Landfill Gas Capture Opportunity -- Sub-Saharan Africa

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Abbreviations and Acronyms

AFREPREN	African Energy Policy Research Network
AF	availability factor
CDM	Clean Development Mechanism
CER	collection efficiency ratio
CET	*centre d'enfouissement technique* (sanitary landfill)
D	aridity factor
EC	energy conversion
ECE	electricity conversion efficiency
EPA	Environmental Protection Agency (United States)
Enda-Tiers Monde	*Environnement et Développement Tiers Monde* (non-governmental organization)
ESKOM	South Africa Electricity Company
ESMAP	Energy Sector Management Assistance Program
EWDEN	Energy Unit
FWL	fraction of waste landfilled
GEF	Global Environmental Facility
GHV	gas heating value
IEPF	*Institut de l'Energie et de l'Environnement de la Francophonie* (Canada)
IRR	internal rate of return
LFG	landfill gas
LFG-IC	landfill gas installed capacity

LHV	low heating value
MLW	municipal liquid waste
MSW	municipal solid waste
NPV	net present value
PCLFG	potential collectable landfill gas
PEP	potential electricity production
PGR	population growth rate
SENELEC	*Société Nationale d'Electricité du Sénégal* (national power utility of Senegal)
SMEs	small and medium enterprises
SOGEL	*Société Guinéenne d'Electricité* (national power utility of Guinea)
SPTD	*Services Publics de Transport de Déchets* (waste transportation public services)
SSA	Sub-Saharan Africa
UNDP	United Nations Development Program
UP	urban population
W	total waste in place
WGR	waste generation rate
WIPM	waste in place model
WL	waste landfilled
WTE	waste-to-energy

Units of Measure

kV	Kilovolt
kWh	kilowatt hour
MJ	Megajoules
MW	Megawatt = 1,000 kilowatts
MWh	Megawatt hour

Acknowledgments

This report presents the results of the study "Landfill Gas Recovery: Opportunity and Feasibility" in Sub-Saharan Africa conducted by Mrs. Fatimata Ouedraogo (power engineer and economist), Consultant to the Energy Unit [EWDEN] of the World Bank and the Energy Sector Management Assistance Programme [ESMAP]. ESMAP is a joint program of the United Nations Development Programme [UNDP] and the World Bank. The methodology and findings of the study were discussed and validated during an energy seminar on November 4, 2003, co-hosted by the Energy Unit and ESMAP, and attended by Bank staff from the Sub-Saharan Africa, Latin America and the Caribbean, and East Asia Regions, EWDEN and ESMAP.

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Executive Summary

1. This study analyzes urban waste in both quantitative and qualitative terms in selected Sub-Saharan African (SSA) countries to find out if the available methane from municipal waste could be used as a supplementary energy source and evaluate whether potential waste-to-energy (WTE) project candidates meet a certain level of cost-effectiveness, which is valuable to investors. The report focuses on municipal solid waste (MSW) rather than municipal liquid waste (MLW) because, in most SSA countries, MSW represents a far larger potential for energy production than the digestion of liquid waste streams.

2. The study addresses a number of pertinent questions: (a) Is there any opportunity for landfill gas (LFG) capture and use in SSA? (b) Can the methane generated from landfill be used as a sustainable source of energy? (c) What are the two most promising cities in SSA for LFG capture? (d) What is the potential of methane that can be generated? (e) What are the financial indicators for an LFG capture and use project in the two selected cities in SSA?

3. A tailored methodology has been designed to select some cities in SSA for LFG recovery purposes. The methodology used is progressive and integrates recommendations from various sources, including the World Bank Landfill Gas Recovery Project—Summary Matrix, the U.S. Environmental Protection Agency (EPA) Guide for Methane Mitigation Project and the Environment Canada Guidance Document for Landfill Gas Management. The following steps have been adopted:

- First screening on a combined three-criteria approach: selection of cities with more than 1 million inhabitants, then selection of cities with precipitation more than 635 millimeters per year, finally selection of cities with an electricity price of more than US¢7 per kilowatt hour (kWh).

- Final screening: after identification of promising candidates, a deeper analysis was conducted on their overall environment—that is, analysis of landfill (size and characteristics), analysis of waste (characteristics and composition), analysis of the country MSW management regulatory framework (collection and transfer, disposal, policies and structures, main players, analysis of the power sector regulatory framework, and marketability analysis of energy from waste.

4. The preliminary results showed that Conakry, Guinea, and Dakar, Senegal, appear to be good candidates for WTE projects in SSA.

5. In Conakry, the following parameters were highlighted:

- There is a sanitary landfill with 1,978,729 tons of waste in place.
- The site contains MSW with 58 percent organic content and is located in the city.
- Ninety percent of MSW is disposed of in the landfill.
- There is a power distribution system that can be supplied from the landfill, and nearby residential areas are potential consumers.
- There are a chronic energy supply shortage and an electricity price higher than US¢15/kWh.
- A waste management framework with private sector and small and medium enterprise (SME) participation is evolving.
- A new power sector reform process is under way.
- There is strong indication of an attractive market.

6. In Dakar, similar features were observed:

- There is a large open dump with 5,032,877 tons of waste in place.
- The site contains MSW with 50.1 percent organic waste and is located within 30 kilometers of the city.
- Seventy-seven percent of MSW is disposed of in the open dump.
- The power distribution system can be supplied from the landfill, and nearby residential areas are potential consumers.
- The demand-supply balance is challenged, and the average electricity price is US¢11/kWh.
- The waste management regulatory framework is evolving.
- There is strong indication of an attractive market.

7. The potential power generation for the two selected cities has been estimated with the “waste-in-place model” methodology, with assumptions that (a) the gas has a low heating value (LHV) of 16.8 megajoules (MJ) per cubic meter, and (b) the gas is burned in an internal combustion engine with an electricity conversion efficiency of 33 percent and an availability factor of 95 percent. The power generation potential is 5.37 megawatts (MW) per day for Conakry (with an aridity factor of 0) and 8.5 MW per day for Dakar (with an aridity factor of 1).

8. For completeness of the investigation, the study estimated financial indicators for Conakry and Dakar and conducted various sensitivity analyses. These estimates were based on the following assumptions: (a) the amount of collectable LFG is constant throughout the useful project life of 15 years; (b) the respective tax, discount, and

inflation rates are 30 percent, 12 percent, and 0 percent in the project areas considered. The results are presented in executive summary tables 1 and 2.

Table 1: NPV, IRR, and Energy Costs for the Conakry and Dakar Projects

	Mexico	Conakry	Dakar
Installed capacity (MW)	7.0	5.4	8.5
Discount rate	10.0%	12.0%	12.0%
Inflation rate		0.0%	0.0%
Tax rate	35.0%	30.0%	30.0%
Electricity tariff (US¢/kWh)	8.75	12.00	9.00
Investment costs (US$)	11,463,126	9,781,799	15,339,868
NPV over 15 years (US$)	2,231,844	8,371,146	5,166,809
IRR over 15 years	13.4%	27.3%	18.2%
Unit energy cost (US¢/kWh)		4.41	4.12
Ratio of NPV to investment costs	19.5%	85.6%	33.7%

IRR internal rate of return; NPV net present value.

