The operating margin reserve requirements are met by diesel power generation since the unit capital investment costs for diesel are the lowest of all options and this alternative is only being dispatched in the case of unexpected supply-demand imbalance. Figure 7.1 shows the peak power that each supply alternative needs to meet to satisfy demand at minimum cost, and Table 7.3 shows the installed capacity needed to meet the demand, subject to operation constraints.

The combined construction of the Mt. Coffee and Via reservoirs, which aims at providing better hydrologic distribution between dry and wet seasons as compared with the construction of the Mt. Coffee reservoir alone, and the core biomass scenario are not selected by the model as part of the least-cost expansion plan. The model searches for least-cost solutions based on the unit capital cost and variable cost. The above-mentioned projects represent high capital investment costs and significantly higher variable costs in the case of the core biomass

Figure 7.1 | Scenario 1 (Conservative Demand Growth) Peak Capacity



Source: Authors' calculations.

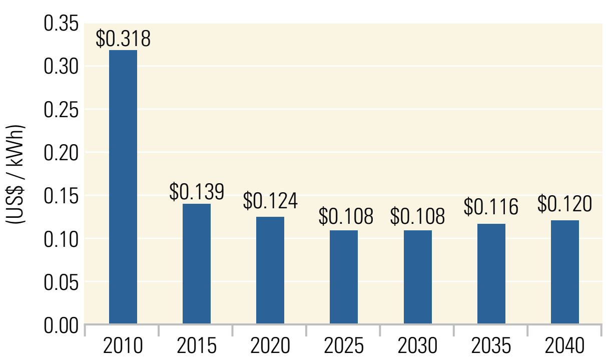
Table 7.3 | Scenario 1 (Conservative Demand Growth) Installed Capacity and Peak Demand (MW)

Supply Alternative	2010	2015	2020	2025	2030	2035	2040
Existing diesel	13	13					
New diesel			2	6	9	17	24
Leasing diesel		0	0	0	0	0	0
Biomass		0	0	0	0	0	0
HFO		4	28	28	50	114	183
WAPP		8	30	33	45	50	50
H. Mt. Coffee		36	36	36	36	36	36
H. Saint Paul			45	45	45	45	45
H. Mano			50	50	50	50	50
Total installed capacity	13	61	141	198	237	312	388
Total peak demand	6	37	104	131	159	214	269

Source: Authors' calculations.
Note: HFO = heavy fuel oil; WAPP = West African Power Pool. H. = hydropower.

scenario. In the case of the Via reservoir, the capital costs are too high. The discounted cost of the scenario is US$465 million. The average cost of generation decreases significantly over time when providing a mixture of supply alternatives that are less expensive than generation costs based on diesel. The generation cost, therefore, decreases to around 55 percent when compared to the current cost. It is expected, as is shown in Figure 7.2 that with this supply mix the average generation cost varies between US$0.14/kWh to US$0.11/kWh over the time horizon of this model investment.[14]

Figure 7.2 | Scenario 1 (Conservative Demand Growth) Average Cost of Generation



Source: Authors' calculations.

Scenario 1: Sensitivity analysis–HFO-fired power plant capital cost variation

As discussed in the previous section, scenario 1 indicates that a significant share of the installed capacity in Liberia's least-cost expansion plan will be based on an HFO-fired power plant. Since HFO plays a significant role in the least-cost expansion plan, it is important to assess how its deployment would vary if capital costs were different. In this regard, a sensitivity analysis based on different capital investment costs for the HFO-fired power plant was conducted. The capital cost of the HFO-fired plant in scenario 1 is US$1,470/kW installed, and at the very

[14] The average cost of electricity is based on the fixed costs, represented largely by the capital investment costs and the variable costs reflecting the O&M and fuel costs. The fixed generation cost is calculated based on a weighted average in which each quantity of power is assigned a weight based on the capacity that each technology alternative contributes to the entire system. Similarly, the variable cost assigns a weight based on the power that is actually dispatched by each supply technology.

high end of these types of plants. The literature suggests that investment capital costs range from US$1,100 to US$1,320/kWh for HFO plant to be plausible.

Considering a lower investment cost of US$1,100/kW, the discounted cost of this scenario is US$427 million, 8 percent lower when compared with scenario 1. But the model only selects as its least-cost expansion plan the HFO-fired power plants, the Mt. Coffee hydropower plant, the Saint Paul River project, and the Mano hydropower plant. The WAPP CLSG transmission line is not selected as part of the least-cost solution since the unit capital cost is not competitive with the HFO unit capital costs. Therefore, this power supply mix is heavily exposed to fuel price fluctuations, and larger investments will be required to handle and store HFO—especially by 2035, when HFO reaches about 50 percent of the installed capacity.

When using a US$1,320/kW investment cost for HFO, the discounted cost of this scenario is US$462 million, 2 percent less than the base scenario. The supply mix includes the Mt. Coffee hydropower plant, the WAPP CLSG transmission lines, the HFO-fired power plants, and diesel generation. The latter is only selected to meet the peak demand and as an operating margin reserve.

Scenario 1: Sensitivity analysis—WAPP CLSG transmission line—higher capacity and lower cost

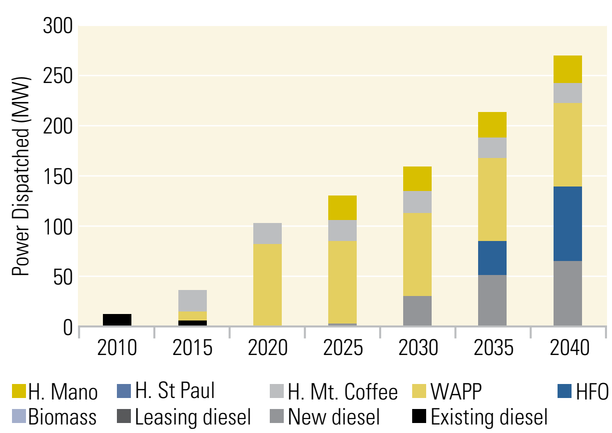
This scenario considers that the WAPP CLSG regional transmission line will provide higher capacity to supply the power system of Liberia, and the cost of electricity will be reduced. This scenario is based on the assumption that an energy surplus is available from neighboring countries, mainly Côte d'Ivoire and Guinea, and that the cost reduction based on the hydropower development in Guinea will lower the cost when compared to the cost related to gas power generation from Côte d'Ivoire in scenario 1. As a result, this scenario provides a discounted capital cost of US$449 million, 2 percent less than the base scenario.

The supply mix relies significantly on the power provided by the WAPP CLSG transmission line, which is fully dispatched, and the Mt. Coffee and Mano hydropower plants. The Saint Paul hydropower project is not selected as part of the least-cost expansion plan. Diesel- and HFO-fired generation contributes significantly from 2030 to 2040, when the capacity limits of the WAPP CLSG transmission line are reached. Figure 7.3 shows the least-cost expansion plan.

Scenario 1: Hydropower development limited to the Mt. Coffee plant

Scenario 1 indicates that both the Mt. Coffee and Saint Paul River projects will be needed to meet the demand. Therefore, this sensitivity analysis here aims at capturing the effects of only developing the Mt. Coffee project and no other hydropower plant. This sensitivity analysis shows that the discounted cost of expanding the system with limited hydropower contribution will be US$567 million, around 22 percent higher than the base scenario. Since only the Mt. Coffee plant is available, thermal capacity is compensating for the lack of this energy and the operating costs increase significantly, around 50 percent when compared with the base scenario.

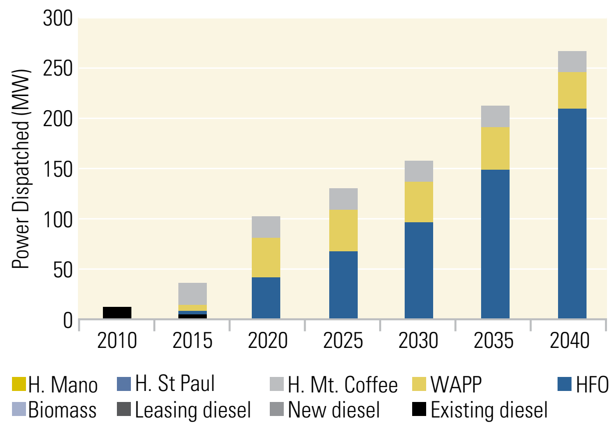
Figure 7.3 | Scenario 1 (Conservative Demand Growth) Sensitivity Analysis Considering WAPP Higher Supply Capacity and Lower Electricity Cost



Source: Authors' calculations.
Note: HFO = heavy fuel oil; WAPP = West African Power Pool.

In this sensitivity scenario, the energy mix is composed only of Mt. Coffee, at 36 MW, the WAPP CLSG transmission line (which is fully dispatched), HFO, and diesel. The latter is only selected to meet the operating margin reserve. Figure 7.4 presents the energy mix of the peak supply to meet the peak demand, and Table 7.4 presents the installed capacity of Liberia's interconnected system if the Saint Paul River and Mano projects were not being developed.

Figure 7.4 | Scenario 1 (Conservative Demand Growth) Sensitivity Analysis Considering Limited Hydropower Development



Source: Authors' calculations.
Note: HFO = heavy fuel oil; WAPP = West African Power Pool; H. = hydropower.

Scenario 1: Sensitivity analysis–biomass-fired power plant capital cost variation

As discussed in the previous section, scenario 1 indicates that the core biomass scenario is not selected as part of the least-cost expansion plant due to the high unit capital cost, estimated at US$4,167/MW installed. Since Liberia is endowed with significant renewable energy resources, including biomass, and this fuel can play a significant role in the least-cost expansion plan, it is important to assess how its deployment would vary if capital costs were different. A sensitivity analysis was conducted based on different capital investment costs for a biomass plant. In particular, an investment capital cost of US$2,419/MW installed was assumed. As discussed in the supply energy options chapter, this is considered to be within the usual range for this type of plant.

Table 7.4 | Scenario 1 (Conservative Demand Growth) Total Capacity and Demand if Limited Hydropower Plants are Developed

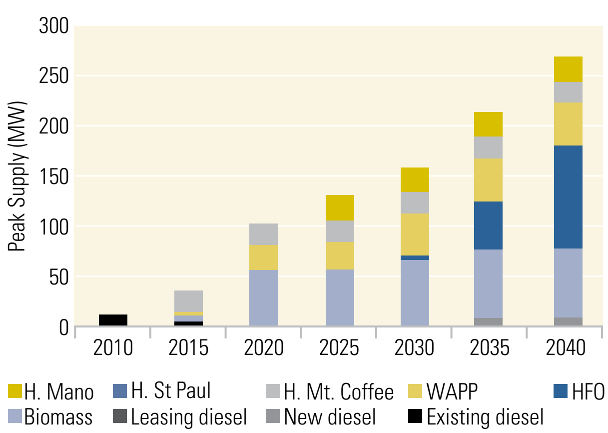
Supply Alternative	2010	2015	2020	2025	2030	2035	2040
Existing diesel	13	13	0	0	0	0	0
New diesel	0	0	2	6	6	17	17
Leasing diesel	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0
HFO	0	4	52	84	123	150	211
WAPP	0	8	48	50	50	50	50
H. Mt. Coffee	0	36	36	36	36	36	36
H. Saint Paul	0	0	0	0	0	0	0
H. Mano	0	0	0	0	0	0	0
Total capacity	13	61	138	176	215	253	313
Total peak demand	6	37	104	131	159	214	269

Source: Authors' calculations.
Note: HFO = heavy fuel oil; WAPP = West African Power Pool. H.=hydropower.

Despite significant biomass resources in Liberia, there is no consensus on the amount of power that can be generated from the various renewable resources in a sustainable from. In assessing the power generation potential of selected crops, Milbrandt (2009) estimated that if only 10 percent of the available cropland were dedicated to oil palm, coconut, or sugarcane, 27,452 gigawatt-hours (GWh) could be generated for electricity consumption, representing 3.7 million hectares.[15] On the other hand, according to independent reports (Aah-Kee 2009; Krishnan 2009), a scoping study has identified five sites of rubber plantations with a power generation potential to support 80 MW of biomass-fired power plants, which represent around 2,500 hectares of rubber trees per year. Therefore, rubber trees have been selected as a type of fuel and, given the generation potential estimated for this fuel, a sensitivity analysis has been undertaken assuming a maximum power capacity of 80 MW.

The discounted cost of this scenario is US$380 million, 1.2 percent less than scenario 1. At a lower capital cost, the least-cost expansion plan now selects the biomass plant at full capacity. The remainder of the supply mix relies significantly on the power provided by the WAPP CLSG (fully dispatched) transmission line, and the Mt. Coffee and Mano hydropower plants. The Saint Paul hydropower project is no longer selected as part of the least-cost expansion plan. Diesel- and HFO-fired generation contributes to power only from 2020 to 2040, since in 2015 there is sufficient capacity provided by the Mt. Coffee plant and the biomass benchmarking alternative. Figure 7.5 shows the supply mix found to be the most economic solution.

Figure 7.5 | Scenario 1 (Conservative Demand Growth) Sensitivity Analysis Considering Biomass Benchmarking Costs



Source: Authors' calculations.
Note: HFO = heavy fuel oil; WAPP = West African Power Pool.

Scenario 1: Sensitivity analysis—No trade available

This scenario is based on the assumption that no power exchange will be available with neighboring countries, and therefore no interconnection with the WAPP CLSG transmission line will be implemented. The purpose of this scenario is to derive the benefits of transmission interconnection for Liberia with its neighboring countries. The supply alternatives considered under this scenario include the Mt. Coffee and Saint Paul projects for hydropower generation, and HFO, diesel, and biomass for thermal generation. The Mano hydropower plan is not taken into account since the development of the project is dependent on the construction of the WAPP CLSG transmission line. The results indicate that the cost of the least-cost expansion plan under this scenario is 11 percent higher when compared with the base scenario: the discounted capital cost of this investment is estimated at US$516 million.

The energy mix of this scenario relies significantly on the construction of HFO and diesel. With respect to hydropower, the model selects 36 MW of the Mt. Coffee and 70.5 MW of the Saint Paul projects. The biomass supply option is not selected as part of the least-cost expansion. Diesel generation is still heavily used from the years 2030 to 2040 to compensate for the lack of power that the WAPP CLSG transmission line or the Mano hydropower project would provide. Figure 7.6 and Table 7.5 show the peak supply mix of the system.

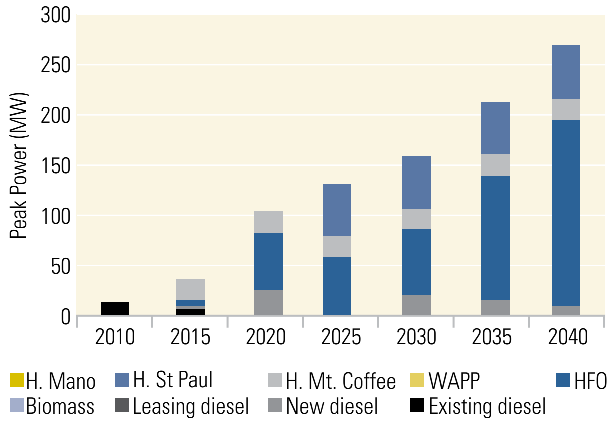
[15] Liberia's agriculture potential is estimated at 3.7 million hectares of arable land, which represent 38 percent of the total land area.

Scenario 2: High demand growth

The most significant drivers of energy demand in the interconnected system are gross domestic product (GDP) growth, the LEC's ability to better attract large consumers that can be connected to a more reliable and less expensive electricity system than offered by self-generation, and the interconnection of the mining sector with the system. In scenario 2, high demand growth is considered. Further, the investment costs taken into consideration represent the upper value of the benchmarking supply analysis. In the case of the regional transmission line, the capacity is assumed to be low due to the limited surplus that the neighboring countries can contribute. The cost of electricity is assumed to be high since it is foreseen that power will initially be provided by the Côte d'Ivoire power system, which is based significantly on gas-fired power generation.

The most economic options for expanding the interconnected power system are a mixture of hydropower generation including the Mt. Coffee hydropower plant rehabilitation, the Saint Paul River and Mano hydropower development, and an addition of thermal power provided by diesel power generation, HFO, and the WAPP CLSG transmission line. The least-cost expansion plan includes the following hydropower mix: the complete capacity of

Figure 7.6 | Scenario 1 (Conservative Demand Growth) Sensitivity Analysis when Power Trade is not Possible



Source: Authors' calculations.
Note: HFO = heavy fuel oil; WAPP = West African Power Pool; H. = hydropower

Table 7.5 | Scenario 1 (Conservative Demand Growth) Total Capacity and Demand when Power Trade is Not Possible

	2010	2015	2020	2025	2030	2035	2040
Existing diesel	13	13	0	0	0	0	0
New diesel	0	5	35	35	35	35	35
Leasing diesel	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0
HFO	0	8	71	71	82	157	233
WAPP	0	0	0	0	0	0	0
H. Mt. Coffee	0	36	36	36	36	36	36
H. St Paul	0	0	0	0	71	71	71
H. Mano	0	0	0	0	0	0	0
Total capacity	13	61	143	143	224	299	375
Total peak demand	6	37	104	131	159	214	269

Source: Authors' calculations.
Note: HFO = heavy fuel oil; WAPP = West African Power Pool; H.=hydropower.