Table 2: Sensitivity of NPV and Unit Energy Cost to Changes in Discount Rates for the Conakry and Dakar Projects

	NPV (US$)		Unit Energy Cost (US¢/kWh)	
Discount Rate	Conakry	Dakar	Conakry	Dakar
8.0%	13,483,081	10,768,964	3.75	3.47
10.0%	10,659,705	7,664,611	4.07	3.79
12.0%	8,371,146	5,166,809	4.41	4.12
14.0%	6,501,914	3,143,027	4.76	4.47
16.0%	4,964,140	1,492,649	5.12	4.82
18.0%	3,690,435	*138,686*	5.49	5.19
20.0%	2,628,715	*-978,224*	5.87	5.57
22.0%	1,738,425	-1,904,194	6.27	5.96
24.0%	987,751	-2,675,305	6.66	6.35
26.0%	*351,557*	-3,319,989	7.07	6.76
28.0%	*-190,152*	-3,860,803	7.48	7.16
30.0%	-653,391	-4,315,764	7.89	7.57

Table 3: Sensitivity of NPV and IRR to Changes in Electricity Price for the Conakry and Dakar Projects

	NPV (US$)		IRR	
Tariff (US¢/kWh)	Conakry	Dakar	Conakry	Dakar
7	-1,141,104	-852,665	9.7%	10.9%
8	761,346	2,157,072	13.5%	14.7%
9	2,663,796	*5,166,809*	17.1%	*18.2%*
10	4,566,246	8,176,546	20.5%	21.7%
11	6,468,696	11,186,283	23.9%	25.1%
12	*8,371,146*	14,196,020	*27.3%*	28.4%
13	10,273,596	17,205,757	30.6%	31.8%
14	12,176,045	20,215,495	33.8%	35.0%

9. The estimates, findings, and conclusions in this report should not be taken as an appraisal study for LFG projection and use. This study also does not provide any technical advice on how to design or construct a landfill for gas capture, nor does it contain detailed technical design measures for electricity generation from landfill or large, open dumps in SSA.

10. However, this study may be considered as an initial step to a larger program that could contribute to poverty reduction in SSA, especially in terms of diversification and increase of peri-urban and rural electrification options. To that effect and to expand the analysis, several approaches could be adopted:

- The first would be to analyze the required steps for the implementation of an LFG capture project for peri-urban electrification in Conakry and Dakar. This will include a review of the policies that can affect the project design and implementation and a proposal for the suitable environment for such a project.
- The second approach would be to conduct a technical and economical feasibility study on LFG capture for electricity generation in Dakar and Conakry, with the possible contribution of Clean Development Mechanism (CDM) instruments. SSA countries with a large population and low electricity tariffs could also benefit from CDM instruments, where the emission reduction is sold at US$2.50– per ton of carbon dioxide

- The third option would be to develop a guidance note for LFG recovery for peri-urban electricity initiatives in SSA. This last approach would extend the study to cities throughout SSA, with site visits for reliable data collection and gas capture opportunity assessment. The findings will be analyzed and presented in a handbook and adequate formats for knowledge sharing and dissemination.

1

Introduction

Background

1.1 The urban and peri-urban poor in Africa bear a disproportionate burden of the impact of externalities resulting from poor management of municipal solid and liquid waste (MSW and MLW). At the same time, in most cities and suburbs in Africa, fuelwood contributes to more than 85–90 percent of the total energy supply. Consumption of modern energy (Africa Development Indicators, 2003) is low.

1.2 Use of urban waste for energy production mitigates the negative environmental impact of urban waste disposal while providing relatively clean energy resources in the form of methane for either direct combustion (heating, cooking, other usages) or electricity, which in turn can provide additional income and jobs that would otherwise not be available. Landfill gas (LFG) capture technology is an efficient, proven, and cost-effective method of disposing of organic wastes and capturing greenhouse gases (methane) while producing electricity and fuels.

1.3 In African cities, where population growth rate exceeds 3 percent per year, municipal waste (always a function of population) will increase proportionally and provide more feedstock for energy and other resource production. However, this potential energy source is not currently tapped, and very few urban areas are aware of how much waste is being generated, collected, and disposed. This will remain so unless policy and decision makers in Africa fully realize its significance and develop and implement the right policies to promote the use of municipal waste for energy.

Objectives of the Study

1.4 The main objective of this study is to collect and analyze urban waste in both quantitative and qualitative terms in selected Sub-Saharan African (SSA) countries and find out if the available methane from municipal waste could be used as a supplementary energy source. In addition, we will evaluate whether potential waste-to-energy (WTE) project candidates meet a certain level of cost-effectiveness, which is valuable to investors. This study could represent the first phase of a bigger program, aimed at fostering new opportunities in waste management and electricity generation in SSA.

1.5 The report will concentrate on MSW rather than MLW because, in most SSA countries, MSW represents a far larger potential for energy production than the digestion of liquid waste streams. It is based on published and unpublished material on the potential and possible energy recovery options from MSW.

Analytical Approach and Limitations

1.6 Data relevant to the objectives of the study were compiled through desk review. Most of the information was obtained from various publications, technical data from design reports, journals, technical papers, books, the Internet, World Bank publications, feasibility studies, and interviews. To ensure consistency, we have made some data adjustment and tried to be as selective as possible.

1.7 Because of time and resource constraints, no site visit or survey has been conducted, which would have been critical in obtaining reliable and accurate data. Thus, the estimates, findings, and conclusions in this report should not be taken as an appraisal study for LFG projection and use. This study also does not provide any technical advice on how to design or construct a landfill for gas capture, nor does it contain detailed technical design measures for electricity generation from landfill or large, open dumps in SSA.

2

Waste Management Practices

2.1 MSW is a heterogeneous mixture of materials that is of no further use to consumers. It is usually discarded as refuse from households and residential areas; non hazardous waste from industrial, commercial, and institutional establishments (including hospitals and clinics); market waste; yard waste; and street sweepings. Hazardous waste and special health care waste are by definition not MSW. Demolition and construction waste are also not considered MSW.

2.2 The two main types of municipal waste management practice in SSA are open dumping, which is widely used, and landfilling. Both of these waste management practices can result in methane production if the waste contains organic matter. Gas recovery projects are appropriate from both landfill and large, open dumps.

The Open Dump Method of Solid Waste Disposal

2.3 The open dump approach is the primitive stage of landfill development and remains the predominant waste disposal option in most of the SSA countries. A default strategy for municipal solid waste management, open dumps involve indiscriminate disposal of waste and limited measures to control operations, including those related to the environmental effects of landfills.

2.4 As cities grow and produce more waste and their solid waste collection systems become more efficient, the environmental impact from open dumps becomes increasingly intolerable. The conversion of open or operated dumps to engineered landfills and sanitary landfills is an essential step to avoid future costs from present mismanagement. The first step and challenge in upgrading open dumps to sanitary landfills involves reducing nuisances such as odors, dust, vermin, and birds. The term *sanitary landfill* is generally used for landfills that engage in waste disposal on land, constructed in a way that reduces hazards to health and safety.

The Landfill Method of Solid Waste Disposal

2.5 Landfills have been found to be the most economical and environmentally safe method for disposal of solid waste. Implementation of preliminary treatment of solid waste normally leaves residue that is finally disposed of by landfilling. Landfilling management incorporates the planning, design, operation, maintenance, closure, and post-closure control.

2.6 A landfill is a physical facility used for the disposal of solid waste on the surface of the earth. It is an engineered facility for the disposal of MSW designed and operated to minimize public health hazards and negative environmental impacts. Landfilling is the process by which solid waste is placed in a landfill. It involves monitoring of the incoming waste stream, placement, and compaction of the waste, covering the waste, and installation of landfill environmental monitoring and control facilities. Landfill control facilities include liners, landfill leachate collection and extraction systems, LFG collection and extraction systems, and daily final cover layers.