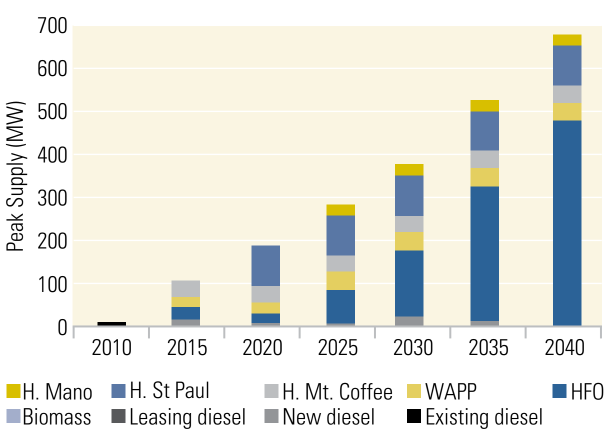
the Mt. Coffee project at 66 MW, Saint Paul River project at 124 MW, and Mano project at 50 MW. In this scenario, the capacity and energy surplus from the Saint Paul River can be supplied into the WAPP transmission line. The costs associated with the investments and the generation costs of this surplus will be covered by customers outside of Liberia's interconnected power system.

Additional power will be provided by diesel power generation, HFO, and the WAPP CLSG transmission line. Figure 7.7 shows the peak power that each supply alternative provides to the system to satisfy the demand at minimum cost, and Table 7.6 shows the installed capacity needed to meet the demand subject to operation constraints.

The proposed core biomass scenario and the combined Mt. Coffee and Via reservoir options are not selected by the model as part of the least-cost expansion plan. The model searches for least-cost solutions based on the unit capital cost and the variable cost, and both costs are significantly higher when compared to the other supply alternatives.

The discounted cost of the entire scenario is US$1,135 million. The average cost of generation decreases significantly when providing a mixture of supply alternatives that are less expensive than the generation cost based on diesel, as was the case in 2010. The generation cost, therefore, decreases around 50 percent when compared to the cost in 2010. As is shown in Figure 7.8, with this supply mix the average generation cost varies between US$0.17/kWh to US$0.15/kWh over the model's time horizon.[16] The increase of the average cost of generation compared with the conservative scenario relies on the investment requirements of the hydropower plants.

Figure 7.7 I Scenario 2 (High Demand Growth) Peak Capacity

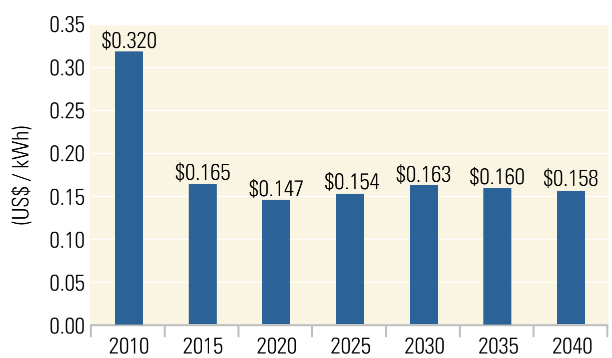


Source: Authors' calculations.
Note: HFO = heavy fuel oil; WAPP = West African Power Pool.

Scenario 2: Sensitivity analysis– HFO-fired power plant capital cost variation

This high demand growth scenario will require developing Liberia's hydropower potential. But the system will still rely on installed capacity based on HFO-fired power plants to compensate for the high

Figure 7.8 I Scenario 2 (High Demand Growth) Average Cost of Generation



Source: Authors' calculations.

[16] The generation average cost for electricity is based on the fixed costs, represented largely by capital investment costs and variable costs reflecting the O&M and fuel costs. The fixed generation average cost is computed on a weighted average basis in which each quantity of power by each technology is assigned a weight based on the capacity that each alternative contributes to the entire system. Similarly, the variable cost assigns a weight based on the power that is actually dispatched by each supply technology.

Table 7.6 | Scenario 2 (High Demand Growth) Total Capacity and Demand

	2010	2015	2020	2025	2030	2035	2040
Existing diesel	13	13					
New diesel	0	26	26	31	71	79	79
Leasing diesel	0	0	0	0	0	0	13
Biomass	0	0	0	0	0	0	0
HFO	0	36	36	101	193	393	599
WAPP	0	28	28	50	50	50	50
H. Mt. Coffee	0	66	66	66	66	66	66
H. St Paul	0	0	124	124	124	124	124
H. Mano	0	0	0	50	50	50	50
Total capacity	13	169	280	422	554	762	981
Total peak demand	6	109	190	284	378	528	679

Source: Authors' calculations.
Note: HFO = heavy fuel oil; WAPP = West African Power Pool; H.= hydropower.

seasonality of hydropower in Liberia. Since HFO retains a significant share in the least-cost expansion plan, it is important to determine the sensitivity of this share in relation to the capital cost of this technology. A sensitivity analysis based on different capital investment costs for HFO-fired power plants was conducted. The assumptions for the investment capital costs for the sensitivity analysis range from US$1,100 to US$1,320/kWh.

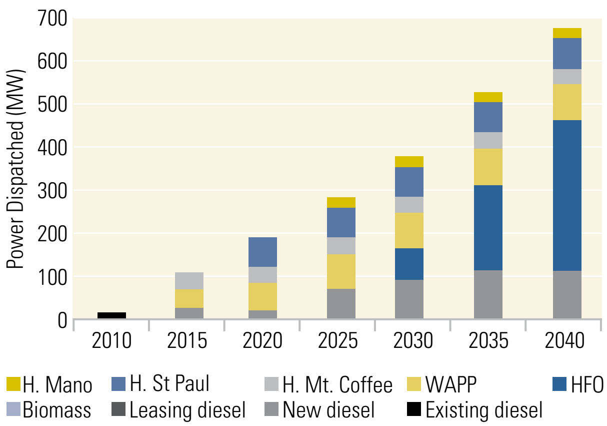
Considering a lower investment cost of US$1,100/kW, the discounted capital cost of this scenario is US$965 million, 14 percent less when compared with scenario 2 for high demand growth. But the model only selects, as the most economic option, HFO-fired power plants and the Mt. Coffee project, Saint Paul River project, and Mano hydropower plant. The WAPP CLSG transmission line is not selected as part of the least-cost solution.

When using the US$1,320/kW investment cost, the discounted capital cost of this scenario is US$932 million, about 17 percent less than scenario 2. The system requires complete utilization of the WAPP CLSG transmission line and diesel generation to meet the operating margin reserve. The Mt. Coffee, Saint Paul River, and Mano projects are selected as the most economic alternatives. The variation of the unit capital cost of the HFO-fired power plant will have an impact on developing the Saint Paul River project, which is sensitive to the investment cost of the different technologies.

Scenario 2: Sensitivity analysis—WAPP CLSG higher capacity and lower cost

This scenario assumes that the regional transmission line will provide higher capacity to supply the power system of Liberia and that the cost of electricity will be lower than in the previous scenario. The discounted cost of this scenario is US$1,114 million, 1.3 percent less than the base scenario for high demand growth. The hydropower mix of the least-cost expansion plan comprises the Mt. Coffee project at 66 MW, Saint Paul River project at 91 MW, and Mano project at 50 MW. Although this scenario reduces the need for capital investment costs, the operating costs increase 20 percent compared with scenario 2 for high growth. Figure 7.9 shows the supply mix found to be the most economic solution.

Figure 7.9 | Scenario 2 (High Demand Growth) Sensitivity Analysis Considering WAPP Higher Supply Capacity and Lower Electricity Cost

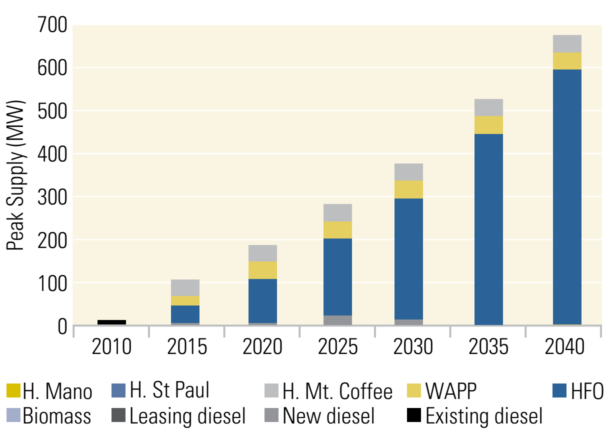


Source: Authors' calculations.
Note: HFO = heavy fuel oil; WAPP = West African Power Pool.

Scenario 2: Hydropower development limited to Mt. Coffee plant

This sensitivity analysis aims at capturing the effects of not developing any hydropower plant except for the Mt. Coffee project and evaluates the impacts in terms of investment in Liberia's interconnected power system. This analysis shows that the discounted cost of expanding the system with limited hydropower contribution will be US$1,174 million or only 3 percent more than the cost of scenario 2.

Figure 7.10 | Scenario 2 (High Demand Growth) Sensitivity Analysis Considering Limited Hydropower Development



Source: Authors' calculations.
Note: HFO = heavy fuel oil; WAPP = West African Power Pool.

In this sensitivity analysis, the energy mix is composed of the Mt. Coffee project at 66 MW, the WAPP CLSG (fully dispatched) transmission line, HFO, and diesel. This scenario relies significantly on HFO and diesel power generation, which exposes Liberia's power sector to fuel oil fluctuations. Figure 7.10 presents the energy mix of the peak supply to meet the peak demand, and Table 7.7 presents the installed capacity of Liberia's interconnected system if the Saint Paul River and Mano projects were not to be developed.

Scenario 2: Sensitivity analysis–Biomass power plant capital cost variation

As discussed above, scenario 2 indicates that the core biomass scenario is not selected as part of the least-cost expansion plan due to the high unit capital cost, estimated at US$4,167/kW installed. In this sensitivity analysis, the impact of a different capital investment cost for the biomass plant is evaluated considering a maximum installed capacity of 80 MW for the biomass plant. The literature suggests that an investment capital cost of US$2,419/kWh installed is in the range that can be expected.

The discounted cost of this scenario is US$987 million, 13 percent less when compared to scenario 2. Under this scenario, the biomass plant is fully dispatched. The supply mix relies significantly on the power provided by the WAPP CLSG (fully dispatched) transmission line, Mt. Coffee project, Saint Paul River project, and the Mano hydropower plant. The HFO-fired power plants are still a significant share of the total installed capacity. Figure 7.11 shows the supply mix found to be the most economic solution.

Table 7.7 I Scenario 2 (High Demand Growth) Total Capacity and Demand if Limited Hydropower Generation is Developed

	2010	2015	2020	2025	2030	2035	2040
Existing diesel	13	13					
New diesel		6	18	60	60	60	79
Leasing diesel							
Biomass							
HFO		54	131	222	351	558	746
WAPP		28	50	50	50	50	50
H. Mt. Coffee		66	66	66	66	66	66
H. St Paul							
H. Mano							
Total capacity	13	154	265	397	527	733	941
Total peak demand	6	109	190	284	378	528	679

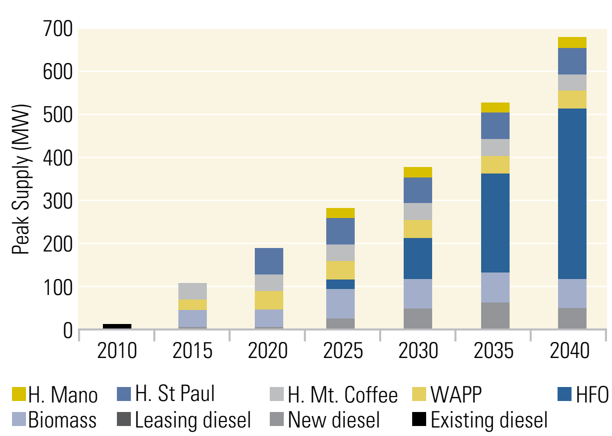
Source: Author's calculations.
Note: HFO = heavy fuel oil; WAPP = West African Power Pool. H. = hydropower.

Scenario 2: Sensitivity analysis–No trade available

This scenario assumes that no power exchange will be available with neighboring countries, and therefore no interconnection with the WAPP CLSG transmission line will be implemented. The supply alternatives considered under this scenario include the Mt. Coffee and Saint Paul projects for hydropower generation, and HFO, diesel, and biomass for thermal generation. The Mano hydropower plant is not taken into account since the development of the project is dependent on the construction of the WAPP CLSG transmission line. The results indicate that the cost of the least-cost expansion plan under this scenario is 10 percent higher when compared to scenario 2—the discounted capital cost of this investment is estimated at US$1,254 million.

The energy mix of this scenario relies significantly on HFO and diesel generation. With respect to hydropower, the model selects the full capacity of Mt. Coffee (66 MW) and 170 MW of the Saint Paul River project. The biomass supply option is not selected as part of the least-cost expansion. Diesel generation increases significantly from the years 2030 to 2040 to compensate for the lack of power that the WAPP CLSG transmission line or the Mano hydropower project would provide. Figure 7.12 and Table 7.8 below shows the peak supply mix of the system.

Figure 7.11 I Scenario 2 (High Demand Growth) Sensitivity Analysis Considering Biomass Benchmarking Costs



Source: Authors' calculations.
Note: HFO = heavy fuel oil; H. = hydropower.

Table 7.8 | Scenario 2 (High Demand Growth) Total Capacity and Demand when Power Trade is not Possible

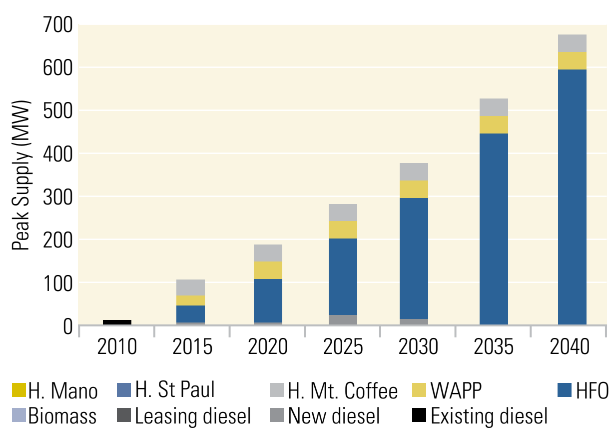
	2010	2015	2020	2025	2030	2035	2040
Existing diesel	13	13					
New diesel		38	38	68	103	103	103
Leasing diesel							
Biomass							
HFO		54	54	151	248	454	661
WAPP							
H. Mt. Coffee		66	66	66	66	66	66
H. St Paul				170	170	170	170
H. Mano							
Total capacity	13	171	327	454	586	793	999
Total peak demand	6	109	190	284	378	528	679

Source: Authors' calculations.
Note: HFO = heavy fuel oil; WAPP = West African Power Pool. H. = hydropower.

Summary of scenarios analyzed (high and low scenarios)

Table 7.9 displays the overall discounted capital cost for expanding the electricity sector of Liberia based on the demand and supply assessment, as described in the previous sections.

Figure 7.12 | Scenario 2 (High Demand Growth) Sensitivity Analysis when Power Trade is not Possible



Source: Authors' calculations.
Note: HFO = heavy fuel oil; WAPP = West African Power Pool; H. = hydropower.

Table 7.9 | Discounted Costs for Liberia's Least-Cost Expansion Plans under Different Scenarios (US$ millions)

Scenario	Demand	WAPP Capacity	WAPP Price	Discounted Capital Cost 2010	Discounted Operating Cost 2010	Total
Scenario 1	Low	Low	High	$172	$292	$465
HFO: US$1,100/kW	Low	Low	High	$172	$255	$427
HFO: US$1,320/kW	Low	Low	High	$163	$289	$453
WAPP high capacity	Low	High	Low	$143	$306	$449
Hydro only Mt. Coffee	Low	Low	High	$129	$438	$567
Biomass benchmarking 80 MW	Low	Low	High	$161	$236	$398
No trade (no WAPP)	Low	—	—	$188	$328	$516
Scenario 2	High	Low	High	$447	$687	$1,135
HFO: US$1,100/kW	High	Low	High	$367	$598	$965
HFO: US$1,320/kW	High	Low	High	$308	$623	$932
WAPP high capacity	High	High	Low	$363	$751	$1,114
Hydro only, Mt. Coffee	High	Low	High	$276	$899	$1,174
Biomass benchmarking 80 MW	High	Low	High	$307	$680	$987
No trade (no WAPP)	High	—	—	$493	$760	$1,254

Source: Authors' calculations.
Note: — Not available. HFO = heavy fuel oil; WAPP = West African Power Pool.

Charcoal vendor at Old Road charcoal market, Monrovia.

Models for Providing Modern Energy Services in Rural Liberia

8

According to Liberia's 2008 population and housing census, about 53 percent of the nation's population resides in rural areas, with the remainder in urban areas that include Monrovia, county capitals, and border towns with relatively large populations. For the purposes of energy planning and analysis, though, there are two categories much more significant in Liberia than "urban" and "rural:" on-grid and off-grid. Prewar, Liberia's power grid was limited to Monrovia and three radial lines that reached Robertsport, Totota, and Buchanan. In addition, there were small isolated power systems operated by the LEC in select county capitals of the interior, including Zwedru, Greenville, Harper, Sanniquellie, Gbarnga, Robertsport, and Voinjama, and a few other towns including Kolahun, Cestos, Ganta, Bellefanai, and Yekepa. But the vast majority of the country depended on self-generation or lacked energy services entirely.

Liberia's National Energy Policy (NEP) states that for the purposes of energy planning all areas outside of Monrovia are considered "rural," as the national grid and its utility do not extend beyond Monrovia. For that reason, in this chapter "rural" will be considered synonymous with "off-grid."

Today the Monrovia power grid covers only a portion of the city, and there are no other energy services offered outside of Monrovia. One exception is the limited municipally run mini-grid in Gbarnga, which supplies street lighting and a small number of residential and commercial connections from a diesel generator. As shown in the previous chapters, the supply scenarios currently being planned or considered for Liberia will change this situation, particularly as the WAPP low-voltage, cross-border interconnection with Côte D'Ivoire, which stands to benefit the residents of Maryland, Grand Gedeh, and Nimba counties, and the WAPP CLSG will be constructed. As the interconnected power system in Liberia increases its supply options through the installation of HFO, biomass plants, and/or other alternatives, and as Mt. Coffee and other hydropower schemes come online over time, residents of Monrovia and the adjacent counties will also see expanded access to electricity services. Nonetheless, this still leaves a large swath of the country in the dark.

The purpose of this chapter is to consider strategies that have worked for rural electrification in other developing countries, and to identify strategies that will work for Liberia's off-grid areas, be they urban or rural. In the near term, the World Bank will assist the Liberian government in the development of an energy sector master plan, to include grid development, as well as a rural energy master plan. It is outside the scope of this report to identify exact grid-extension scenarios, given the uncertainty of the supply strategy at present. Instead, this chapter will consider those general areas that will not be grid connected in the foreseeable future, with a focus on technology, supply, and financing options for meeting the needs of those areas with modern energy services.

Best Practices in Rural Electrification

The recent literature indicates that there is not one proper way to do rural electrification. That said, an underlying set of principles needs to be followed for programs to be successful. Moreover, the institutional form is not as important as the adherence to strict business principles in providing rural electricity services.

The main principles that have proved successful in countries with strong rural electrification programs such as Bangladesh, Chile, China, Costa Rica, Mexico, the Philippines, Thailand, and Tunisia are: (i) adherence to a sound financial and economic basis for electrification; and (ii) staying clear of politics and corruption. To ensure that these principles are adhered to, it will be important to set out transparent criteria for prioritizing areas for electrification—whether through grid extension or off-grid mechanisms—as well as, for off grid, criteria for choosing the technology and scope of electrification. Selection criteria need to incorporate financial and economic principles, and results must be monitored and verified.

Many countries have successfully provided electricity to their rural populations, both on and off grid. In Thailand over 95 percent of rural people have electricity. In Costa Rica cooperatives and the government electricity utility provide electricity to over 95 percent of the rural population. In Tunisia over 85 percent of rural households have access. Other success stories in the developing world include Bangladesh, Chile, China, Mexico, and the Philippines. Thus, there are many good examples of successful programs to counterbalance those that have experienced problems. An overview of successful programs is presented in Table 8.1.

Access models for rural electrification are varied and include utilities, rural electric cooperatives (RECs), decentralized electrification companies, and private electrification companies, which include several models themselves. Several approaches may be employed in one country simultaneously. For example, in Liberia, a private concession such as a mining concession might offer electricity to residents of one of the rural towns, where, due to the high population density, a grid system could be established. This grid system would not necessarily be connected to a national system but might stand on its own. This mining company would generate power from the source used for its own operations. A distribution company based on the cooperative model could make connections and collect tariffs. In another area with less population density, such as Cestos City, a private company based on a dealer sales-and-service model could sell and install solar home systems (SHSs) for residential and commercial customers far from the grid.

Utilities and Main Power Companies

Successful in many countries—such as Mexico, Thailand, and Tunisia—utilities probably constitute the most common path to rural electrification when access rates to electricity services are very low. Recently, many development practitioners have become blind to well-run public companies, insisting that companies must become private even under the most adverse circumstances. It is true that privatization of public companies is a worthy goal, since many public companies are inefficient and driven by political agendas. But many public sector electricity companies were created because the private companies that they replaced were in the business of making profits rather than extending services to the rural poor (Barnes, 2005).

The problem with using main power companies for rural electrification programs is that they often have difficulty meeting the special demands of rural distribution. For integrated power companies, the rural consumer makes up such a small part of the business clientele, that companies often do not pay attention to the numerous ways it is possible to minimize the costs of servicing rural areas. The result is that rural electrification becomes a tolerated loss maker, and ways are found to cut corners in terms of customer service. For instance, rural customers are more often than not the first to be cut off when there are problems with power supply in developing countries.

Success stories of public utilities that have undertaken major rural electrification projects include the Provincial Electricity Authority (PEA) in Thailand and Société

Table 8.1 | Best Practices of Successful Rural Electrification Programs

Country	Agency Responsible (Planning, Fund Management, and so on)	Sources for Rural Electrification Funds	Subsidies	Tariff	Service Providers (Construction, Distribution, Billing, and so on)
Chile	PER—a RE program under the National Energy Commission	Government budget	Subsidies cover 75–80% of construction costs, with a well-defined selection process and criteria.	Cost-recovery tariff	Private companies
Tunisia	Regional offices under STEG—a public vertically integrated utility	Government budget (90%) and donors	Subsidy level increased from US$350/connection 20 years ago to US$1,600/connection. Consumers and utility share the costs.	Universal tariff	Public utilities
Thailand	Office of Rural Electrification in the Provincial Electricity Authority (PEA)—a public distribution company	Cross-subsidy, World Bank, donors	Soft loans from donors and lower bulk supply rate.	Fixed charge and increasing block rate	
Mexico	CFE—a public utility	Government budget	Operating subsidies to utilities. Capital subsidies from the Social Infrastructure Fund to communities, who approach regional utilities.	Increasing block tariffs	
Bangladesh	RE board under the Ministry of Energy with 63 RECs	USAID, World Bank	3% loans and lower bulk supply rates. TA grants and concessional loans from donors.	Operation cost recovery after 5 years	REC
The Philippines	National Electrification Administration with 36 RECs	USAID, World Bank, government budget	Grants and concessional loans.	Cost-recovery tariffs	
Costa Rica	US National Rural Electric Cooperative Association with 4 RECs	USAID	USAID loans—40 years with a grace period of 10 years with an annual interest rate of 1–2.5%. Communities pay 30% of connection costs.	Cost-recovery tariffs with break-even after 5 years	
China	Ministries of Power, Water Resources, and Agriculture	Government budget	Government grants, concessional loans, and low-cost construction material.	Cost-recovery tariffs	Decentralized companies

Source: Douglas Barnes, 2005.
Note: RE = rural electrification; REC = rural electric cooperatives; TA = technical assistance.

Tunisienne de l'Electricité et du Gaz (STEG) in Tunisia. The success of both utilities was due to the implementation of strict business principles and steering clear from politics. The STEG's program, for example, had four factors of note: (i) private sector participation was encouraged during the construction phase; (ii) local industry was developed to supply equipment and material (these suppliers have been so successful that they are now turning toward export markets); (iii) a sophisticated, computerized inventory management system was introduced; and (iv) rigorous commercial practices, including control of nontechnical losses and effective billing and connection payment procedures, were utilized.

Given that the LEC remains a small power utility with great difficulty supplying Monrovia, this model does not seem applicable to Liberia.

The Rural Electric Cooperative Model

The REC model was derived from the experience of the United States, and its application in developing countries has been substantially supported by U.S. agencies, including USAID. Examples of developing countries following this model include Bangladesh, Costa Rica, and the Philippines. Rural cooperatives are generally organized as nonprofit membership corporations whose goal is to distribute electric power in designated areas where they act as regulated monopolies. All households and enterprises that are located in the franchise area of the cooperative are eligible to become members. Well-functioning cooperatives are characterized by their independent, egalitarian, and public-service attitude, as well as their deep and genuine belief in the value of rural electrification.

The cooperative model works well when the society where it is implanted has a generally egalitarian attitude. This is the case in Costa Rica, where the principles of "*cooperativismo*"[17] are taught in schools. One strongly held egalitarian principle in Costa Rica is that everyone in the service area of a cooperative is entitled to supply. But such views do not override the cooperative's role as a business enterprise in which full cost-recovery is a precondition for any supply.

While in most successful cooperative models the direct involvement of members is minimal in day-to-day operations, local people, not a remote bureaucracy, manage the operation. This fact seems to promote a sense of local responsibility, making it easier for members to accept that cooperatives in remote areas must charge considerably higher prices than those operating under more favorable conditions.

Effective cooperative management requires careful and objective choice of service areas, professionally competent design of distribution systems, and effective management thereafter. Because cooperatives are small organizations with limited technical and administrative capacities, their personnel need to be trained regularly. They also need access to the skills and resources required for dealing with emergencies and more specialized problems.

Proper supervision and accountability are critical, since cooperative management tends to be relatively fragile and isolated, making it susceptible to local corrupting influences. As long as a central support structure remains effective, such as a rural energy agency, these problems can be detected and dealt with, or at least kept within acceptable limits. Where leadership and discipline are lacking at the core, the system inevitably begins to break down. Examples of such central support structures are Costa Rica's national regulator, Servicio Nacional de Electricidad (SNE), and the National Electrification Administration (NEA) in the Philippines. These support structures facilitate the start-up and operation of rural cooperatives by: (i) providing concessionary start-up funds for putting a distribution system in place; (ii) assisting in system planning (including expansion) and tariff setting; (iii) monitoring and evaluating the performance of cooperatives; and (iv) assisting in training and raising awareness.

While some cooperatives generate electricity, many purchase power in bulk from a power utility. This often proves cheaper. In the Philippines, for example, the bulk of the approximately 116 cooperatives merely serve as distribution companies. In contrast to that, a consortium

[17] Cooperative movement.

of four cooperatives in Costa Rica has joined forces to construct a hydroelectric plant. Financial analysis shows that this plant will be able to deliver power at lower costs than these cooperatives can purchase in bulk from the main power company.

Community electric cooperatives. These are small community-based organizations that typically own and operate small systems. Their success often depends on the technical, personal, and political skills of one or more local entrepreneurs that have established the power generation and distribution system. Community electric cooperatives exist in Nepal, the Philippines, and Central and South America.

Community participation is a prerequisite to ensuring the equity and sustainability of local infrastructure investments under this model. It will depend on the local culture and the extent to which all members of a community have been involved in decision making—for example, women's groups, farmers' cooperatives, different ethnic groups, and so on. Where community divisions are an issue, an intermediary organization (for example, the Rural and Renewable Energy Agency in Liberia) will have to help the local planning process.

Prewar power pole in Yandohun, Lofa County.

Liberia's RREA is starting a first pilot venture with the financial support of the World Bank, to reconstruct a micro-hydropower plant in the town of Yandohun in Lofa county. Before the civil war a 30 kW plant was in operation, which was completely destroyed during the war. Yandohun is a community of about 2000 people that will be provided with the power from the plant. Construction began in June 2011 and completion is expected in June 2012. The micro-hydropower plant to be rehabilitated in Yandohun will be owned and run by the local community, who has pledged in-kind manual labor support. The RREA will provide capacity building and training in the establishment and structure of the community cooperative and ensure best practices are followed in setting and collecting connection fees and tariffs. It is hoped that this pilot project will provide a good example to be replicated elsewhere in the country.

Decentralized Electrification Companies

These are traditionally nurtured at the country level before they gain full independence over time. China's electricity distribution program, for example, developed in a decentralized manner. Throughout China, both local and central governments have been important in promoting rural electrification. The role of the central government included the setting of policy objectives, support in financing, and technical assistance. Local electricity companies worked with county and regional governments and adapted these policies to their own rural electrification programs.

The power companies servicing rural areas in China are quite diverse in terms of their size. Regional and provincial systems provide energy supplies primarily to large cities and towns. About 700 out of the 2,400 rural counties in China are directly supplied from the State Power Corporation, which owns and operates regional or provincial networks. In rural areas and smaller townships outside the jurisdiction of these regional systems, electricity supplies are usually the responsibility of decentralized power companies (DPCs). These companies are administered by the government at the township, county, or prefecture level. DPCs are not just in the power distribution business; they also own and operate subtransmission (35 kilovolt, kV) systems, medium- and low-voltage distribution systems, and (in most cases) generation plants. But most are interconnected with adjacent large grids, and about 1,000 rural counties receive most of their supplies from these grids.

Private Rural Electrification or Service Companies

These are commonly private sector electricity distribution companies that are subject to a subsidy program to create an incentive to serve rural areas. Chile has had private sector electricity distribution companies for over 20 years, and has a unique subsidy program to encourage these rural companies to serve the rural populations. Such companies were established as investor-owned utilities and more than two dozen smaller distributors in the early 1990s. These investor-owned utilities have generally been better organized, better capitalized, and more aggressive than the cooperatives that have also been present in the market.

It may be useful to note that most electrification processes started on the basis of private initiatives. These were commonly transferred to public ownership when the quality of supply did not live up to required standards. The Marcos administration in the Philippines, for example, developed a national approach to rural electrification when it recognized the weaknesses of the private franchise system in the mid-1960s. Similarly, in Costa Rica there was early concern in the 1940s about the private operation of the country's largest power producer at the time, as its focus appeared to be more on profit than public service. A constraint of this model is that dealers have high up-front costs, and that cash flows take time to turn positive.

Of the private sector service delivery models, the following could be applied in Liberia: dealer sales and service, leasing, fee for service, and competitive concessions. These models would be pursued under the direction and support of the RREA and Rural Energy Fund (REFund), respectively.

The dealer sales and service model is useful when the technology used is free-standing/stand-alone such as solar photovoltaic (PV) and PV/wind microsystems. Local dealers (supplying PV modules, controllers, batteries, lights, low-wattage direct current DC appliances, and so on) are often consumers with access to credit, and include an initial period (for example, six months) of after-sales service in the sales contract. In the case of financed sales, the equipment is owned by the finance company or the supplier until the loan is paid off. The PV equipment often serves as the primary collateral securing the loan. Loan terms and conditions are typically for three to four years, with a down payment equivalent to 10 to 20 percent of the capital cost of the installation. This is the business approach of Shell Solar, SELCO-India, SOLUZ Inc., and many others. The dealer either installs the system or contracts with local system installers. This is to assure proper installation and applicability of the warranty. Dealer sales and service (direct and financed sales) operations are active in Bangladesh, Brazil, Central America, China, India, Indonesia, Kenya, Mexico, Morocco, the Philippines, South Africa, Sri Lanka, Uganda, and Vietnam.

Leasing also applies primarily to free-standing systems, but in principle could be used, for example, to lease a hydroturbine to an energy service supplier, cooperative, or community-based organization to power a local minigrid. The equipment remains the property of the leasing company, unless there is a lease-to-own option available. SELCO and SOLUZ, among others, have used leasing as a way of lowering the monthly costs of SHSs for customers who could not afford a short-term (three- to four-year) loan. In many cases donor agencies and government agencies using international development assistance or other low-interest funds will subsidize the interest rates to make such units affordable to consumers. Leasing programs (usually from dealers) exist in Bangladesh, Brazil, Central America, China, India, Indonesia, Laos, Meixico, the Philippines, Sri Lanka, and Vietnam.

Fee for service is the most common mechanism for the provision of electricity services by electric utilities, cooperatives, and rural energy service companies (RESCOs). In the latter case, the RESCO owns the generation and power distribution equipment and provides an electricity service. This service can range from 0.1–1 kWh/day DC power from a PV system to full-time alternate current (AC) power from a small hydro minigrid. Customers typically pay an installation or connection fee plus an electricity tariff. RESCOs can include community-owned small electricity cooperatives, RECs, privately owned generation and distribution companies, and nongovernmental organization (NGO)–owned and operated systems. Fee-for-service organizations can be private, nongovernmental, public, or parastatal; such organizations operate in many countries, including Bolivia, the Dominican Republica, Ethiopia, Kiribati (a Pacific island nation), and Mali.

The basic principles behind the RESCO include the following:

- The serviced household does not own the generation equipment; it is owned by an external organization such as a government agency or the RESCO.
- The user does not participate in maintenance—all maintenance and repair service is provided by the RESCO.
- The RESCO establishes and supports equipment standards and quality control.
- The user pays a periodic fee for the use of the system, essentially a rental fee that covers the capital repayment requirement and the cost of providing maintenance, repair, and replacement services. Often a RESCO uses a prepayment system (prepayment cards for energy and power services) rather than attempting any kind of metering, billing, and collections approach. The latter almost always fails.
- The RESCO serves all customers in a geographic area that will become a service territory.
- The RESCO meets customers' priority energy requirements, commensurate with their willingness and ability to pay (recognizing that donors and government will probably need to subsidize the capital costs of the equipment, and that customer fees will need to cover the full operating and business expenses of the RESCO). Public-private partnerships are absolutely essential in Liberia if RESCOs are to provide reliable high-quality services.
- The RESCO provides a mechanism to accept donor supplies of equipment (rarely accompanied by funds or technical support for local training or maintenance) to minimize the need for a capital recovery component in the electricity services fees.
- Finally, the RESCO works with institutional and commercial customers to establish the most efficient and effective basic electricity supply systems and services, tailored to the specific needs of clinics, schools, government offices, water supply, public lighting, microenterprises, and small-scale agriculture.

For successful RESCO set-up and creation, the first task is to identify potential energy service providers in rural areas based on existing skill sets. Potential providers could include entrepreneurs, small and medium enterprises (SMEs), community-based organizations, and cooperatives. The next steps include educating, training, and supporting these entities in the development of a RESCO.

Competitive concessions are being offered in a few countries to create electricity service markets for private concessionaires (enterprises). In a competitive bidding process, proponents that can offer the required level(s) of electricity service at the lowest life-cycle cost or the lowest level of required subsidy have the first right of refusal for an exclusive time-limited franchise. This is in essence the energy service company (ESCO) model under specific market and regulatory conditions. In principle the concession approach can be used for free-standing, microgrid, and minigrid services. A pilot project in Argentina is supporting electricity supply for lighting, radio and TV to about 30,000 rural households and 1,100 provincial public service institutions through private concessionaires using mainly renewable energy systems. Competitive concessions exist in Argentina and Bangladesh.