LFG

2.7 LFG is generated during the natural process of bacterial decomposition of organic material contained in MSW landfills. It is a mixture of gases (predominantly methane and carbon dioxide) produced through microbial activity in anaerobic conditions during the degradation of waste that is landfilled or dumped. A number of factors influence the quantity of gas that a MSW landfill generates and the components of that gas. These factors include, but are not limited to, the types and age of the waste buried in the landfill, the quantity and types of organic compounds in the waste, and the moisture content and temperature of the waste. Temperature and moisture levels are influenced by the surrounding climate.

3

Initial Screening for Identifying Opportunity Cities

Screening Hypotheses

3.1 This section presents the practical steps taken to select some cities in SSA for LFG recovery purpose. The methodology used (see figure 3.1) is progressive and integrates recommendations from various sources, including the World Bank Landfill Gas Recovery Project—Summary Matrix, the U.S. Environmental Protection Agency (EPA) Guide for Methane Mitigation Project and the Environment Canada Guidance Document for Landfill Gas Management.

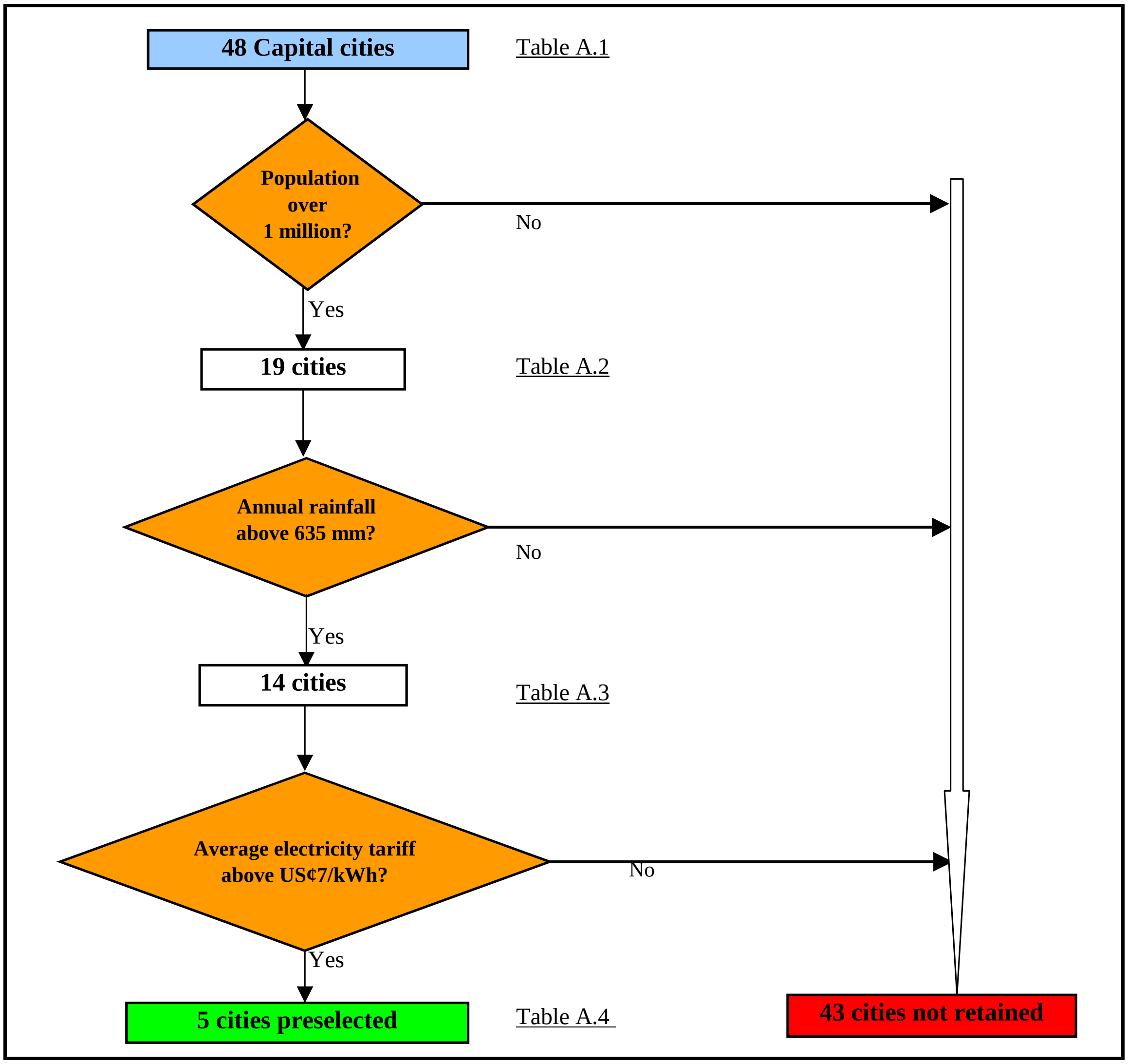
3.2 The following guiding principles were adopted:

- We focused on the capital cities of SSA countries (table A.1 in the annex) for several reasons: These cities usually have the largest population of a country and because they have substantially developed in a short time, they face substantial waste management problems. Also, leaders take great interest projects development in capital cities.
- Countries where LFG capture and use projects are already operational were not included (for example, South Africa and Tanzania).
- Countries with political instability or in a postconflict situation also were not considered.

3.3 We applied the EPA and Environment Canada guidelines and the World Bank matrix data recommendations and took into account population, an average precipitation requirement, and electricity price. This led to these selections:

- Cities with more than 1 million inhabitants (table A.2, annex)
- Cities with precipitation higher than 635 millimeters per year (table A.3, annex)
- Cities with an electricity price higher than US¢7per kilowatt hour (kWh) (table A.4, annex).

Figure 3.1: Initial Screening Methodology



Step-by-Step Analysis and Results

Quantity of waste: LFG as a function of city size (population of more than 1 million)

3.4 The quantity of waste in a landfill or that a landfill receives daily is related to the waste produced by the population, assuming that a large percentage of the waste is being collected and landfilled. According to Johannessen (1999), for commercial recovery of generated LFG, a landfill should receive at least 200 tons per day of waste, be designed for a minimum total capacity of 500,000 tons, and have a minimum filling height of 10 meters. The waste should not have been deposited for more than 5–10 years before LFG recovery is attempted. Or if this is the case, the landfill should still receive waste at the time of project implementation. The first step of the screening will be the selection of cities with a population of more than 1 million. This choice of cities does not mean that LFG capture for commercial use is not possible with less population: cities with a small population but more organic content in MSW could generate as much LFG as a large city.

Moisture content and ambient temperature: LFG as a function of annual average rain fall of more than 635 millimeters per year

3.5 As with the generation of leachate, moisture is the most important factor in methane generation; wetter waste produces more methane, though low-moisture waste will still produce a small quantity of methane. The amount of precipitation influences the moisture content of landfilled waste, and this has a direct relationship to the amount of methane produced, which subsequently will influence the potential amount of electricity. A higher ambient air temperature will enhance the biodegradation processes. The second level of selection led to cities with an annual average rainfall of more than 635 millimeters. However, a city with a large population can also generate a substantial amount of LFG with less rain.

Electricity price of more than US¢7/kWh

3.6 The gas recovered from a landfill can be used on the site or sold to a nearby facility through a gas distribution grid. This approach, however, will be difficult to implement in most SSA countries because of the lack of a gas distribution system. Another way of using this gas is through generation of electricity and distribution through the power grid. This has a direct implication because the periurban population does not generally have access to electricity. For this last approach to be economically viable, the electricity generated should have competitive price in the market and a cost per kWh generated less than US¢7/kWh.