A variant of the concession approach is being piloted in Liberia with World Bank financing and under implementation of the RREA. It is called the Sustainable Solar Market Packages (SSMP) approach and is catered to the low population densities prevailing in rural Sub-Saharan Africa. The SSMP approach was developed under a World Bank funded project for the Philippines and has also been applied in Tanzania and Zambia. This approach utilizes a combination of innovative instruments to achieve expanded access to modern energy services in rural areas, including:

- Clustering of local areas (e.g., villages, etc.) into commercially viable packages that are bid out on a competitive basis;
- Comprising the base load from community facilities (e.g., schools, health clinics, administrative buildings, police stations, and street lighting) and expanding from there for residential services;
- Utilizing performance-based subsidies and financial incentives to improve affordability and to assist installation/service firms to address market barriers; and
- Including a strong focus on after-sales service and continued marketing.

Selection of geographic areas and communities for this approach still adhere to the selection criteria applied to all rural energy interventions. The SSMP approach has already been implemented in the Philippines, Tanzania, and Zambia. In these countries a single contract was possible that bundled supply, installation, and three- to five-year maintenance, along with an obligation to provide a minimum number of systems on a more commercial basis to households and businesses. Contractors selected competitively are providing such services to over 250 villages in the Philippines. In Liberia the SSMP approach is being piloted as an early demonstration project of the RREA under the World Bank's "Catalyzing New Renewable Energy in Rural Liberia" program.

Technology Options

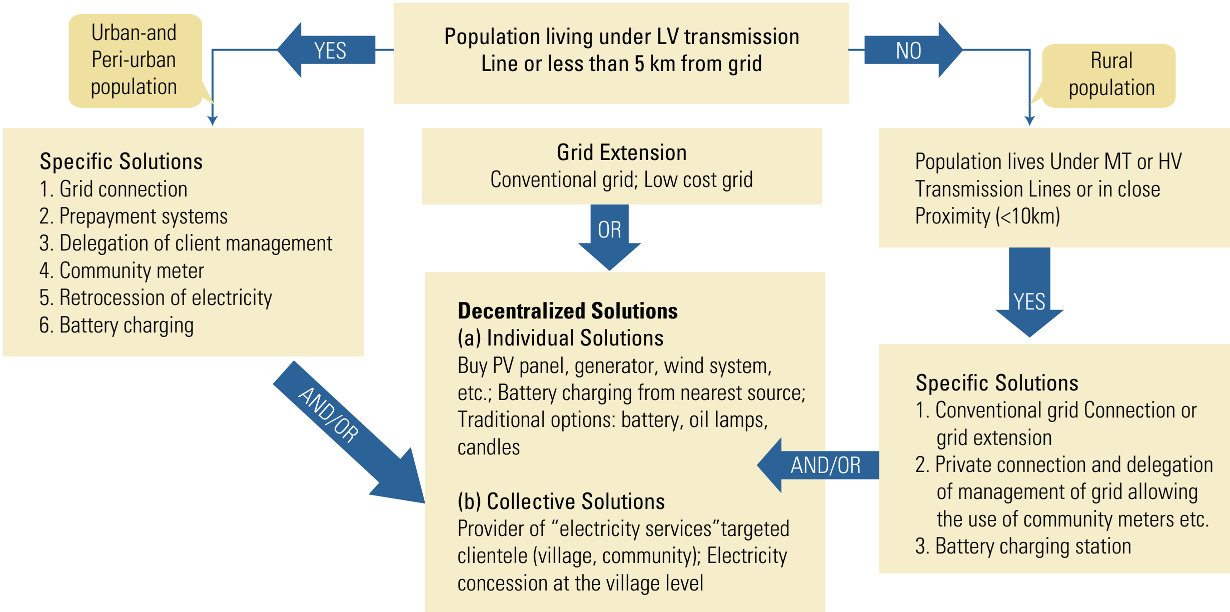
The electricity needs of Liberia's population are relatively low, especially in rural areas. They mainly include home and community lighting, improved health-care and educational facilities, and communication tools for access to information through radio, telephone (cell-phone charging), and television. Electricity provides only some of the energy needs. For thermal applications such as cooking, needs are most often met using firewood or charcoal.

In Liberia over 80 percent of household energy requirements are met using thermal energy for cooking, and both urban and rural households rely almost exclusively on charcoal and firewood—the United Nations Development Programme (UNDP) has estimated that 99.5 percent of the population relies on firewood, charcoal, and palm oil for their energy needs. For off-grid lighting, households expend a significant amount of their income on inferior forms such as candles, flashlights, small battery-operated LED lamps, and kerosene or oil lanterns; they also create "jack-o'-lanterns"—crude lamps using milk cans, cloth wicks, and palm oil, which create dense and harmful smoke. Production activities, notably agriculture, rely primarily on human power. Some households have small Tiger generators of 500–900 watts to serve larger processing loads such as rice mills. Off-grid businesses may be able to afford larger diesel generators for other uses, such as video clubs. The use of car batteries is also common.

Worldwide, on-grid electrification is the most common and most desired means of electricity supply. But in low-density or remote areas, on-grid electrification is often not the least-cost option. Where population densities are low, diesel generators, renewable energy (solar, micro-hydropower, wind, and small biomass-fired generators), and hybrids of such options are often more cost effective. Specific solutions depend on the organizations involved as well as the energy choices, needs, and abilities of the local population: no solution is applicable under all circumstances. Figure 8.1 lists rules of thumb for identifying the most appropriate intervention option given a certain target group or population. In principle, for populations located within 10 km of an existing medium- or high-tension transmission line, the grid connection is the best option. If the distance to the grid exceeds 10 km, off-grid/decentralized options are likely to be least cost.

For Liberia, given the limited range of the current grid and the relatively low load requirements of the current rural population, decentralized off-grid solutions, including minigrids and stand-alone systems designed

Figure 8.1 | Rural Electrification Intervention Options



Source: Author's schematics.

for small loads and single applications, appear the best strategy. Serving the areas not accessible to the Monrovia grid or regional interconnection with an integrated electric power network will be a long-term process, and this is impractical for the more remote areas of Liberia. Running power lines over long distances and between isolated households is costly, and it is unlikely that associated costs be borne by the rural population past the donor support period.

Renewable energy technologies are particularly well suited to an off-grid, distributed generation scenario, and Liberia is endowed with significant renewable energy resources, including solar, biomass, and hydropower resources. Table 8.2 below provides an overview of the renewable energy applications that are available as an alternative to the conventional fossil-fueled or grid-based approach, and the needs they meet.

There is no single technology that is most suitable for providing rural energy services in Liberia. Determining the appropriate technology, supply, and delivery options will require consideration of the following:

- The resources indigenous to the area (solar insulation, rivers and characteristics, agricultural waste and other biomass sources, and so on)
- Population (household) density
- Proximity to existing grid or other electrified villages
- Size of demand, especially commercial and industrial, and number of initial connections indicated
- The ability of households and the commercial sector to pay
- Existing infrastructure (water, roads) and access to markets
- Existing industry including agricultural activities (rice mills and so on) and other productive uses (for power tools and so on)
- Number of commercial establishments
- Local political support as well as community willingness to contribute toward labor, management, and/or capital costs
- Existing public infrastructure facilities (schools, health clinics, and so on)

Table 8.2 | Renewable Energy Services for Off-Grid Applications

Energy Services	Renewable Energy Applications	Conventional Alternatives
Lighting and other small electric needs (homes, schools, street lighting, telecommunications, hand tools, vaccine storage)	• Hydropower (pico-scale, microscale, small-scale) • Biogas from household-scale digester • Small-scale biomass gasifier with gas engine • Village-scale minigrids and solar/wind hybrid systems • Solar home systems (SHSs)	Candles, kerosene, batteries, central battery recharging, diesel generators
Small industry	• Small hydro with electric motor • Biomass power generation and electric motor • Biomass gasification with gas engine	Diesel generators
Water pumping (agriculture and drinking)	• Mechanical wind pumps • Solar photovoltaic (PV) pumps	Diesel pumps
Heating and cooling (crop drying and other agricultural processing, hot water)	• Biomass direct combustion • Biogas from small- and medium-scale digesters • Solar crop dryers • Solar water heaters • Ice making for food preparation	Liquefied petroleum gas (LPG), kerosene, diesel generators

Source: Draft Action Plan and Rationale for Renewable Energy and Rural Development. Ministry of Lands, Mines and Energy, Monrovia, Liberia, 2007.

The rural energy master plan to be developed by the RREA is expected to use geographic information system (GIS) mapping, socioeconomic surveys, and resource assessments to determine which technology, delivery, and supply options are most appropriate for Liberia's diverse geographic areas. General technology delivery options include:

» Minigrids
» Stand-alone systems
» Distributed appliances

Each is considered in more detail below.

Minigrids

A minigrid is technically a small electricity distribution system providing grid-quality, AC power with self-contained generation, distribution, and transmission for an area separate from and generally smaller than that covered by the national grid. It is often low voltage, but there is no threshold size that makes a minigrid "mini." In general, minigrids are suitable for areas where the following conditions are present:

» No national grid-extension plans for the next five years at minimum
» No other off-grid plans
» Reasonable number of regional or district-level public facilities to establish a substantial base public load
» General household density of ✥50 households per square kilometer in clusters
» Overall population size of at least 2,000 persons
» Community commitment of in-kind support or cofinancing of start-up costs
» Indication of willingness and ability to pay the requisite tariff, allowing for cost recovery of operating and fuel (if applicable) costs
» Evidence of existing productive uses and robust economic activity (such as in thriving border areas)
» Supportive political landscape
» Measures in place to prevent theft and manage the electricity system

A multicriteria analysis should be performed to consider and weigh the values for the above measures. Areas meeting the conditions should be considered for a minigrid. In Liberia these areas will most likely include county capitals such as Gbarnga and Voinjama, and other large urban areas such as Ganta and Zorzor.

The multicriteria analysis should be overlaid with a resource assessment to determine what natural assets are available, if any. Resource availability, together with the load forecast and the ability of residents to pay, will determine the least-cost approach to service provision. In areas such as Zorzor, proximity of rivers may yield a feasible hydropower approach. But in areas such as Gbarnga, diesel may prove the lowest-cost option. Hybrid systems combining two or more technologies are likely the best approach for many areas (for example, using a diesel backup for hydrosystems during the dry season).

A key element for the success of these minigrids is that the sale of electricity in the communities benefiting from minigrids has to generate enough revenue to finance the maintenance and extension of the network to other communities. As more communities meet the criteria to be provided with power, the financial requirements will continue to increase.

Though it may seem that the above criteria may necessitate the exclusion of poorer areas, it should be noted that electricity can only stimulate development that is already taking place—it will not initiate development. Communities that are very poor and have little economic activity are unlikely to derive much economic benefit from an electricity supply, although they may derive substantial social benefits from better lighting and communications. For this reason smaller interventions, such as stand-alone systems and distributed appliances, are better suited for poorer populations.

When designing rural minigrids, potential issues of electricity theft should be preempted, for example, by installing prepaid meters and considering other measures such as master meters that are shared by residential and commercial structures in close proximity, where a community representative collects payments from the group. Alternatively, simple wiring looms with connection boards have worked well in Nepal and South Africa.

Stand-Alone or Freestanding Systems

Stand-alone systems are dedicated to the space where they are located. Examples include SHSs, which include, typically, roof- or pole-mounted solar panels, batteries, and a controller/inverter; mechanical wind turbines to pump water out of a well; household biogas systems that take methane from animal waste slurry and convert it for cooking and/or electricity; and small generator sets that run on diesel, gas, or biofuel. Stand-alone systems can also be used for community services, such as solar-powered battery charging stations where individuals can charge lanterns, cell phones, and car batteries. Stand-alone systems work well as hybrids, combining, for example, small solar and wind technologies, or solar, diesel, and a battery bank.

Stand-alone systems are in use all over Liberia. Most commonly, households and businesses use diesel or gas generators to run small appliances and power tools. But companies such as Club Beer in Monrovia also use their own generators to run large industrial applications. In addition, SHSs are in use to a limited extent throughout Liberia by small businesses and a few homes. However, solar home system prices are prohibitive compared to diesel generation and as a result their use is very limited.

The challenge with such systems is maintenance: diesel systems require constant maintenance as well as a consistent and costly supply of fuel and oil; solar systems require monitoring of voltage and battery discharge levels, load management, and some maintenance to keep panels clean. There are very few solar engineers in Liberia and all are located in Monrovia. Therefore, the challenge for solar technology—and also for introducing new renewable energy technologies such as wind for water pumping or biogas—is creating a network of service providers with sufficient knowledge of installation standards, and maintenance and upkeep requirements.

Battery-charging stations are in use as well, to a limited extent, most popularly for charging cell phones. These use small diesel generators. Through the World Bank/International Finance Corporation

(IFC)–supported Lighting Africa initiative, a private sector–NGO partnership is providing microfinanced solar lanterns and solar-battery-charging stations in Nimba, Bong, and Lofa counties. There is a good opportunity to expand upon this model: solar-charging stations could be put to use in booths that currently sell scratch cards, and could be used to charge cell phones as well as solar lanterns. These booths could then become lantern vendors (through direct sale or lease) to expand upon their current business. Such a model could also be put in place where cell-phone companies have their signal towers. Such towers in remote areas currently spend an exorbitant amount on power generation for fuel and generator maintenance. Solar power for these remote stations would lower the cost of service, and could be combined with battery-charging services to generate additional revenue for the company.

Distributed Appliances

At the lowest end of the energy ladder are consumers who cannot afford generators or connections to the current grid, and whose electricity needs include basic lighting. Such consumers would depend upon dry-cell batteries for small radios, and communal charging stations for a household cell phone. Currently these consumers buy dry-cell batteries for small, usually LED, Chinese-made flashlights and desk lamps. The poorer consumers buy candles and construct jack-o'-lanterns.

The generally held assumption is that both within and outside of Monrovia, the major barrier to facilitating expanded access to energy is a lack of ability to pay for these services. But the evidence shows the contrary: residents without access to the grid pay more per kilowatt-hour for inferior sources of lighting than their counterparts with grid electricity—which, as of June 2011, costs US$0.55/kWh. Table 8.3 shows that Liberian consumers at the bottom of the energy ladder actually pay the most:

- Dry-cell batteries US$74.01/kWh
- Car batteries US$8.43/kWh
- Candles US$8.27/kWh
- Generator (Tiger) US$3.96/kWh
- Kerosene (lighting) US$1.53/kWh
- Grid tariff US$0.43/kWh

Facilitating access to improved sources of lighting and battery charging can be accomplished through distributed appliances for those with the least capital. For example, solar lanterns that cost US$30 and last for 5 to 10 years, if made available through microfinance, can save a significant amount of money for consumers who currently spend US$5 per month on candles and batteries (US$300–US$600 over 5 to 10 years), making their limited income available for other uses.

Other distributed appliances include manually (crank)-powered lanterns, solar or crank-powered radios, prewired integrated solar PV systems with a 10 to 20 watt-peak PV module, battery, controller, two CFL or LED lamps and built-in radio and speakers; solar phone chargers; improved cook stoves that reduce biomass inputs by 50 percent or more; and solar vaccine refrigerators.

Renewable Resources in Liberia

Liberia is endowed with significant renewable energy resources, including biomass, hydropower, and solar energy. Milbrandt (2009) conducted a biomass resource assessment for Liberia that concluded that Liberia has a power production potential from biomass resources of 21,600 GWh/year assuming up to 30 percent of the cropland were to be used for expanded cash crops production. In addition, a number of feasibility studies carried out over the period of 1976 to 1983 identified significant hydropower resources, including 14 large-scale schemes in 6 main rivers and 24 small hydropower schemes (up to 5 MW).