Results

3.7 These screening tests left five potential cities (table 3.1) - Abidjan, Côte d'Ivoire; Bamako, Mali; Conakry, Guinea; Kinshasa, Democratic Republic of Congo; and Yaoundé, Cameroon - that could be considered for further analysis to gauge their suitability for LFG recovery. The political situation in Abidjan, the absence of waste in the new landfill in Bamako, and the lack of data on Kinshasa resulted in the elimination of these three cities. Of the remaining two from the screening tests, only Conakry has all the required information to finalize the analysis.

Table 3.1: Potential Candidates for WTE Projects

Country	Capital	Population	Average precipitation (mm)	Growth rate (%)	Electricity price (US¢/kWh)
Mali	Bamako	1,069,242	1,018.2	3.17	16.88
Guinea	Conakry	1,800,000	3,869.6	4.89	15.15
Cote d'Ivoire	Abidjan	3,395,976	1,421.0		9.40
Cameroon	Yaoundé	1,239,100	1,555.0		9.20
Congo, Dem. Rep.	Kinshasa	6,301,100	1,358.0	3.15	8.20

3.8 Based on different interviews and the data availability, the city of Dakar, Senegal, could be retained as a potential candidate even though Dakar failed the average rainfall test. For the second part of the analysis (figures 3.1 and 3.2), Dakar is used as a substitute for Yaoundé.

Table 3.2: Selected Data on Dakar

Country	Capital	Population	Average precipitation (mm)	Growth rate (%)	Electricity price (US¢/kWh)
Senegal	Dakar	2,476,400	542.0	2.60	11.00

Figure 3.2: Group 1 Analysis

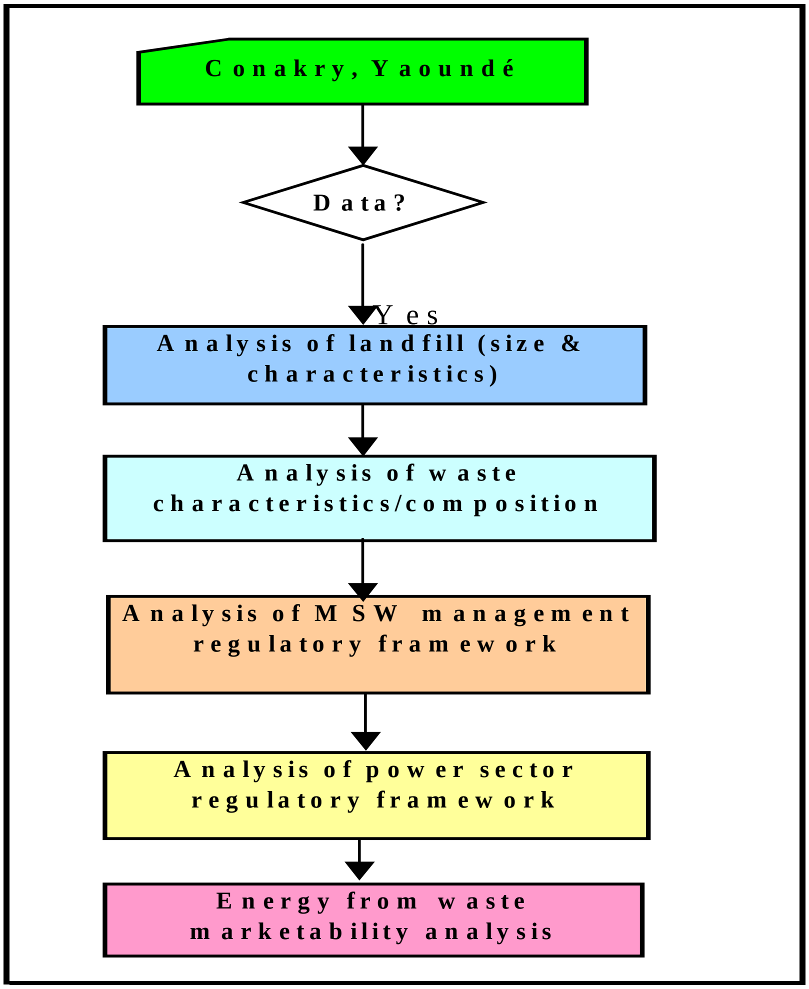
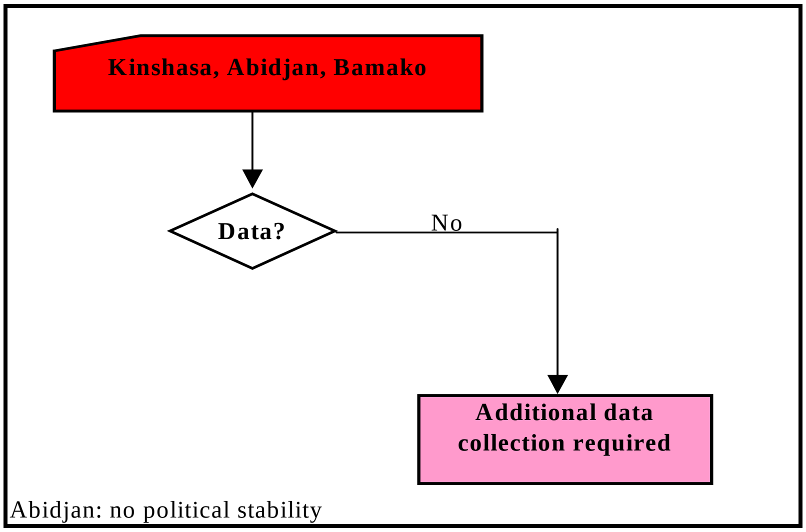


Figure 3.3: Group 2 Analysis



4

The Potential of Energy from MSW in Conakry

Country Background

Please see “Guinea at a Glance” in the annex.

4.1 Guinea, located in West Africa, is surrounded on the north by Guinea-Bissau, Senegal, and Mali, on the east by Cote d’Ivoire, on the south by Liberia and Sierra Leone, and on the west by the Atlantic Ocean. The country is rich in natural resources, in terms of both minerals and fertile agricultural land, and thus offers numerous opportunities for the processing of raw materials. With economic reforms under way and a deep commitment to the private sector, there is a growing sense of optimism and potential for sustained growth and development. The climate is generally hot and humid; there is a monoseasonal-type rainy season (June to November) with southwesterly winds and a dry season (December to May) with northeasterly harmattan winds

4.2 Since 1995, Guinea has experienced real growth in gross domestic product of 4.4 percent, with major growth originating from the primary sector, agriculture and mining. This was a result of the implementation of various structural adjustment reforms with the help of the World Bank and the International Monetary Fund, which included (a) elimination of price controls, (b) liberalization of foreign exchange, (c) improvements in tax revenues with the introduction of a value added tax, (d) emphasis on private sector initiative, and (e) financial sector and monetary policy reforms.

4.3 The country possesses more than 30 percent of the world’s bauxite reserves and is the second largest bauxite producer. The mining sector accounted for about 75 percent of exports in 1999. Long-run improvements in government fiscal arrangements, literacy, and the legal framework are needed if the country is to move out of poverty.

Urban energy demand and supply

4.4 Some 70 percent of Guinea’s population, of 7.58 million, live in rural areas. Overall, less than 5 percent of the population has access to electricity: about 35 percent of urban households, including the capital Conakry and large prefectures, and less than 1 percent of rural households (districts or *sous-préfectures*) has access to electricity.

Many rural households have no prospects of receiving electricity services in the foreseeable future.