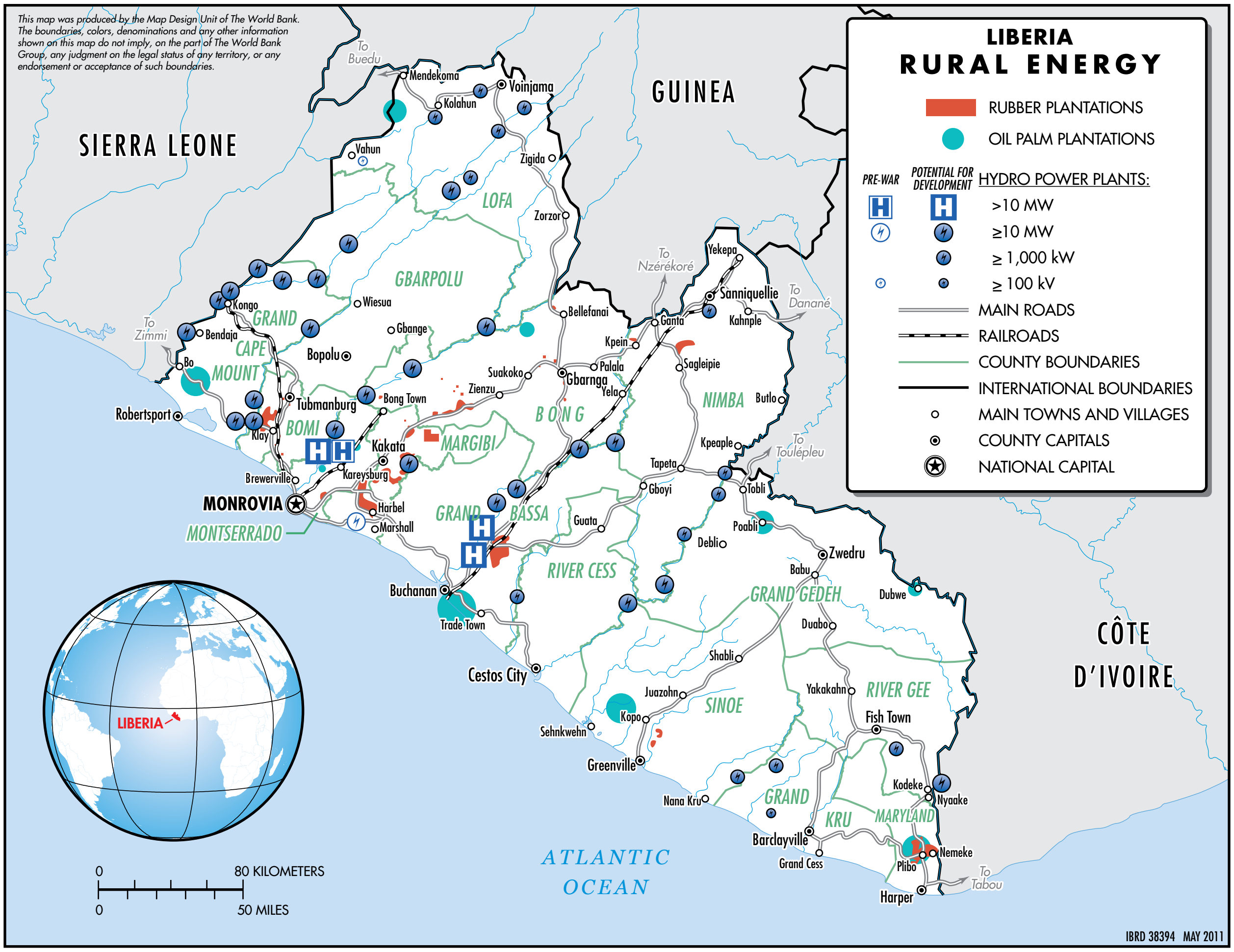
Finally, despite the lack of national data on the solar resources, global weather data from NREL and other sources show that the monthly average daily solar radiation on horizontal surfaces in Liberia is between 4.0 and 6.0 kWh/ m^2/day. This is supported by existing donor-funded pilot projects utilizing solar energy, which have proven a strong solar resource year round. The map in Figure 8.2 shows the hydropower resources identified in Liberia prewar, as well as the rubber and oil

Table 8.3 | Costs of Useful Energy in Liberia

1. Fuel	Wood (rural)	Charcoal (rural)	Charcoal (city)	Wood (city)	Kerosene (>10 Litre)	LP Gas	Kerosene (100 ml)	Kerosene	LP Gas	Grid	PV	Grid	Kerosene (100 ml)	SHS PV (cash)	Generator (Tiger)	Car Batts	Candles
2. Unit of sale	[kg]	[kg]	[kg]	[kg]	[litre]	[kg]	[litre]	[litre]	[kg]	[kWh]	[kWh]	[kWh]	[litre]	[kWh]	[kWh]	[Batt 80Ah]	[pkt]
3. End-use	cooking	cooking	cooking	cooking	cooking	cooking	cooking	fridge	fridge	fridge	fridge	elec	lighting	elec	elec	lighting/ TV	lighting
4. Price [LD] (incl VAT)	1	5	13	10	60	162	120	60	162	32	105	32	120	105	250	408	60
5. Gross energy [MJ]	17	27	27	17	37	49	37	37	49	3.6	3.6	3.6	37	3.6	3.6	2.8	20.7
6. Conversion to useful	30%	30%	30%	30%	62%	78%	62%	120%	120%	190%	190%	90%	11%	90%	90%	90%	2%
7. Useful energy cost [LD/kWh]	1	2	6	7	9	15	19	5	10	17	55	35	107	117	277	590	579
8. Useful energy cost [USD/kWh]	0.01	0.03	0.08	0.10	0.13	0.22	0.27	0.07	0.14	0.24	0.79	0.50	1.53	1.67	3.96	8.43	8.27

Source: Calculations by Chris Purcell, 2009.

Figure 8.2 | Liberia's Potential Hydropower and Rubber/Oil Palm Resources



Source: World Bank Map Unit, 2011.

palm resources currently available under concessions. The following sections provide more detail on each of Liberia's renewable resources.

Biomass

The chapter covering Liberia's demand assessment reviewed the scope and size of the agriculture and forestry sectors. Liberia's landscape is almost entirely either under forest cover or being used as agricultural cropland. Between these two land uses, biomass opportunities are significant.

Biomass resources currently meet about 99.5 percent of the Liberian population's energy needs and are therefore vital to basic welfare and economic activity. Traditional biomass products such as firewood and charcoal are the primary energy source used for domestic cooking and heating. But other more efficient biomass technologies are available that could open opportunities for agriculture and rural development, and provide other socioeconomic and environmental benefits.

A variety of biomass resources exist in the country in large quantities and with opportunities for expansion. While the contribution of food crop residues, animal manure, and municipal solid waste (MSW) is small in comparison with other resources at a national level, they could play a valuable role in stand-alone electricity applications and be particularly effective for households in remote rural areas. On the other hand, cash crop and forest residues, resulting mainly from medium and large enterprises, provide opportunities for large-scale centralized power generation.

Considering the potential biomass resources or the expansion of key existing resources such as oil palm, coconut, and sugarcane, Milbrandt (2009) evaluated fuel and power production potential on available cropland. The study estimated that of the total cropland in Liberia, only 6 percent is currently cultivated and that the remaining cropland amounts to some 3 million hectares. It is unrealistic to assume that all of this land would go to cash crop cultivation—a portion of it may be needed to maintain forest ecosystems and their unique biodiversity, or be used for food crop production and other agricultural activities, or be converted to urban land.

Therefore, the study evaluated the fuel and power production potential of biomass resources under three scenarios: using 10 percent, 25 percent, and 50 percent of the available cropland for cash crop expansion. Table 8.4 presents the results of using up to 30 percent of the available cropland for expanded cash crop production. These figures have to be considered with great caution and certainly only refer to the theoretically available resources evaluated largely on the basis of satellite imaging.

Beyond Milbrandt's (2009) general biomass resource assessment, a scoping study carried out by Schaffer & Associates International in 2008 (Aah-Kee, 2009) found that there is concrete potential to develop over 80 MW of power from rubber trees on five sites in Liberia. The proposed sites include Kakata, Guthrie Plantation, Saint Paul River, the Fendell Campus of the University of Liberia, and the Firestone Plantation. At the Guthrie Plantation site, there are sufficient confirmed supplies of water and rubber trees for a 20 MW wood-fired power plant.

Fuel wood and charcoal consumption. The latest data from the National Charcoal Union of Liberia (NACUL) shows that charcoal production in Liberia in 2005 stood at 36,500 tonnes per year. There are no firm data on firewood consumption in Liberia, but findings from a survey conducted by the Center for Sustainable Energy Technologies (CSET) in 2004 indicated that scarcity of firewood is becoming a serious problem in most parts of Liberia. Nationally, Liberia is harvesting above the level that can be sustained annually without depleting the current stock and degrading the environment. It is estimated that about 960,000 trees are cut down annually for charcoal to serve the Monrovia area alone. Forecasts for the country estimate an annual increase in demand of about 0.6 m^3 per household.

Therefore, as Liberia's dependence on its biomass resources continue to evolve, it is critical that measures are put in place for sustainable harvesting and replanting practices, as well as measures to reduce consumption. In addition, the impacts of firewood shortages need to be researched to formulate policy that will protect the resource. Without such a policy, demand for charcoal and firewood will continue to grow in the absence of electricity and energy efficiency measures. The use of woody biomass as a source of energy will continue to increase in relation to rural population growth and poverty. If this demand is not met in a sustainable manner, it will eventually lead to deforestation, environmental degradation, and desertification in Liberia.

In addition, indoor pollution from cooking smoke and poor ventilation, and the time and effort required to collect firewood, negatively impact the well-being of Liberia's rural population, especially women and children. Kilns that increase the efficiency of charcoal production are one option for better biomass use, as well as improved and clean-burning cook stoves. It is outside the scope of this report to investigate technology options or recommend strategies for disseminating improved cook stoves, but this should be an early initiative of the RREA.

Hydropower. Liberia has six major rivers, which drain 66 percent of the country's water. These include the rivers Mano, Saint Paul, Lofa, Saint John, Cestos, and Cavalla. Short coastal waterways drain about 3 percent of the country's water. This intensive drainage pattern indicates considerable potential for hydroelectric power

Table 8.4 | Theoretical Potential for Biopower and Biofuels from Existing and Potential Biomass Resources Assuming 30% of Available Cropland Is Planted

Existing Resources	Biopower (GWh/year)	Biodiesel (1,000 m^3/year)	Ethanol (1,000 m^3/year)
Food crop residues	188	n.a.	n.a.
Cash crop residues	5,889	n.a.	n.a.
Biogas from animal manure	219	n.a.	n.a.
Forest residues	15,248	n.a.	n.a.
MSW (biogenic material only)	52	n.a.	n.a.
Total	**21,596**	n.a.	n.a.
Potential resources			
Vegetable oils *	4,946	2,473	n.a.
Sugarcane **	n.a.		1,527
Crop residues ***	26,923		5,385
Total	**31,869**	**2,473**	**6,912**

Source: Milbrandt, 2009.

Note: n.a. = Not applicable; MSW = municipal solid waste; * Includes palm and coconut oil—using 10 percent of available cropland for oil palm and 10 percent for coconut; ** Using 10 percent of available cropland; *** Includes oil palm, coconut, and sugarcane residues—using 30 percent of available land (10 percent for each crop); 1 liter of vegetable oil = 2 kWh at 21 percent conversion efficiency; 1 ton of lignocellulosic biomass yields 300 liters of ethanol.

In mid-2011, Liberia produces vegetable oils, which are mostly used in food consumption, medicinal, and few other purposes. Thus, it is unlikely that these resources would be used as a diesel substitute in the near future.

in Liberia. A number of feasibility studies were carried out over the period 1976–1983. At least 14 large-scale schemes were identified in the 6 main rivers. The most significant of these are discussed in the chapter on supply options.

About 24 sites have been identified for small hydroelectric schemes. In 1988 the LEC sought investment capital to develop six mini-hydropower schemes with total installed capacity of about 20 MW, which was intended to supply 3 rural grids serving 14 major population centers in the northern half of Liberia. This proposal was disrupted by the civil conflict. The 24 potential sites identified are shown in Table 8.5, and span most of the country.

In recent years UNDP, together with the United Nations Industrial Development Organization (UNIDO), have conducted six prefeasibility studies on small hydropower resources included in Table 8.5. The results of these studies have not yet been made available. An early initiative of the RREA should be the assessment of Liberia's small hydropower resources for minigrid and community electrification.

Solar. Although Liberia has high rainfall, annual solar insulation shows good prospects for the application of solar technologies such as PV and solar thermal systems for health care, education, agriculture, community livelihood, and microenterprises. Despite the lack of national data on solar resources in Liberia, global weather data obtained from RET Screen International of Canada and NREL show that the monthly average daily solar radiation on horizontal surfaces in Liberia is between 4.0 and 6.0 kWh/m^2/day. During the summer months of the rainy season, insolation averages between 4.0 and 5.0 kWh/m^2/day; during the winter months of the dry season it is higher—5.0 to 6.0 kWh/m^2/day. Inland areas of Liberia receive slightly greater insolation than coastal areas.

Because the sun does not shine with equal intensity every day, at night, and during inclement weather—cloud cover, rain, and so on—a storage factor must be

Table 8.5 | Potential Sites for Small Hydroelectric Development, Reported March 1988

River Basin	Site	Design Flow (m^3/sec)	Head (meters)	Installed KW Potential
Mano	MR1	10.40	30.0	2,474
	MR2	9.47	30.1	2,252
	MR3	8.09	25.0	1,603
	MR4	3.61	20.0	572
	MR5	2.43	12.0	231
Lofa	LR1	55.70	17.0	7,508
	LR2	37.10	20.0	5,884
	LR3	3.48	55.0	1,517
	LR4	3.42	10.0	271
	LR5	3.35	7.0	186
	LR6	3.25	6.0	153
Farmington	FR1	16.90	15.0	2,010
Saint John	SJR1	60.40	33.0	15,806
	SJR2	57.50	28.0	12,767
	SJR3	37.70	28.0	8,370
	SJR4	2.32	25.0	460
Timbo	TR1	6.51	12.0	619
Cestos	CR1	8.30	12.0	789
	CR2	7.35	10.0	582
	CR3	6.51	15.0	774
Sehnkweh	SR1	5.78	12.0	550
	SR2	3.47	12.0	330
Buto	BR1	0.26	20.0	44
Cavalla	GR1	0.66	25.0	130

Source: LEC.

employed with solar power technologies. This is why PV systems employ batteries, which provide backup for reliable system operation during periods of rain and after sunset. Most PV systems are designed with sufficient battery capacity to allow for 3 to 5 days of autonomy—that is, days without adequate sunlight. Even during the rainy season in Liberia the sun shines for some amount of time on most days. Therefore, with appropriate system design, solar technologies are considered highly suitable for widespread deployment and for all seasons.

Wind. There are few data available on wind speeds in Liberia since no assessment has been performed. However, global and regional wind maps show a poor resource for West Africa. Mechanical turbines for water pumping could nevertheless be well suited for Liberia. A wind resource assessment for Liberia would help determine the applicability of wind energy for Liberia.

Geothermal. There does not appear to be a geothermal resource in Liberia. Though higher heat flow values are found offshore to the south and west in the Guinea and Sierra Leone Basins, and are attributed to possible tectonic activity, the thermal effects of the activity are not thought to extend inland to the Liberian Shield.

As of 2011 the potential of Liberia's existing renewable resources with the exception of traditionally used biomass is hardly being harnessed. Modern renewable-energy-based appliances are available on a limited basis only in Monrovia, and there is no quality control for the products that are being imported. Similarly, both technical and engineering skills in the area of new renewable energy technologies are extremely scarce. Moreover, there is no financing mechanism in place that would be available either to individual consumers or communities for purchase and installation of new renewable energy technologies or for private providers of these technologies. The only two exceptions are small pilot projects that the USAID funded during late 2006–early 2009 on a full grant basis, and the award of a grant to one of the few active renewable energy entrepreneurs through the Lighting Africa initiative.

Financing Modern Energy Services

Rural electrification requires a long planning horizon and significant resources. A planning horizon of 30 years such as the one chosen in this report is typical for rural electrification programs, such as those in Thailand (25 years) and Bangladesh (ongoing since 1978). Programs are often developed and adjusted along 5-year segments, such as in Ghana. An overall master plan developed at the outset of a rural electrification program is required to delineate the scope of rural electrification based on realistic criteria. The strategy for how it will be financed over the long term is a crucial part of the master plan.

The funding requirements are huge, as is illustrated by some of the most successful programs highlighted in this chapter. Rural electrification in Bangladesh has attracted donor finance alone in excess of US$1 billion over 1975–2001. Similarly, the Thai program has cost in excess of US$1.5 billion in the period 1977–96. The investments made under Tunisia's program cost approximately US$340 million between 1977 and 2001.

Cofinancing, including by multilateral and bilateral donors, has been used to enhance available government finance. When Costa Rica's cooperative COOPESANTOS, for example, started out in the mid-1960s, it benefited from a major loan the nation signed with the USAID in 1966 for 40 years with a 10-year grace period at an annual interest rate of 1 percent and a 2.5 percent rate during the amortization period. Loans on concessionary terms such as these provide the basis on which rural electrification programs can prove to be financially and economically sound.

A sound financial and economic basis for electrification is determined by the following factors: (i) potential benefits being maximized; (ii) costs being minimized; (iii) subsidies being used wisely; and (iv) an enabling environment.

Maximization of Potential Benefits

Different countries have selected different types of methods to evaluate such benefits. These range from a purely quantitative analysis of projected revenue streams to a more indicator-based analysis, which takes account of numerous qualitative benefits as well. But at the origin of revenue is the projection of how household demand in an area is likely to develop compared with commercial or industrial activity. It is the latter that will bring the bulk of the revenue. Put differently, if an area has little commercial/industrial prospect, it might be more difficult to justify electrification by any means other than the smallest interventions (SHS and distributed appliances). This is not to say that revenues have to reach a break-even point immediately after following electrification. The principle of average coverage rural electrification (ACRE), which was developed in the United States, suggests that the objective is to develop infrastructure that is expected to lose money in the early years followed by profitability as the load grows to cover the cost of service.

When considering the geographical reach for rural electrification, taking account of productive uses is important if economic viability of the extension is to be reached. A rural expansion strategy should thus target those areas that demonstrate existing or immediately feasible and solid productive uses. This may require rural agencies such as Liberia's RREA to help in the creation of productive uses in many rural areas, where economic activities are stagnant or based almost exclusively on manual labor (for example, farming).

Once the areas for rural electrification are selected—including all strata of technology interventions mentioned above—promotional strategies can be used to increase the use of electricity and thus the revenue from rural areas. In Bangladesh, for example, the Rural Electrification Board (REB) promoted productive uses such as irrigation, rice milling, and household power looms. One of the ideas going into this initiative was the fact that productive uses of electricity can help generate the cash needed among rural customers to support lighting and other lifestyle improvements afforded by electricity.

In Liberia innovative strategies can be employed—for example, where solar systems are placed on schools, teachers can be offered the opportunity to manage a charging station for lights and possibly cell phones; work with cell-phone companies to have their retail agents offer cell-phone and LED lamp recharging services; and target lighting technologies at shops and outdoor markets to extend working hours and improve security. In the case of cell-phone companies, despite the very high cost of powering cell-phone base stations with diesel power (an estimated US$1,500 a month for fuel per base station plus extremely difficult supply conditions during the rainy season), none of the cell-phone companies (Lonestar, Cellcom, and so on) are using PV. But both Lonestar and Cellcom have indicated an interest in converting some of their "noncritical" base stations to PV.

Keeping payment discipline up in rural areas and establishing consumer confidence are also key to keeping a satisfactory revenue stream. Both can be supported with the help of a responsive customer service regime.

Minimizing Costs

Cost savings can make significant contributions to a program's viability. In Thailand, for example, an additional 837 villages or 22 percent more than had been estimated could be electrified under the Accelerated Rural Electrification Project I. Where applicable, the costs of grid extension can be minimized in numerous ways: (i) standardization of equipment and components; (ii) reliance on locally manufactured materials; and (iii) provision of incentives to communities to contribute to the costs of electrification.

In Thailand the Provincial Electricity Authority (PEA)—the national distribution utility charged with electrification—opted to standardize all equipment and components used for constructing the distribution systems of all electrification projects. This enabled the project engineers to minimize the variety of equipment and components used. As a result, the PEA was able to reduce procurement, materials handling, and purchasing expenses through bulk purchases. That gave the PEA control over an important component of overall project costs. It also significantly reduced the risk of equipment and component shortages, providing project managers an efficient way to handle materials required for field construction. Because they were familiar with the equipment and technical standards, field construction crews were better able to complete assigned tasks on time and within the allocated budget.

Similarly, the PEA in Thailand realized that imported materials were costly and might require a longer procurement time. To reduce these costs they developed local capacity to produce wires and cables. The PEA purchased aluminum ingots from abroad, but also hired local contractors to process the imported ingots into aluminum wire for project use. In Ghana similar cost-saving measures were used by promoting the plantation of teak trees to be used as poles in the distribution sector.

In many instances using innovative institutional structures can also help reduce costs. In the Philippines, for example, the concept of the Barangay Power Association (BAPA) was developed and applied by many cooperatives to reduce billing and metering costs. A BAPA consists of a cluster of 30 or more customers who draw their supplies from a common meter, which registers their overall consumption. These consumers, who also have their own individual meters, pay their bills to the BAPA; in turn, the BAPA pays the overall bill of the REC. The BAPA receives a quantity discount on the electricity supplied through it, thus reducing billing and collection costs. In addition, the BAPA acts to deter pilferage.

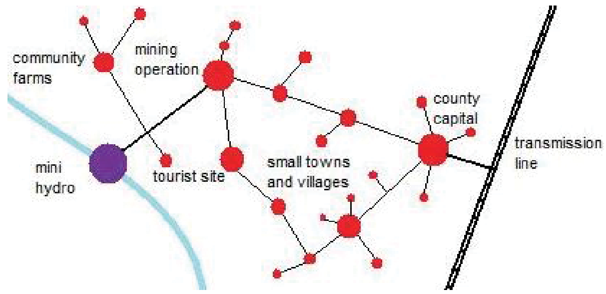
In Liberia, though extension of the Monrovia grid may be a faraway prospect for many communities in the interior, the idea of organic grid development—whereby a number of separate or minigrids are developed in urban or border areas that meet the criteria, gradually expanding out to potentially connect with other minigrids—should not be discounted. Establishment of minigrids should be carried out based on the same technological standardization and other cost-saving measures mentioned above as traditional grid extension.

Figure 8.3 depicts an example of organic grid development. In this scenario the installation of minigrids is not seen as a one-time or static measure. Rather, minigrids are envisioned as seeds of eventual grid expansion. The grid grows with each additional minigrid, so that eventually within regions, especially those adjacent to the planned WAPP CLSG interconnection, an entire grid develops and allows for connection to more remote communities that might not have been considered for a minigrid initially. In this way the installation of remote grids can be seen as mobile grid development, whereby a near-term economically feasible intervention translates into a long-term electrification strategy.

Use of Subsidies

Effective rural electricity programs are generally based on good subsidy policies. Subsidy programs are efficient when they respond to the three criteria of efficiency, equity, and effectiveness. Efficiency refers to maximizing the social (or economic) benefits by comparing the rural electrification program to its opportunity costs. For example, many rural electrification programs have run into difficulties

Figure 8.3 I A Sample Organic Grid Development Scenario



Source: Matthew Troniak, 2007.

because of overexpansion to regions with very little demand. Equity refers to the extent to which subsidies should reach poor people that do not have electricity service. Effectiveness refers to the fact that, to be justified, subsidies have to be for programs that work; otherwise they are poorly targeted.

Often subsidies for the provision of affordable modern energy services are well intentioned, but may have counterproductive side effects. These include: (i) causing the clients to not choose the least-cost option and thus limiting the range of access that could be reached in the absence of subsidies; (ii) promoting fiscally unsustainable programs; and (iii) discouraging efficient energy use. In addition, subsidies can distort the market. For example, if a private company is selling SHSs in one community at full price, but the government is subsidizing similar systems in the community next door, the cost of the systems will be perceived as too high by those not receiving subsidies and free market development will be hampered.

Subsidies generally work best if they are directly targeted to alleviate market failure. In the context of developing countries this relates mainly to high start-up costs and risks, and external costs and benefits. Costs of rural extension programs are often US$0.40 to US$0.70 or more per kilowatt hour initially for distribution extensions only, but such rates can decline rapidly as densities rise toward levels found in urban areas. To be sustainable, the financing of the access agenda ultimately needs to be resourced from within the country. But the capital required up-front for the necessary infrastructure has in many of the success stories in developing countries come from bilateral or multilateral donors.

The problems posed by start-up costs and risks arise partly from the real or perceived lack of creditworthiness of low-income consumers, and partly from a shortage of long-term credit. Solutions to lacking credit can be found by establishing access to microcredit from banks, the private sector, or electricity companies. Electricity companies, for example, can provide credit by including connection and service fees in consumers' bills and spreading them over several years. External costs and benefits often stem from negative or positive environmental and health externalities that various sources of energy generate. While the taxation of externalities is highly successful in developed countries, rural education and extension services to inform people about the poor health effects of traditional technologies (generator fumes, open fires, and so on) have proven more effective in the developing world. Where energy sources provide global environmental benefits such as in the fight for climate change and the depletion of the ozone layer, international finances are now available to reduce the costs of technologies that generate these benefits.

Enabling Environment

Even well-conceived investments in rural energy may falter, not because they are intrinsically wrong, but because economic conditions may be working against them. For example, in rapidly developing agricultural regions, the provision of electricity helps to raise the productivity of local agroindustrial and commercial activities by supplying motive power, refrigeration, lighting, and process heating. In turn increased earnings from agriculture, local industry, and commerce raise households' demands for electricity. But when development efforts fail because of, say, poor crop pricing and marketing policies, electricity supplies may be able to do little to remedy the situation, nor will electricity or other modern fuels be in great demand. If it is to serve a purpose, electricity needs a market, as do other energy forms such as improved cook stoves and renewables. In this sense, coordination within the sector and across other sectors is critical to achieving optimal results.

Involving the future recipients of modern energy services. Local stakeholders such as county development committees and village leaders must be included in the planning and selection of electrification interventions from the very beginning. This could initially take the form of focus groups to determine the needs, technical and economic capacity, and priorities of communities under consideration. Communities must be encouraged to articulate their own demand patterns and decide how these can best be met from a range of energy supply options. Focus groups can also help educate communities on the potential uses of renewable energy and modern energy services. Rendering local, community, and individual cost sharing, whether in-kind or actual, mandatory to supplement donor funding is key in facilitating local ownership (especially where local management is required) and sustainability.

Providing information and enhancing access to good technologies. Liberia does not as yet have a market for renewable energy technologies, but the existence of a thriving market for LED lamps is evidence of a demand for better, low-cost lighting, even if the products currently offered in the market still lack in quality. Existing supply chains for kerosene, LED lamps, compact fluorescent lamp (CFL) bulbs, cook stoves, and even generators could be utilized to introduce improved technologies to all areas of the country. The RREA has an important role to play in making new and good quality products visible to the market through its own network of contacts and through bringing demonstration products from a number of sources. Examples include:

» Small portable LED lamps, such as those being tested under the Lighting Africa program, from suppliers (such as Ammini, Cosmos Ignite, and Thrive in India; Barefoot Power in Australia; Philips in the Netherlands; SunNight Solar in the United States; or Shanghai Roy Solar in China) that use LED cells that produce over 100 lumens per watt. These solar LED lights are priced in the US$10–US$50 range. A product from "Thrive" is well suited to a light rental arrangement—the kit comprises a 20 watt peak solar PV panel charging unit that can charge 5 lamps simultaneously and 25 small LED lamps, where each lamp can provide up to 12 hours of lighting on a single charge. In addition, Thrive provides a good model for establishing manufacturing capability in-country. Under the Lighting Africa program, this is being piloted in Kenya.

» LED street lights that produce light intensity of 20 lux on the road surface (recommended for street lighting) on a 50 m^2 area—there are products now available that cost about US$900 each per street light.
» Prewired integrated solar PV systems with a 10 to 20 watt peak PV module, battery, controller, two CFL or LED lamps, and built-in radio and speakers from China in the US$80 to US$150 range.
» Larger systems for public facilities using high-efficiency LED lamps that produce 900–2,700 lumens per fixture with 100 lumens per watt LEDs.

Overcoming the lack of population density to the supply of modern energy services. The SSMP approach is designed to overcome the major constraints to the sustainable delivery of energy services in remote areas with dispersed populations, which predominantly characterize rural areas in Liberia. In many such areas, solar PV can be the least-cost means of providing basic electricity services for lighting and communications. By aggregating the PV applications (social service and commercial) in a single market package, the provision of PV electricity services can be commercially viable. Donor support to this approach allows for a larger number of packages and/or connections per package—thus contributing to increased rural access to modern energy services. If designed well, donor support will contribute to leveraging both private investment and local public funding, as well as an overall deepening of the local solar PV markets. This approach has been discussed in detail in the section on Best Practices of rural electrification under the concession model.

Compensating for Liberia's high risk environment: Liberia is a country considered high risk especially from a private investor point of view. The reasons for this include the only recently overcome period of civil strife, lack of a legal and regulatory framework for both the energy sector and private sector, and numerous commercial barriers to private sector operations. In addition, law enforcement is difficult and the security situation still challenging. As investing in rural energy is itself considered a risky venture, any added risk requires careful attention. The RREA will have to play an important role in identifying these risks to private sector participants and in developing strategies on how to mitigate these.

Providing services that are affordable. Technologies made available must be suited to the economic conditions of the target group and the context of the country. A sustained switch to modern fuels and away from the rural use of fuel wood and charcoal, for example, has been shown to be only sustainable for a country as a whole once annual per capita incomes reach US$1,000 to US$1,500 per year (World Bank, 2005). Income levels in Liberia are far below this, and far below the Sub-Saharan African average. For this reason, thermal energy interventions should focus on affordable option for the provision of modern energy services. For example in the context of services for cooking, the focus should be on introducing improved firewood or charcoal-burning cook stoves instead of cooking with LPG until the economic baseline indicates the country's population has climbed farther up the energy ladder.

Harnessing synergies. When development policies are such that they encourage synergies, they are more likely to "work" and show better returns. When assessing the prospects for policies and investments focused directly on improving energy supplies, therefore, one should ask whether local health and education programs are being put in place, whether complementary infrastructure (roads, water supplies, sanitation) is being given proper attention, and whether macroeconomic and pricing policies are such that the investments will function and will serve useful purposes. Rural energy policies and investments are an adjunct to good general development policies, and their chances of success are greatly enhanced when answers to such questions are positive.

In the international practice of rural electrification, a number of generic lessons are emerging that point toward the need for establishing an adequate enabling environment to guarantee a sustainable and sustained increase in access to modern energy services in rural areas. Only then will markets for energy be stronger, including the supply of electricity, SHSs, improved cooking technologies, biofuels, and so on.

Financing Liberia's Energy Access

While the GOL works to improve its fiscal performance and national accounts, it will be reliant on a combination of donor funding and private sector interventions for the foreseeable future. Donor funding is envisioned as critical in the near term for the capital cost of expanding the Monrovia grid as well as installing rural electricity systems, be they minigrids for county capitals or stand-alone solar systems for public facilities. Donor funding will also be necessary to subsidize rural energy services through capacity building and livelihood programs, including microfinance and credit facilitation. As incomes improve, rural consumers may begin paying small portions of rural electrification initiatives, as their ability to pay increases and as the quantity of energy consumed grows.

The cost of operation and maintenance should be borne by consumers from the beginning, through consumption-based tariffs. Tariffs should be designed initially to be less than or equal to the amount rural consumers already pay for traditional energy sources such as candles, flashlights, diesel, and kerosene lanterns. In many countries prepayment meters are commonly used for those with the ability to pay, to encourage payment of services and conservation of resources.

Worldwide, all rural electrification programs have involved some form of subsidy. The experience of most countries is that the market for decentralized rural electrification of all models has required initial stimulation to make it attractive to developers, consultants, manufacturers, and financiers. The initial attraction for private developers may be in relation to specific productive end uses—for example, grain milling in Nepal and Zimbabwe, where the power unit is also used for battery charging or domestic electricity supplies. PV schemes may also be attractive for loan financing on an individual basis, since the equipment may be removed if payments are not made.

Subsidies can be provided in a variety of ways: low interest rates on loans to rural energy service companies and/or their customers; government budgetary support for dedicated rural electrification funds—in Liberia's case, the REFund is managed by the RREA; and financing and credit mechanisms that allow the initial costs for new customers to be spread over time so services are affordable to poor households. Subsidies are usually more effective and sustainable when applied to capital investment and should not be applied to ongoing operation and maintenance (O&M) costs. For example, in China, households wishing to purchase a stand-alone renewable energy system under the state electrification program pay about one-third of the up-front cost; the rest is subsidized by the government. The household is then responsible for paying subsequent equipment replacement and maintenance costs.

Rural electrification is not the sort of activity that will attract private investors interested in maximizing their return on investment. Private investors are motivated by providing power for their own productive uses and secondarily may be encouraged to provide power as a public service at a low marginal cost. In the case of Liberia, there is an opportunity to work with iron ore and precious metal/gem mining companies, agricultural concessions, and others to develop concession agreements toward this end. As the above demand assessment has shown, the majority of the electricity demand forecast for Liberia in the next 30 years will come from mining, industry, and agriculture.

Private finance is more commonly a loan component complementing a mix of government grant/subsidy and local equity capital. Where such private sources of credit are available there can be a role for development finance institutions to provide bank guarantees or credit packages specifically for energy intervention. There is currently little interest from conventional banks, but they may be encouraged to lend at least a proportion of the capital cost if the schemes are accredited or supervised by an intermediary agency (such as in Sri Lanka). The capital cost of decentralized rural electrification in Liberia will be best met in the medium term from a mixture of local equity capital (community or private) and a loan component from a bank or other credit organization, at commercial rates backed if necessary by loan guarantee funds.

Regulation and Policy Development

Rural electrification programs are particularly subject to lobbying by politicians eager to demonstrate their ability to provide low-cost electricity to their constituents. Once a program succumbs to such pressures, however, it is virtually impossible to maintain financial viability because of the expense of providing electricity to remote locations. Staying clear of politics and corruption is fostered by: (i) independent institutions; (ii) involvement of highly reputed authorities or bodies; and (iii) broad participation. It is also fostered by basing the selection of sites on clear and transparent criteria, as previously stated.

Independent Institutions

Independent institutions such as the RREA, recently established in Liberia, can assist in the rural electrification process by staying clear of politics. Autonomous agencies such as the RREA are fully accountable for their own performance and have full control over their own budget—therefore, they have an inherent incentive to reduce costs. The PEA in Thailand, for example, had been given full control over its costs and was fully accountable for its performance. In the face of an intensive capital investment that the initial years of the program would entail, the PEA management made a concerted effort to ensure that rural electrification would not jeopardize its own financing.

Involvement of Highly Reputed Authorities or Bodies

This will reduce the risk of abuse of programs for political purposes and fraud. In Thailand, for example, the king issued a decree that publicly supported rural electrification throughout the country. Although the king is a constitutional monarch, his public endorsement gave the PEA management and its staff confidence in their capacity to act independently. To date Liberia's current administration has yet to publicly highlight the establishment of the RREA, but the full vocal support of the president will be important in establishing the tone of the nation's rural electrification efforts.

In the Philippines a potential problem of corruption within the cooperatives was recognized and addressed at the outset. A public service ethic and need for dedication and honesty were emphasized in all training provided to staff and board members. Where appropriate, these messages were reinforced by incorporating a religious element and involving local religious leaders.

Broad Participation

Participation enhances the transparency of processes. While participatory approaches are not a guarantee for success, they can over time significantly contribute to the sustainability of programs. Cooperatives, NGOs, and local community organizations can be highly effective vehicles for supporting the delivery of energy services of all kinds and for managing natural resources. Such organizations are familiar with and understand local resources and needs, and are often willing to assume responsibility for implementing policies and projects.