4.5 Private picogenerators are being used by a few wealthy households and small businesses. At least 10 different types of generators below five kilovolt-amperes (kVA) can be found in Conakry's hardware stores. The power company, *Electricité de Guinée*, supplies electricity to Conakry and a number of small towns. Both the quality and reliability of supply have been low, despite many attempts to improve them through private sector participation. In periurban areas, there are still thousands of potential consumers who are not connected to the grid for technical or financial reasons or both, and they use batteries to run their televisions and provide light.

4.6 Guinea has an installed capacity of 127 megawatts (MW): electricity generation is provided by 63.8 percent fossil fuel and 36.2 percent hydropower.

Municipal waste as renewable energy

4.7 In Guinea, where there are chronic energy supply shortages, the generation of methane from MSW can be a viable alternative source of energy that would supplement other existing forms of energy. The energy potential from municipal waste in Conakry urban centers is a readily available source of renewable energy, which can be tapped to enlarge the existing sources of energy. Ninety percent of the waste is delivered to the local disposal site.

Regulatory Framework and Marketability Analysis

Regulatory framework of waste management

4.8 The waste management framework in Conakry is currently evolving. Through the Third Urban Development Project, the World Bank provides assistance to solid waste management in Conakry with these key objectives: (a) increase the solid waste collection rate, (b) improve the solid waste disposal system and protect the environment, and (c) enhance the managerial and operational capacity of the participating private sector and the public service in charge of the solid waste transfer to the sanitary landfill (*Services Publics de Transport de Déchets* [SPTD]).

4.9 The solid waste subcomponent of the World Bank project includes several activities related to the pre-collection and transfer of garbage to the sanitary landfill, supervision and monitoring of the interventions of the small and medium enterprises (SMEs), cleaning the streets and public places, and enhancing the capacity of the SPDT and the SMEs. Decisionmakers in Conakry consider the overall design and operation of a disposal site a high priority.

4.10 ***Collection and transfer.*** In Conakry, the collection of MSW is provided by private operators, on a fee basis, to subscribed households and commercial establishments. As of December 31, 2001, 31 contracted SMEs provide solid waste collection service to the whole metropolitan area and collect approximately 90 percent of the solid waste generated in Conakry. The waste is being disposed of in 39 small transfer stations by the SMEs; from there, it is transported in bulk by the SPTD to the sanitary landfill.

4.11 ***Disposal.*** The point of disposal of the MSW is located in the city, within easy reach of vehicles and collection crews. The collection vehicles go directly from the transfer station to the landfill. The existing open dump, which is 20 years old, has been rehabilitated to a sanitary landfill (fence, bulldozer, daily cover of the waste, treatment of the leachate, operational management and monitoring plan, and so forth).

4.12 ***Policies and structure.*** In Conakry, the key actors in waste management are mainly the government (also the key decisionmaker), the municipalities, and the private sector and SMEs involved in street cleaning in the five municipalities of Conakry and the waste collection from households. Through the urban waste project development, the World Bank is involved in the establishment of legal and institutional mechanisms to facilitate SMEs' access to credit from local banks.

Regulatory framework of the electricity sector

4.13 ***Laws and regulation for foreign participation in energy project development.*** In June 1997, the government of Guinea promulgated Law 97/012/AN, which allows the financing, construction, and management of infrastructure assets by the private sector.

4.14 ***Power sector reform status and future plan.*** In 1997, the government contracted out system operations for 10 years to a foreign private operator, *Société Guinéene d'électricité* [SOGEL], under an *affermage* (lease) agreement. SOGEL's mandate is to operate in urban areas already connected to the main grid or receiving electricity supply, leaving rural and periurban areas without service. In 2001, the lease agreement fell through because of disagreements between SOGEL and the government over tariff adjustments and other cost recovery measures that could not be resolved to the satisfaction of both parties.

4.15 The government has reiterated its commitment to reform and to launch a new reform process in the power sector. The government strategy for power sector reform that was endorsed by the World bank is aimed at (a) ensuring a reliable electricity supply to support economic activity; (b) adopting and enforcing an effective economic tariff; (c) mobilizing private sector financing for the generation, transmission, and distribution of electricity; (d) promoting decentralized electricity supply; and (e) limiting the government's activities to policymaking and regulation of the energy sector.

4.16 However, the implementation of this ambitious plan is at a very early stage, and the government has so far not passed specific laws and regulations for either IPP (Independent power producers) or for right of way to utility transmission lines or pipelines.

Marketability of LFG

4.17 This section assesses whether there is a suitable use for the gas recovered and if an LFG recovery project can be attractive in the context of Conakry.

4.18 ***Energy supply and demand balance.*** As a result of the large unmet demand for electricity from both commercial and residential users, there are numerous opportunities for private sector participation and investments by international companies. Given the extent of recovery of LFG, there is a large potential for further investments through expansion of electricity generation sources.

4.19 ***Use of energy recovered and access to market.*** The Conakry landfill is located within the city and within 1 kilometer of the local power grid. The checklist below is a quick proof that the energy use criterion is met, per landfill guidelines, for initial screening purposes:

- There are households nearby that could use supplemental power produced.
- There are industrial facilities nearby (approximately within a 10-kilometer radius) that can use medium-quality gas, electricity, or both.
- There is a power distribution system that can be supplied from a landfill.

4.20 Thus, it is reasonable to conclude that there is an attractive market for an electricity-use option in Conakry. A better assessment would require discussions with energy planners in the Ministry of Energy and the local power supplier, which could be done in the next phase of this project.

Better Characterization of the Urban WTE Option in Conakry

Study approach

4.21 This section analyzes and calculates parameters, which have great implications in the potential LFG project in Conakry. Biodegradation of MSW disposed of in a landfill will begin within a few months to two years (or even longer), and LFG will be generated in quantities that should be managed through either flaring or recovery and use. It is advisable to consider LFG recovery projects during the appropriate life cycle of the landfill and waste biodegradation to expect a large quantity of gas production.

Landfill size analysis

4.22 This section analyzes landfill characteristics presented in table 4.1 below, including the approximation of the total waste in place and received by the Conakry *centre d’enfouissement technique* [CET] (sanitary landfill).

Table 4.1: Landfill Characteristics in Conakry

Landfill type	*Sanitary landfill*
Capacity (cubic meters)	1,330,000
Actual depth of waste (meters)—filling status	5–20
Final depth of waste (meters)	62–110
Remaining time to closure (years)	3–6
Waste in place: time since landfilled (years)	20
Daily cover type	Sand
Average annual temperature (degrees centigrade)	27
Precipitation (millimeters annually)	3,828
Leachate management	Yes
Gas management	Yes
Surrounding fence	Yes

4.23 ***Age of the landfill.*** Conakry has a sanitary landfill, converted from an open dumpsite, which is 20 years old and still receiving 90 percent of the waste generated in the five municipalities of the city.

4.24 ***Leachate management.*** The Conakry sanitary landfill is equipped with a leachate and gas management system. The landfill leachate is a polluted liquid produced as a result of rain or other water percolating through the landfilled waste. Recirculating the leachate in a landfill adds moisture to the disposed waste and enhances the biodegradation process in the waste.

4.25 ***Estimated quantity of waste landfilled: assumptions.*** For the calculation of the total waste landfilled over the most recent 20-year period, the following adjustment was made: to calculate the quantity of waste landfilled every year (as presented in Table 4.1), (a) the population growth rate (PGR) and the waste generation rate (WGR) are considered to be constant over the period of landfilling; (b) the fraction of waste landfilled is assumed to be constant and equal to 0.65 from 1983 to 2000 and 0.90 for the period 2000–03; (Marron, Jean Claude, 2001) (c) for every year, the constant growth rate is used to calculate the urban population. The various parameters are computed as follows:

Total waste landfilled = $W = \sum WL_I = \sum \left(UP_I * WGR * FWL_I \right)$

- with I = a given year between 1983 and 2003
- UP_I = urban population during the year I = $UP_{2003}/((1+PGR)^\wedge(2003-I))$, with UP_{2003} = 1,800,000 and PGR = 4.9 percent
- WGR = waste generation rate (kilograms/person/year)
- FWL_I = fraction of waste landfilled during the year I.