Financial Incentives

Financial incentives for renewable and/or efficient energy generation and supply include tax and fee exemptions, grants, and various forms of guarantees. Box 8.1 provides an example of supportive U.S. tax incentives. An example of another incentive is found in the Small Power Purchase Agreements (SPPAs), which may be contracted between utilities and private generators for long-term (10- to 15-year) periods with set tariffs; such agreements protect both the investors in the project and the end-use consumers and are a form of feed-in law. SPPAs have been used successfully in small-scale hydropower projects in Sri Lanka and

Box 8.1 | Tax Incentives for Renewable Energy Development in the United States

Tax incentives have often proven effective in encouraging private sector development of renewable energy resources. They can be provided in several forms: corporate, income, property, and production. Corporate tax incentives allow corporations to receive credits or deductions or more against the cost of renewable energy equipment or installation. Personal income tax credits are designed to cover the expense of purchasing and installing renewable energy equipment and may be limited to a certain number of years following the purchase or installation. Property tax incentives take the form of exemptions, exclusions, or credits; most property tax provisions in the United States allow for property to be taxed based on conventional energy equipment prices. Finally, sales tax incentives typically provide an exemption for renewable energy equipment from the typical sales tax.

Source: Draft Action Plan and Rationale for Renewable Energy and Rural Development. Ministry of Lands, Mines and Energy, Monrovia, Liberia, 2007.

Nepal as well as large-scale wind farms in Germany and elsewhere.

To increase the role of private sector investment in the provision of renewable energy supply, infrastructure, and services, further policy development in Liberia should:

- » Encourage financing through the banking system and other private sectors.
- » Provide selective sovereign guarantees for renewable energy or energy-efficiency projects of strategic importance.
- » Provide fiscal and financial incentives for the development of the renewables subsector.
- » Put in place and implement administrative and regulatory measures that will attract private sector investment.

In addition to tax incentives and grants, supportive financial policies include special benefits and tariffs to encourage community-owned stand-alone minigrids. For instance, exemptions from taxes (as in Box 8.1) and regulatory obligations may be allowed, and grants may be obtained through participation in carbon credit programs such as the Clean Development Mechanism. Other financial incentives include lease programs, whereby a remotely located customer can lease renewable energy equipment from a service company with the option of purchasing the equipment after a certain period.

Loan and microloan programs offer financing for the purchase of renewable energy equipment at low or no interest, or innovative collateral, for example, agricultural products. Production incentives provide renewable energy project owners with cash payments based on electricity production either on a US$/kWh basis for electricity or a US$/gallon basis for renewable fuels. Payments based on performance rather than capital investments are often more effective and help to ensure the efficiency and quality of projects. Finally, rebate programs provide incentives for the purchase and installation of specific renewable energy technologies.

Other promotional policies include public competitive bidding, which guarantees that contracts for energy generation and supply are publicly advertised and then awarded to the lowest responsible bidder in a transparent manner. This is often linked with obligations for suppliers to purchase renewable energy at a premium price and pass the cost on to consumers as a small additional tariff. Construction and design policies are also common, and include construction, green building programs, and energy codes. Construction policies are typically legislative mandates requiring an evaluation of the cost and performance benefits of incorporating renewable energy technologies into construction projects such as schools and administrative buildings.

Trade Incentives

Import duty reductions should be considered in the near term. In Liberia current import duties are discouraging to the development of renewable energy plants, biofuel processing facilities, and other alternative technology projects. Reducing import duties on parts and equipments used for renewable energy production facilities is particularly useful in the early stages of a renewable energy industry, before a host country has its own equipment-manufacturing facilities and the technical knowledge to compete in the world market.

Regulatory Incentives

To ensure that small-scale renewable and rural energy generators are not hampered from entering the energy services market, it is recommended that small-scale projects below a predetermined capacity (such as 1 MW) be permitted to operate license free in rural areas under a special provision. Small-scale producers often lack both the financial and the human capacity to follow the paperwork and procedures required of large-scale producers, and regulating small producers is often more difficult to accomplish and costly due to their remote location. Removal of licensing and regulatory bureaucracy for small-scale generators and minigrids allows producers in rural areas to sell power "over the fence" to households and enterprises, thus facilitating the ease of access to rural electrification. It is also important to note that overregulation tends to facilitate corruption.

Regulation and Policy Development in Liberia

Legislation establishing and supporting Liberia's energy sector and the expansion of energy services is nascent but under way. Prior to the outbreak of the civil war in the early 1980s, work on a NEP had begun within the Ministry of Land, Mines and Energy (MLME). Though this was halted by the war, Liberia did, with the support of the USAID, produce and approve its NEP in June 2009. The NEP stipulates facilitating increased private sector investment in the electricity sector through unbundling manufacture, generation, transmission, distribution, and retail sales, as well as establishing a transparent regulatory process and promoting regional cooperation. It calls for: (i) the creation of an Energy Regulatory Board (ERB) and the RREA; (ii) reorganization of the MLME to expand its capacity in and focus on energy; (iii) creation of a Saint Paul River authority or other river authority; and (iv) changes to the legislation establishing the LEC, the National Oil Company of Liberia (NOCAL), and Liberia Petroleum Refining Corporation (LPRC), to separate policy making from operational functions and, in the case of the LEC, to clarify jurisdiction over generation, transmission, and distribution according to geographic area, generation type, and size.

The NEP provides a broad context for sector reform, but this needs to be translated into primary and secondary legislation along with a strategic plan and timetable. This will be necessary to achieve the reforms called for by the policy. Since preparation of the NEP, the most important follow-up action has been the establishment of the RREA. The RREA was officially established by executive order in January 2010, based on prior financial support of the USAID and both financial and technical support of the Bank.

The next critical step is that the RREA should be fully endorsed by the legislature with relevant statutes, which include GOL budgetary support and creation of the REFund, the proposed rural electrification fund. The World Bank is supporting the full establishment and functionality of the RREA and assisting RREA in piloting the implementation of renewables-based village electrification projects.

It is critical that non-Monrovia residents begin to see tangible results of this government intervention in the near term. In the context of the rural energy master plan and urban non-Monrovia, clarity will be needed as to who has the jurisdiction over operation and regulation of urban minigrids and regional interconnections in the interior.

USAID has pledged to support the development of an action plan toward establishment of the ERB. The NORAD plans to support capacity building of the MLME as its reorganization proceeds toward equal representation of energy capacities. Support of the LEC in carrying out its newly defined functions and jurisdiction is being provided by the consortium of energy donors under the management contract which took effect July 1, 2010. These are all positive steps toward further institutional and regulatory reform. But additional policy and legislative measures need to be put in place to encourage expanded access and the deployment of sustainable technologies.

Components of a sound policy to support the above principles and promote scaled-up energy access for sustainable development include:

- Allowing the private sector to operate in the energy sector along with or in place of the traditional utility

- » Allowing minigrids to sell excess energy back to the grid should the grid be expanded subsequent to establishment of distributed generation (net metering)
- » Financial incentives such as tax and fee exemptions
- » Exemption from regulatory obligations for small-scale power producers (for example, under 1 MW)
- » Simplification of laws and regulatory procedures pertaining to rural energy producers
- » Feed-in laws whereby energy suppliers are paid a premium for power produced by renewable energy generators
- » Quotas or standards for the amount or percentage of power to be produced from renewable energy
- » Linking rural energy initiatives and policies with agricultural programs and policies
- » Establishing a regulation scenario whereby energy pricing reflects the purchase ability and energy needs of the rural population
- » Ensuring the participation of women in energy decisions and identification of appropriate technologies

Finally, development of a national policy on biomass energy is recommended to foster the development of biomass power generation for off-grid rural areas including the potential sites identified for rubber wood, and to ensure that the economic benefits of such development will accrue to Liberia. Properly designed biomass projects can provide an important source of low-cost energy for Liberia, with indigenous wood substituting for imported fossil fuels, and can also provide an economic benefit to Liberian farmers. But to ensure that this is the case in Liberia, measures must be put in place to ensure rubber plantation owners and farmers are adequately compensated, and that they rehabilitate the land and follow sustainable forestry practices.

Roles and Responsibilities of the RREA

Liberia's rural energy program is only beginning, and as such, offers limited lessons learned to date. But there are ample lessons learned to be learned from other developing countries, as presented in this chapter. Liberia has the opportunity to avoid the pitfalls encountered in other countries over the past 40 years by developing institutional and planning strategies designed to avoid such costly mistakes. Ensuring sound and principled development of the rural energy master plan and overall sector master plan will help guide interventions and ensure monitoring and verification of results. The establishment of the RREA is a solid first step toward implementing principles of transparency, efficiency, and sustainability in Liberia's rural energy program.

In accordance with its Executive Order, the RREA will work as an intermediary level institution between the GOL and the targeted population. Its roles will include:

- » Provision of appropriate guidance and support for policy formulation to the MLME
- » Advice on development of the national energy strategy as well as direct development of the rural energy strategy, including definition of grid coverage and jurisdiction of the utility versus other service providers
- » Development of networks within the sector to guide communities on sources of advice, expertise, and equipment
- » Support and advice to local manufacturers, when and where appropriate
- » Facilitation of financing through the REFund
- » Information brokering—acting as the rural and renewable energy information clearinghouse for Liberia in terms of projects, programs, technical and service standards, and opportunities
- » Provision of some level of consumer protection to ensure the market for off-grid systems can grow
- » Creation of standard contracts and legal agreements for small projects, especially where project administration and management costs are a significant proportion of the total project cost, such as that done in Sri Lanka for off-grid hydropower projects
- » Provision of guidelines to potential service providers on quantifying/qualifying energy service needs, and presenting the technical options available along with their costs, benefits, advantages, and disadvantages
- » Facilitation of community planning

» Identification of training requirements, and running training courses for all actors in the sector (for example, developers, operators, local government, communities, and manufacturers)
» Development of technical standards and setting of standard supplier contracts to include technical support and warranties
» Setting the framework for tariff and subsidy options
» Promotion of rural electrification as well as renewable energy technologies, and their uses
» Coordination among other energy sector actors and cross-sector for rural development
» Coordination of research and development

As the financing facility of the RREA, the REFund will be set up to provide for modern rural and renewable energy services. Draft guidelines for the fund are available and an account has been set up. It is planned that the REFund will be funded to provide for rural and renewable energy services through both international sources (traditional bilateral and multilateral loans and grants, and potentially carbon finance) and domestic sources (energy taxes, levies, and fees; general taxes; user fees and capital contributions; and both voluntary and mandatory corporate social responsibility contributions). Corporate social responsibility contributions include a requirement that all companies operating under oil exploration concessions with the GOL contribute a certain percentage (a special levy or fee) to the REFund for rural electrification projects. These contributions are to be collected by the NOCAL and transferred to the MLME for the REFund. As of mid-2011, one contribution hadbeen collected in the amount of US$250,000. But ensuring that the REFund is adequately funded to allow the RREA to achieve its mission will be a challenge for the foreseeable future, one that the government must share with its multilateral and government partners.

It is envisioned that the RREA will institute a credit support facility to involve the financial sector in providing credit for rural electrification initiatives. In support of this, a member of the financial sector will sit on the RREA's board. Development of microcredit facilities throughout the country to complement energy-access efforts and increase the potential interest in energy of existing financial institutions—especially those targeted at off-grid investments—is also advised. The emerging network of rural banks could provide a potential institutional anchor.

In the near term the RREA's mandate includes development of the rural energy strategy. The strategy needs to take into consideration a number of important factors:

» Given the logistical difficulties of delivering fuel and the increasing cost of crude oil prices, alternatives must be prioritized. The most logical alternatives are locally available renewable energy sources, in particular small or micro-hydro, biomass-based minigrids, and individual solar PV systems.
» Priority should be accorded to energy services that benefit the whole community, such as those needed to deliver health, education, security, trading, communications, and administrative services. Next, household-level services and energy for private businesses should be supported as they improve productivity, and increase incomes and quality of life.
» There is limited knowledge of hydropower resources or year-round availability of biomass resources. Resource monitoring is important.
» Given the limited capabilities in the energy sector specifically, the RREA needs to consider alternative energy service-delivery models, in particular taking advantage of locally functioning companies or institutions. For example, using cell-phone sales agents, schools, churches, or administrative centers to offer solar recharging services for lighting or cell phones; linking up with mining or commercial agricultural operations to offer rental or lease-to-own lighting and basic electricity services to their employees or out-growers/artisanal miners; and establishing community-owned and operated minigrids.
» While mobilizing and providing funding through the REFund facility for concrete project activities is important, equally important is the RREA's "market enabling" role in information/knowledge dissemination; development and piloting of nontraditional electricity service business models; encouraging commercial businesses and community service organizations operating in rural areas to become partners in energy service

delivery; training and capacity building; supporting/cooperating with other government agencies to ensure consumers have access to affordable but good-quality products (and the knowledge and ability to recognize quality); setting standards and undertaking bulk procurement when appropriate; introducing new and improved technology; and protecting consumers.

In the near term it may be unrealistic to plan for the introduction of IPPs or true RESCOs, given the high risk in the sector, the relatively small size of systems, and the economic situation of rural areas. Rural cooperatives may be the best strategy, and Liberia has ample experience with cooperatives in the agricultural sector, from which the energy sector could draw important lessons. It is recommended that, under the energy sector and rural energy master plans, particular focus be given to developing a practical strategy for REC facilitation, development, and sustainability. Indeed, this strategy will form an integral part of the RREA's business plan, for it will bear the ultimate responsibility of ensuring its energy investments (Liberia's rural energy service providers) are sustainable.

Rural service interventions will need to remain subsidized in the near and likely medium terms, through the REFund for capital costs and guarantees and through the RREA for technical support and outreach. Though it is true that most rural electrification processes worldwide started out as private initiatives, experience has shown that for maximum efficiency and equity some measure of public participation is necessary. Liberia's best strategy may be one that combines the two approaches. As mentioned previously, innovation will be key as the RREA undertakes the challenges lying ahead, for it cannot proceed along the lines of traditional rural energy agencies amid the current challenges.

The rural energy master plan that the RREA is preparing will shed more light on the appropriate phased approach for rural energy development in Liberia, but it may well be that in the beginning the more remote and economically dormant areas of Liberia—such as the southeast (River Cess, Sinoe, River Gee, Grand Kru, and so on) will benefit most from small interventions such as PV lighting and improved cook stoves in the near to medium term. The northwest corridor (Bong, Nimba, and Lofa) will benefit from minigrids and more substantial interventions in the near and medium terms, since economic recovery and thus ability to pay of potential customers has been more pronounced in these areas.

To make these determinations, however, it is key that Liberia, together with its government and multilateral partners, begin the path of strategy development toward achieving concrete and visible results. Though the country's achievements in infrastructure rehabilitation, improvements in social services, and governance since 2006 have been commendable, in many areas of the country the evidence of these changes is small. Though the development of the rural energy master plans is critical and necessary for further action, they will require time. It is recommended therefore that parallel activities be undertaken in the immediate term—outreach, education, small interventions with rural communities—so that the government's intentions are known.

Over 50 percent of Liberia's population is age 18 or under. Most of these children are growing up in the dark, with only candles, flashlights, and kerosene or oil lamps by which to study. Yandohun, Lofa County.

Establishing a Supportive Policy Framework for Implementation

9

Liberia's current government, upon taking office in 2006, inherited an environment lacking not only public electricity infrastructure, a functioning utility, and a petroleum company, but also a coordinated energy policy and strategy. President Ellen Johnson Sirleaf recognized that access to modern energy services by both the urban and rural populations was the key to accelerating the reconstruction and economic revitalization of the country. The government's solution was to adopt a three-phase strategy—a short term, emergency phase; a medium term, capacity-building phase; and a long term, development phase—and to engage international partners to assist in the implementation. An integral part of the solution was the development of a national energy policy to provide the general guidelines for a legal and regulatory framework for the sector.

The framework for the legal and regulatory activities of the energy sector is nascent but moving forward. The NEP adopted by the cabinet in June 2009, which articulates the national vision for the energy sector, was a major step in this direction. The NEP suggests facilitating increased private sector investment in the electricity sector, including through unbundling generation, transmission, distribution, and retail sales, as well as establishing a transparent regulatory process and promoting regional cooperation.

The NEP has its origins in the Energy Sector White Paper, published in February 2007. Though the MLME initiated a process for development of an energy policy in the early 1980s, it was halted by the war. The white paper was therefore the first comprehensive step toward a national energy policy in the country's history. It was well received by the international community as well as officials within the GOL, and represented a shift away from the stance of self-reliance, especially within the electricity sector, to embrace the concept of opening the power sector to private participation.

The energy sector approach of the GOL at the time of the white paper was driven by the urgent need to expand services and restore infrastructure that remained inoperable from the war, and by a severely constrained public budget. The president's 150-Day Plan and Emergency Power Program helped to restore electricity to parts of Monrovia, but the white paper and policy were oriented toward a long-term vision that incorporated development strategies, policy, environmental considerations, and economic reform.

Other documents relevant to the GOL's sustainable energy strategy are the National Environmental Policy, the Environmental Protection Agency Act, and the Environment Protection and Management Law, all enacted in 2002. These documents recommended the development and use of renewable energy resources, energy conservation, and equitable access to energy. But they do not include concrete recommendations for action.

The aim of the National Energy Sector White Paper was to formulate into a national energy policy the recommendations that arose from a National Energy Stakeholder's Forum, which was held in October 2006 and addressed the overall state of the energy sector in Liberia, as well as sector reforms, innovations, policies, and strategies for ensuring national energy access. The white paper was to provide a strategic vision to address the energy-poverty relationship in Liberia. It recommended that the MLME be restructured to give the three functional areas—land, mines, and energy—equal prominence while providing for enhanced human capacity. It recommended reinstituting the National Energy Committee (NEC), which was established in 1984 but became inactive during the war. It proposed a rural energy authority (called a Rural Electrification and Renewable Energy Agency in the paper) to be created to support progressive electrification of underserved areas using sustainable sources of energy. Additional recommended policy reforms included the creation of a regulatory authority, and unbundling of LEC to allow for power production by IPPs including private corporations and concessionaires. Arguably, some of the proposals made in the White Paper appear somewhat ambitious and possibly out of place in the context of post-conflict Liberia.

The NEP effectively refined the recommendations of the white paper into expressions of policy. Development of the policy was initiated by evaluating local realities and experiences, and then considering regional and international best practices to come up with a draft document, which was presented for validation in three regional workshops in the summer of 2008. Recommendations from the validation workshops were incorporated in the final iteration of the policy.

The objective of the NEP is ambitious: to achieve universal and sustainable access to affordable and reliable energy supplies and thus foster the economic, political, and social development of Liberia. Key policy goals include: (i) restructuring the MLME to elevate the attention given to energy; (ii) creation of a regulatory environment to facilitate private sector investment in the energy sector; (iii) creation of a body dedicated to increased energy access in rural areas that were marginalized in the past; and (iv) leveraging the WAPP for the development of the country's hydropower potential. The NEP is based on three principles: (i) demonstrating the GOL's resolve for good governance and ensuring financial transparency in all sector transactions; (ii) overcoming the significant obstacles to private sector investment in energy supply; and (iii) creating the requisite institutional and legal framework and independent regulatory regime.

As shown in Table 9.1, the NEP illustrates how energy policy issues cut across the four pillars of the Poverty Reduction Strategy (PRS), which is the government's blueprint for the overall socioeconomic development of the country.

The NEP thus sets out an ambitious agenda, which highlights strong dichotomies that are not readily resolved within the context of the policy. For example, the NEP calls for the private sector to take on an important role as financier and agent for technology and human capital transfer for both on-grid (IPPs) and off-grid (RESCOs) companies. But the policy does not resolve how the private sector could be incentivized to assume these responsibilities in a country that due to its postconflict nature would inherently be somewhat less attractive for investment. Another example relates to the capacity constraints that exist in the energy sector as highlighted in the NEP. By the same token the NEP advocates the establishment of a long list of new institutions, but it is difficult to see how these would be appropriately staffed or resourced when existing institutions lack the requisite support.

Finally, the NEP sets out very ambitious targets, but leaves it unclear how these are to be met and what the budgetary implications would be. The key goals in the proposed policy related to the 2015 Millennium Development Goals include:

- The 40 percent of Liberian citizens living in rural and periurban areas and using traditional biomass for cooking shall have access to improved stoves and kerosene or efficient-gas cookers to cut indoor pollution.
- Thirty (30) percent of the urban and periurban population shall have access to reliable modern energy services, enabling them to meet their basic needs (lighting, cooking, communication, and small production-related activities).

Table 9.1 | Relationship of Liberia's National Energy Policy to its Poverty Reduction Strategy

Energy Policy Issue	Energy Policy Objective	PRS Pillar	Energy Stakeholder Roles: Policy Setting	Policy Monitoring	Policy Operation
Access	Universal access to modern energy services *(social equity; urban and rural coverage)*	I. Consolidating peace and security (*strong interrelationships between security, poverty, justice, and peace)*	Licensing requirements: Ministry of Lands, Mines and Energy (MLME)	Licensing and licensee supervision: Energy Regulatory Board (ERB)	Delivery of energy products and services (operators—as defined under institutional framework)
Cost	Least-cost production and utilization *(economic, financial, social, environmental)*	II. Revitalizing the economy *(reduce production costs [for] competitive production)*	Pricing principles *(cost-recovery; affordability)* (MLME)	Cost monitoring (ERB)	Price setting (operators)
Quality	International best practices *(safety, reliability, security, timeliness)*	III. Strengthening governance and the rule of law (*building a system of national integrity)*	Product and service standards (MLME)	Enforcing standards (ERB)	Fulfilling standards (operators)
Institutional framework	Public/private sector partnership *(involvement of private sector to the greatest extent possible)*	IV. Rehabilitating infrastructure and delivering basic services *(appropriate frameworks for the maintenance and sustainability of infrastructure assets)*	Government (MLME)	Quasi-government (ERB)	Public sector (LEC, RREA, St. Paul River Authority, LPRC, NOCAL), communities (cooperatives, and so on), private Sector (Producers, Transporters, Wholesalers, Retailers, Contractors, Suppliers, Manufacturers)

Source: Evaluation of the National Energy Policy as carried out under the USAID program *Liberia Energy Assistance Program*, 2008.

- Fifteen (15) percent of the rural population shall have access to reliable modern energy services toward meeting the same basic needs.
- Twenty-five (25) percent of the schools, clinics, and community centers in rural areas shall have access to modern energy services (for lighting, refrigeration, information and communication, and so on) and shall be equipped with productive energy capacity.

Table 9.2 translates the above targets into the number of household connections that need to be achieved on an annual basis until 2015 to meet the NEP target. Based on the policies in place, it is not obvious how these targets are to be met. For example, the management contract has a target to connect 33,000 customers by 2015 but the NEP target would imply that 119,007 connections would have to be made to reach that target. It is unclear how the difference will be made up for. Similar questions hold for other targets, even though some programs are arguably underway. No policy or measures beyond small pilot activities have been taken as of early 2010 that would indicate any measures are under way for improved cook stoves. This makes the cook stove target the most difficult to reach.

Furthermore, the NEP states that these access targets are to be achieved while reducing greenhouse gas emissions by 10 percent, improving energy efficiency by 20 percent, raising the share of renewable energy to

Table 9.2 | Translating the NEP Access Targets for 2015 into Connections to be Achieved per Household by the LEC and RREA

	2010	2011	2012	2013	2014	2015
Urban and Peri-Urban Electricity						
Access targets	1%	7%	13%	18%	24%	30%
Population (household connections) targets	3,455	24,154	46,009	69,069	93,385	119,007
Rural Electricity						
Access targets	0.50%	3%	6%	9%	12%	15%
Population (households) targets	1,814	11,190	23,006	35,476	48,626	62,484
Public Facilities						
Access targets	1%	5%	10%	15%	20%	25%
# of facilities	101	507	1,013	1,520	2,026	2,533
Improved Cook Stoves						
Access targets	0.50%	8%	16%	24%	32%	40%
Population (households) targets	2,429	39,951	82,139	126,659	173,607	223,085

Source: Authors' calculations.

30 percent of electricity production and 10 percent of overall energy consumption, and increasing the level of biofuels in transport fuel to 5 percent. Beyond 2015 the long-term strategy is to make Liberia a carbon-neutral country within a specified target period.

With respect to greenhouse gas emissions it is to be noted that in mid-2011 no greenhouse gas inventory of Liberia existed, and that therefore the proposed greenhouse gas emission reductions appeared difficult to verify. Moreover, the large forest cover of Liberia may actually be a net sink of greenhouse gas emissions in mid-2011. This would mean, however, that the self-imposed greenhouse gas target could become a barrier for economic growth to Liberia. Similarly, the targets for renewable energy penetration, energy efficiency, and use of biofuels, while certainly desirable, need further underpinning to be credible.

Despite this incongruence the NEP has led to a number of concrete important developments on the ground:

» *The Rural and Renewable Energy Agency,* stipulated by the policy, was created by executive order in January 2010. Full legislative enactment is expected later in 2011.
» *Management contract for LEC.* The GOL has been able to attract a management contractor for Liberia indicating a first step toward public-private partnerships as spelled out in the NEP.
» Liberia has made big strides toward its integration with the WAPP, which spans the ECOWAS region. As a first step toward integration of its domestic energy policies with those of the ECOWAS, the GOL has both signed and ratified the ECOWAS Energy Protocol. Further, preparations are underway for the construction of the WAPP CLSG transmission line, and rehabilitation of the Mt. Coffee power station is also being discussed within the framework of the WAPP.

Important issues that remain on the agenda and might warrant a review of the NEP:

» *Restructuring of the MLME.* In the current structure, the ministry has three deputy ministers responsible for operations, planning, and administration. The deputy minister responsible for operations is subject to a heady workload, with four assistant ministers responsible for lands, mines, minerals exploration, and energy. To elevate the attention given to the three functional areas of the ministry, the NEP suggests the appointment of three deputy ministers responsible for lands, mines, and energy respectively, and the downgrade of planning and administration functions to the level of an assistant minister. This new structure is intended to elevate the attention given to energy, thereby improving the ministry's policy-making and supervisory role for the energy sector. The GOL needs to decide whether the structure foreseen in the NEP is still preferred. If so, restructuring of the MLME should be advanced.

» Regulatory environment for promotion of private sector participation. The establishment of *an independent and transparent regulatory process* is often considered essential for the creation of an investment environment conducive to increased private sector involvement in the energy sector. Independence and transparency are fundamentally rooted in an overall institutional framework that avoids conflicts of interest and overlapping roles by separating policy setting, policy monitoring, and policy implementation and operation. The NEP prescribes that the government, through the MLME, define and review energy policy. A proposed Energy Regulatory Board (ERB) would monitor policy implementation by all operators whether owned by the public and private sector or local communities. The ERB would monitor costs, review sector plans, define and uphold quality standards for equipment and services, and promote fair competition, including dispute resolution among stakeholders. In mid-2011 USAID is providing technical assistance to explore options for setting up an ERB for Liberia. Given the small size of Liberia's energy sector, the GOL may wish to consider keeping the regulatory function with the MLME in order to reduce transaction costs and aggregate human capacity in the sector.

» For the foreseeable future the LEC will be the primary electric power company in Monrovia and, in consultation with the MLME, will be responsible for national system expansion planning (both on and off grid). In the medium and long term, the GOL will consider other options for the operation and ownership of the electricity transmission and distribution systems. The suggestion that the LEC be unbundled as proposed in the NEP appears removed from the reality on the ground at the time given that the LEC is among the smallest power utilities in the world. Best practice in this area suggests that with small power utilities the costs of unbundling, especially the increased transaction costs, outweigh the benefits. In the *petroleum sector* there will be a need to review legislation especially with respect to the functions exercised by NOCAL and LPRC. In the upstream sector, the policy of the GOL is to bring the country's petroleum investment climate in line with international best practices so that the extraction of petroleum resources will benefit all Liberians and exploration and development will be conducted in an environmentally friendly manner. In the downstream sector, the NEP supports competitive private sector investment or participation in new storage depot management or ownership, port management, offloading facilities for petroleum products, up-country storage depots, tankers moving petroleum products around the country, and in-construction and operation of a refinery primarily devoted to exports.

The NEP provides a broad context for sector reform, but to ensure its due implementation, it needs to be translated into primary and secondary legislation along with a strategic plan and timetable. These are among the next steps that should be taken to ensure that the NEP is followed by uninterrupted progress in sector reform:

» *The timeline for implementation needs to be defined.* On page 43 of the policy the following statement is made: "It is the policy of the Government to adopt an implementation timeline to serve as a reference for performance measurement in the implementation of the NEP." This remains to be carried out.

» *The policy needs to be written into law.* Reform of Liberia's power sector must include adoption of a new law expressly regulating the broad principles that the NEP sets out. The legislation establishing the RREA need to be accompanied by an overarching energy law that writes the entire policy into supportive statutes and ensures clarity in overall institutional reform. This law should also address consumer protection, in the context of the ERB, as well as clarify which entity would be charged with monitoring and planning the growth and development of the sector. It is critical that the law clearly defines the duties of each energy institution to avoid overlapping and conflicts of interest. In addition, secondary legislation will be needed to address issues such as rights over land required for development of energy infrastructure.

» *Greater clarity is needed on the roles and jurisdictions of the government's energy companies*, particularly as the energy sector master plan and other sector strategy documents are developed. It will be important to clearly define which entity will be responsible for various developments, and to ensure that entity has the capacity to do so.
» A *financing plan* for developing the proposed institutional structure needs to be developed so that it can be demonstrated to be sustainable over time.
» *As recommended in the NEP, the National Energy Committee (NEC) should be reestablished*. The NEC is an important mechanism for facilitating multisector and multistakeholder (GOL, donor, NGO, and so on) coordination.
» *GOL needs better publicity of its energy sector developments and plans*. In addition, it will be critical that the general public be aware of the options available to them in terms of rural energy, which will require a comprehensive information campaign coordinated between the GOL and the RREA.

In the short term, Liberia will be dependent on donor support for technical and financial assistance required to implement the NEP. The GOL, however, must take the initiative in establishing the timeline and strategic road map for implementation to guarantee continued donor support. Nearly two years have passed since the NEP was adopted, so it is critical that progress on energy policy is made.

Annex: Summary of Postconflict Demand Analyses for Liberia

Since Liberia's conflict ended, no comprehensive demand assessment has been carried out that includes all sectors or covers all of Liberia's counties. A few studies have been conducted that have assessed Monrovia, including its residential, commercial, and industrial customers. A study carried out by the International Finance Corporation (IFC, 2007) included a survey of 1,000 households in Monrovia and its environs, as well as large commercial and public customers. A feasibility study conducted for the West African Power Pool (AETS & SOGREAH, 2010) considered Liberia's prewar energy consumption, Monrovia's current consumption, and an estimate of mining demand to conduct a brief assessment. A Norconsult report (2008) reviewed demand studies by A3i Consortium & AETS (2005), Manitoba Hydro International (2006), IFC (2007), IFC (2008), Stanley Consultants (2008), and LEC (2008) to carry out a demand forecast. Except for the Norconsult report (2008), none estimated demand outside of Monrovia. The Norconsult (2008) demand estimate considered two scenarios: one based on the IFC assessment and one based on the LEC's assessment. These estimates are summarized in Tables A.1 and A.2.

IFC (2008) load forecast estimated that 20 percent of Monrovia's households would connect to the Monrovia grid, and that 10 percent would connect in the first two years of the anticipated management contract for the LEC. This estimate was based on a willingness-to-pay estimate derived from the survey of 1,000 households. Based on this, the derived load forecast estimated that 3,000–5,000 connections would occur per year until 2012, and 400 additional connections per year until 2020. Growth in sector demand of 1.8 percent annually due to demographic growth, and 1.8 percent annually due to economic growth, was assumed.

For the commercial sector, the forecast included a peak demand of between 15 kW and 40 kW per customer, with 15–30 percent connected during the first year, increasing 10 percent annually until 75 percent of the sector is connected. Finally, for the industrial sector, the forecast included 35 major consumers with an average load of 0.7 MW, all connected by 2010, and a 1.8 percent growth factor as a result of economic growth.

The LEC load forecast was based on the estimated 2008 power demand of 63.1 MW, assuming all of this would be met by 2013, when the management contract is to conclude. It assumed a gradual increase in demand during the contract period, with a postcontract 4 percent growth from 2013 figures from institutional, commercial, and residential customers, and a postcontract 10 percent growth from industrial customers.

Norconsult's forecast for outside Monrovia was based on increased mining activities, starting from a base of 50 MW in 2013 and reaching prewar levels (200 MW) by 2015, then remaining constant. It assumed that rubber concessions would reach 5 MW by 2013 and remain there, with a gradual increase until that time. Agriculture, forestry, and fishing jointly were assumed to account for 10 percent of total consumption. Commercial and

Table A.1 | Total Load Forecast for Liberia Based on IFC Scenario for Monrovia (MW)

Area	Demand Est. 2010	Demand Est. 2011	Demand Est. 2012	Demand Est. 2013	Demand Est. 2014	Demand Est. 2015	Demand Est. 2016	Demand Est. 2017	Demand Est. 2018	Demand Est. 2019	Demand Est. 2020
Monrovia	19.0	30.4	31.6	32.5	33.6	34.6	35.7	37.0	38.2	39.6	41.0
Outside Monrovia	3.4	4.5	6.2	62.4	117.5	227.6	227.7	227.8	227.9	228.0	228.2
Total Liberia	22.4	34.9	37.8	94.9	151.1	262.2	263.4	264.8	266.1	267.6	269.2

Source: Norconsult, 2008.

Table A.2 | Total Load Forecast for Liberia Based on LEC Scenario for Monrovia (MW)

Area	Demand Est. 2010	Demand Est. 2011	Demand Est. 2012	Demand Est. 2013	Demand Est. 2014	Demand Est. 2015	Demand Est. 2016	Demand Est. 2017	Demand Est. 2018	Demand Est. 2019	Demand Est. 2020
Monrovia	20.0	31.0	43.0	50.0	53.0	56.3	59.7	63.5	67.5	71.9	76.6
Outside Monrovia	3.4	4.5	6.2	62.4	117.5	227.6	227.7	227.8	227.9	228.0	228.2
Total Liberia	23.4	35.5	49.2	112.4	170.5	283.9	287.4	291.3	295.4	299.9	304.8

Source: Norconsult, 2008.

household demand outside of Monrovia was assumed to be approximately one-third of Monrovia's, adjusted by an annual growth factor of 3.2 percent until 2013, thereafter increasing by an estimated GDP growth of 4 percent per annum.

Data collected by LEC since these documented assessments contain more detailed information for Monrovia, and include industry by company (Coca-Cola, Cemenco, and Club Brewery), fishing companies, ministries and other governmental institutions, nongovernmental organizations (NGOs), foreign missions, and the commercial and household sectors. Including the load already connected by year-end 2009, the total peak demand is estimated at 46.1 MW, were all consumers to connect immediately. Aside from fishing companies, the household sector accounts for the lowest percentage of this load.

Reading by the light of a solar street lamp, Nimba County.

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