For Conakry, W = 1,978,729 tons.

Table 4.2: Total Waste Landfilled in Conakry, 1983–2003

Year	*UP*	*WGR*	*FWL*	*WL*
2003	1,800,000	121	0.90	98,010
2002	1,715,920	121	0.90	186,864
2001	1,635,767	121	0.90	178,135
2000	1,559,359	121	0.65	122,644
1999	1,486,519	121	0.65	116,915
1998	1,417,082	121	0.65	111,454
1997	1,350,889	121	0.65	106,247
1996	1,287,787	121	0.65	101,284
1995	1,227,633	121	0.65	96,553
1994	1,170,289	121	0.65	92,043
1993	1,115,623	121	0.65	87,744
1992	1,063,511	121	0.65	83,645
1991	1,013,834	121	0.65	79,738
1990	966,476	121	0.65	76,013
1989	921,331	121	0.65	72,463
1988	878,295	121	0.65	69,078
1987	837,268	121	0.65	65,851
1986	798,159	121	0.65	62,775
1985	760,876	121	0.65	59,843
1984	725,334	121	0.65	57,048
1983	691,453	121	0.65	54,383
W (tons)				1,978,729

Waste characteristics analysis

4.26 Table 4.3 presents the composition of the waste in Conakry. The waste landfilled has approximately 58 percent organic content, which produces methane in an anaerobic environment.

Table 4.3: Waste Composition in Conakry

Nature of waste	*Content (%)*
Organic waste	58.0
Textiles and cloth	4.0
Paper and cardboard	9.0
Metallic, ferrous	1.0
Plastic	4.0
Glass	1.0
Leather	1.0
Other—stones	4.0
Fine (diameter<2.5mm)	18.0
Total	100.0

Preliminary site assessment

4.27 The preliminary site assessment is recommended by the landfill guidelines to examine the attractiveness of a gas recovery project, including gas generation and usage.

4.28 ***Potential LFG production.*** This section provides an estimate, using the waste in place model (WIPM), of the current amount of gas that can be produced. The amount of gas that can be collected depends on several factors, including the amount of waste in place, waste characteristics or composition, and collection system design.

4.29 There are several approaches for estimating current and potential gas production. The most reliable one is to drill test wells into the waste. However, this is costly and should not be used until initial assessment indicates that there is enough waste to produce a reasonable amount of gas.

4.30 The WIPM was developed from data on gas recovery projects in the United States. The model relates gas production to the quantity of waste in the facility, but it does not consider the aging of the waste and the changing rate of gas production over time. The model is:

$$LFG = 2 * (4.32 + 2.91 * W - 1.1W * D)$$

where:

- LFG = total landfill gas generated in a current year (cubic meters)
- W = total waste in place that is less than 30 years old (tons)
- D = aridity factor (1 when rainfall is less than 635 millimeters per year and 0 otherwise).

For Conakry, D = 0 and LFG = 11,516,214 cubic meters.

4.31 ***Potential collectable gas.*** It should be noted that not all LFG generated can be collected. Some of the gas generated in the landfill will escape. According to the landfill guidelines, a reasonable assumption for a new collection system, which will operate for energy efficient recovery, is within the range of 70–80 percent collection efficiency ratio (CER). The estimate from the WIPM should be multiplied by the CER to determine the potential collectable gas from the landfill. This study considers the worst-case scenario of 70 percent CER. This rate of production can be sustained for 5 to 15 years, depending on the site, and estimating the gas potential is critical in determining the technical specifications of the project and assessing its economic feasibility.

$$PCLFG = LFG * CER$$

where:

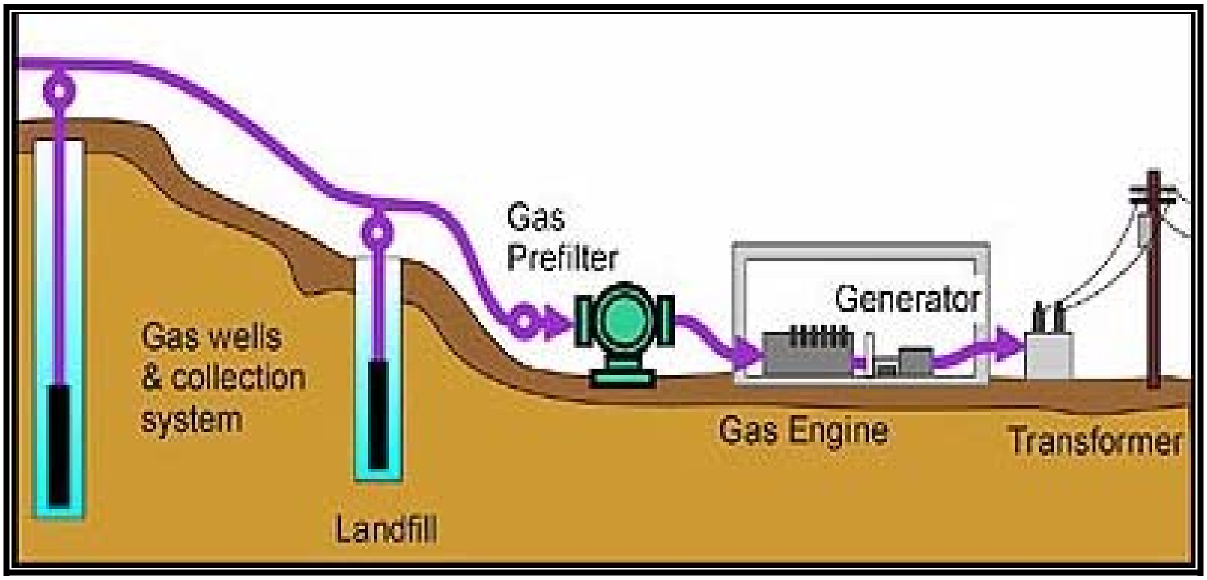
- PCLFG = potential collectable landfill gas.

For Conakry, PCLFG = 8,061,350 cubic meters.

4.32 ***Potential electricity production.*** Figure 4.1 presents the process of electricity production from LFG. The process consists of two parts: (a) the collection and treatment of gas to make it suitable for combustion (see section on potential collectable gas above) and (b) combustion in an internal combustion engine and production of electricity through a generator.

4.33 Depending on how far the power station is from the load center, the electricity produced could also be fed into a transformer for transmission. The purpose of the next section is to determine the amount of electricity that can be produced by the generator.

Figure 4.1: Electricity Production from LFG



4.34 ***Assumptions.*** The calculation of potential electricity production (PEP) considered (a) raw LFG is 50 percent methane by volume and has a low heating value (LHV) of 16.8 megajoules (MJ) per cubic meter; and (b) the gas is burned in an internal combustion engine, which has an overall 33.0 percent electricity conversion efficiency (ECE) and an overall availability factor (AF) of 95 percent.

PEP = PCLFG * LHV * ECE

Landfill gas installed capacity (LFG-IC) = PEP/(number of hours during a year * AF)

For Conakry, potential PEP = 44,682 megawatt hours (MWh) and LFG-IC = 5.37 MW.

4.35 Table 4.4 summarizes the calculations for Conakry.

Table 4.4: Potential LFG-Generated Electricity in Conakry

W (tons)	1,978,729
LFG (cubic meters)	11,516,214
CER (%)	70
PCLFG (cubic meters per year)	8,061,350
LHV (MJ per cubic meter)	16.8
GHV (MJ)	135,430,673
ECE (%)	33.0
PEP (MWh per year)	44,692
AF	0.95
LFG-IC (MW per year)	5.37

4.36 Forecasting the quantity and quality of LFG available for present and future energy production can be uncertain. More reliable prediction will need field data and further testing for potential collectable gas.

4.37 The level of methane concentration in LFG (generally assumed to be within the range of 35–50 percent) is generally acceptable for use in a wide variety of equipment, including the internal combustion engine and gas turbine for electricity generation. However, gas turbine use required a stringent filtering process to avoid the deterioration of the turbine blades.

4.38 LFG recovery and LFG-to-energy technologies are generally well developed and commercially available in most countries. The internal combustion engine, which needs less gas flow than the gas turbine and can be easily turned on and off, is more suitable when the electricity loads are changing during the day.

Initial Appraisal Result and Conclusion

4.39 The initial appraisal screening criteria aim at determining if the landfill of Conakry has the characteristics that generally support economically viable gas recovery projects. The conduct of this evaluation follows the guidelines' recommendations.

Energy shortage

4.40 In Conakry, as noted, there is an acute energy shortage, and a gas recovery project may be highly desirable as an additional electricity supply for the area.

High energy cost

4.41 Currently, electricity prices are very high in Conakry (averaging US¢15.15/kWh), and this environment would favor—and even potentially support—profitable gas recovery projects.

Initial appraisal results from the guidelines' checklist

4.42 The guidelines provide four questions, each of which can be answered "yes" in the case of Conakry:

- Are there landfills or large open dumps (currently receiving waste or closed recently) that could be potential candidates?
- At the potential candidate sites, are there potential uses for the energy recovered?
- Does the candidate site have more than 1 million tons of waste in place?
- Does the candidate site contain primarily MSW?

4.43 The affirmative answer to all these questions means that there are promising options for gas recovery in Conakry. After this step, the technical and economic feasibility of gas recovery of the candidate site should be thoroughly evaluated. This is conducted in the next phase of this study.

5

The Potential of Energy from MSW in Dakar

Country Background

Please see “Senegal at a Glance” in the annex.

5.1 Senegal’s population is estimated at 9,770,000. Dakar, the capital and largest city, has a population of 2,476,400. Like most other Sahelian countries, continued use of forest-based fuels and charcoal places huge constraints on the environment and land cover to cater for increasing urban demands on fuelwood and charcoal. Like most countries in the Sahel, Senegal is highly dependent on petroleum fuels. There is no residential gas infrastructure in Senegal, although heavy petroleum was discovered in the 1950s at the Dome Flore in Casamance, Senegal’s southern secessionist province (100 million tons), and natural gas and light petroleum were discovered in the 1960s at Diamnado Kabor, near Dakar. However, such discoveries show no signs of becoming part of a broad range of interfuel substitution schemes.

5.2 The urban spaces of greater Dakar remain highly congested, with a high concentration of commercial services in the city center.

Urban energy demand and supply

5.3 The energy sector in Senegal is diversified in spite of its modest energy resource base.

5.4 In terms of hydroelectricity potential, the *Organisation de la Mise en Valeur du Fleuve Senegal* (Senegal River Basin Organization) enabled Senegal to produce 280 Gigawatthours (GWh) per year at the Manantali power station. Senegal has an installed capacity of 388 MW.

5.5 Traditional fuels are much more difficult to estimate in terms of either potential or production. In 1980, Senegal’s forestland was estimated at 12 million hectares, 60 percent of the country’s area. According to several studies, it is also estimated that Senegal should be able to cover its needs in woodfuels if sustainable management schemes are established and maintained. However, energy consumption is estimated at 1.5 million tons of oil equivalent, of which traditional forest-based fuels used for household needs represent 53 percent; petroleum fuels, 34 percent; electricity, 12 percent; and agricultural residue, 1 percent. In Dakar alone, charcoal consumption is estimated at 150,000 tons per year. In 1992, total consumption of wood was 1.5 million tons, 86 percent of which was consumed in rural Senegal (Libasse Ba, Fatma Denton 2002, Dakar).

5.6 The power company, *Société Nationale d'Electricité du Sénégal* (SENELEC), supplies electricity to Dakar and a number of small towns. Some other companies and large consumers generate electricity for their own use.

Municipal waste as renewable energy

5.7 The energy potential from municipal waste in Dakar's urban centers has been recognized as a readily available source of renewable energy, which can be tapped to enlarge the existing sources of energy. Most waste is delivered at the local disposal site of Mbeubeuss.

Regulatory Framework and Marketability Analysis

Regulatory framework of waste management

5.8 ***Collection and transfer.*** Municipality and private operators provide collection services on a fee basis to households and commercial establishments. Dakar has an established municipal waste collection system. The collection rate is approximately 77 percent and is carried out by human- and animal-drawn carts (wheelbarrows, pushcarts), open-back trucks, compactor trucks, and trailers. Collections from market places and commercial centers tend to be made in the evening, and collections from residential areas and of street sweepings are made at dawn.

5.9 ***Disposal.*** All waste collected in the city is disposed of at the Mbeubeuss waste site, where part of it is recycled to be reintroduced into the commercial and craft sector. Initially, waste was disposed of at a dumping site in the Hann district. The site was later moved to Mbeubeuss, a 25-year-old, large, open dump with more than 6 millions tons of waste in place. Mbeubeuss receives approximately 77 percent of the municipal solid waste produced. It is located on the perimeter of the city, approximately 30 kilometers from Dakar and closer to a village with roughly 3,000 inhabitants. It is within easy reach of vehicles and collection crews.

5.10 Mbeubeuss is in an area where market gardening is one of the main activities. However, market gardening activities are unable to flourish because of hazards caused by waste. The closure of the site has been discussed, but the problem of finding a suitable replacement remains. In other words, there is not enough infrastructure in place to facilitate the closure of the site and put in place a new dumping site.

5.11 ***Policies and structure.*** The responsibility for waste management lies with local authorities through the *Communauté Urbaine de Dakar* (Dakar Urban Community), a department common to the three main towns, Dakar, Pikine, and Rufisque. This department is responsible for the coordination of all waste management activities in the

Dakar region. It has at its disposal the relevant personnel and the logistics to carry out the operations.

5.12 The Senegalese government has recently signed an agreement with Alycon, a Swiss company whose main responsibility is to collect and manage waste and keep the streets of Dakar clean. The contract was signed on January 5, 2000, and is expected to end on December 31, 2026. It includes the distribution of waste bins to households, the introduction of boxes for communities, a new approach for the transportation and removal of waste, and the clearing of the Mbeubeuss site (passages, access, lighting, and so on).

5.13 In Dakar, the collection of waste is dependent on the usability of roads. Whenever and wherever, roads are in reasonable condition, heavy-duty refuse collection vehicles with built-in compressors conduct door-to-door waste removal.

Regulatory framework of the electricity sector

5.14 ***Laws and regulation for foreign participation in energy project development.*** One of the major objectives of the reform plan is to foster private sector participation and introduction of an innovative financial mechanism.

5.15 ***The power sector reform situation and future plans.*** The private sector was active in electricity development, with a 25-year concession agreement for system operations with a foreign consortium in 1998. In 2000, the concession agreement fell through as a result of a failure to achieve one of the main goals of power sector reform, the improvement of the supply-demand balance. The government and the consortium decided to put an end to their partnership in SENELEC, and the government continued examining its options for privatization and liberalization of the power sector. This paved the way for a second attempt—not yet completed—to establish SENELEC as a vertically integrated, state-owned utility. There is no open access to the utility transmission lines in Senegal.

5.16 Regulatory barriers are key obstacles to potential LFG recovery projects. LFG-to-energy projects must comply with local, state, and national regulatory and permitting requirements. In Dakar, alternative energy prices are relatively high, and LFG cost may be attractive.

Marketability of LFG

5.17 This step assesses whether there is a suitable use for the gas recovered and if the project can be attractive. We will follow the same steps as we did for Conakry, using the checklist of the guidelines.

5.18 ***Energy supply and demand balance.*** The excessive energy prices and the willingness of the government to favor renewable energy sources offer opportunities for an LFG development initiative in Dakar. The private sector is already involved in waste collection, disposal and treatment. The government is open to new developments, and there are numerous opportunities for private sector participation and investments by international companies.

5.19 Given the large quantity of waste in place and the composition of the waste in Dakar, as well as the likely opportunity that LFG recuperation may provide, there is a large potential for further investments through expansion of electricity generation sources.

5.20 ***Use of energy recovered and access to market.*** The Dakar landfill is within 30 kilometers of the city's downtown, and the local power grid is less than 1 kilometer from the open dump. The checklist below shows that the energy use criterion is satisfied for initial screening purposes, according to the landfill guidelines:

- Nearby residential areas can use a supplemental source of electricity.
- Industrial facilities within a radius of approximately 20 kilometers can use medium-quality gas, electricity, or both.
- A power distribution system can be supplied from the landfill.

5.21 One can conclude that there is an attractive market for an electricity use option in Dakar. A more exhaustive assessment would include discussion with energy planners in the Ministry of Energy and SENELEC.

Better Characterization of the Urban WTE Option in Dakar

Study approach

5.22 This section analyzes and calculates parameters that have great implications for the potential LFG project in Dakar. Biodegradation of MSW disposed of in a landfill will begin within a few months to two years (or even longer), and LFG will be generated in quantities that should be managed through either flaring or recovery and use. It is advisable to consider LFG recovery projects during the appropriate life cycle of the landfill and waste biodegradation to expect large quantities of gas production.

Landfill size analysis

5.23 This section analyzes the landfill characteristics, including the approximation of the total waste in place and received by Mbeubeuss.

Table 5.1: Landfill Characteristics in Dakar

Landfill type	Large, open dump
Capacity (cubic meters)	—
Actual depth of waste (meters)—filling status	—
Final depth of waste (meters)	—
Remaining time to closure (years)	1–3
Waste in place: time since landfilled (years)	25
Daily cover type	No
Average annual temperature (degrees centigrade)	35
Precipitation (millimeters annually)	542.0
Leachate management	No
Gas management	No
Surrounding fence	Yes

5.24 ***Age of the landfill.*** Dakar's large, open dump, Mbeubeuss, is 25 years old and is still receiving 77 percent of the waste generated in the city. LFG is still being produced.

5.25 ***Leachate management.*** There is no leachate treatment or recirculation in Mbeubeuss. Recirculating the leachate in a landfill adds to moisture in the disposed waste and thereby enhances the biodegradation process in the waste. If the leachate recirculation is optimal, for example, the organic load in the leachate will be significantly reduced and a greater amount of LFG will be produced. This needs to be considered for implementation in Dakar when considering an LFG project.

5.26 ***Estimated total waste landfilled: assumptions.*** For the calculation of the total waste landfilled over the most recent 25-year period, the following adjustment was made: to calculate the quantity of waste landfilled every year, (a) the population growth rate (PGR) and the waste generation rate (WGR) were considered to be constant over the period of landfilling; (b) the fraction of waste landfilled was assumed constant and equal to 0.77 over the whole 25-year period (Nora, Benrabia, 1998); (c) for every year, the constant growth rate was applied to calculate the urban population. The various parameters are computed as follows:

$$\text{Total waste landfilled} = W = \sum WL_I = \sum \left(UP_I * WGR * FWL_I\right)$$

Where:

- I = a given year between 1978 and 2003
- UP_I = urban population during year I = $UP_{2003}/((1+PGR)\wedge(2003-I))$, with UP_{2003} = 2,476,400 and PGR = 2.6%

- WGR = waste generation rate (kilograms/person/year)
- FWL_I = fraction of waste landfilled during year I.

For Dakar, W = 5,032,877 tons.

5.27 Table 5.2 presents the calculation of total waste landfilled.

Table 5.2: Total Waste Landfilled in Dakar, 1978–2003.

Year	*UP*	*WGR*	*FWL*	*WL*
2003	2,476,400	182.5	0.77	173,998
2002	2,413,645	182.5	0.77	339,177
2001	2,352,481	182.5	0.77	330,582
2000	2,292,866	182.5	0.77	322,205
1999	2,234,762	182.5	0.77	314,040
1998	2,178,131	182.5	0.77	306,082
1997	2,122,935	182.5	0.77	298,325
1996	2,069,137	182.5	0.77	290,765
1995	2,016,703	182.5	0.77	283,397
1994	1,965,597	182.5	0.77	276,216
1993	1,915,787	182.5	0.77	269,216
1992	1,867,239	182.5	0.77	262,394
1991	1,819,921	182.5	0.77	255,744
1990	1,773,802	182.5	0.77	249,264
1989	1,728,852	182.5	0.77	242,947
1988	1,685,041	182.5	0.77	236,790
1987	1,642,340	182.5	0.77	230,790
1986	1,600,721	182.5	0.77	224,941
1985	1,560,157	182.5	0.77	219,241
1984	1,520,621	182.5	0.77	213,685
1983	1,482,087	182.5	0.77	208,270
1982	1,444,529	182.5	0.77	202,992
1981	1,407,923	182.5	0.77	197,848
1980	1,372,244	182.5	0.77	192,835
1979	1,337,470	182.5	0.77	187,948
1978	1,303,577	182.5	0.77	183,185
W (tons)				5,032,877

Waste characteristics analysis

5.28 ***Waste composition.*** Table 5.3 presents the waste composition in Dakar. The waste landfilled has approximately 50.1 percent of organic content, which produces methane in an anaerobic environment.

Table 5.3: Waste Composition in Dakar

Nature	*Content (%)*
Organic waste	50.1
Textiles and cloth	5.2
Paper and cardboard	9.7
Metallic, ferrous	3.4
Plastic	2.7
Rubber	1.5
Glass	1.1
Wood	0.2
Leather	0.3
Nails and ceramic	2.4
Other—stones	4.3
Fine(diameter <2.5mm)	19.1
Total	100.0

5.29 ***Moisture content.*** Dakar does not have enough rainfall to wet the waste and therefore enhance the biodegradation to produce more gas. Because Dakar is a big city with many ongoing waste management initiatives, the arid conditions could be overcome.

Preliminary site assessment

5.30 The landfill guidelines recommend the preliminary site assessment to examine the attractiveness of gas recovery project, including gas generation and usage.

5.31 ***Potential LFG production.*** This section provides an estimate, using the WIPM, of the current amount of gas that can be produced. The amount of gas that can be collected depends on several factors, including the amount of waste in place, waste characteristics and composition, and collection system design.

5.32 There are several approaches for estimating current and potential gas production. The most reliable one is to drill test wells into the waste. However, this is costly and should not be used until the initial assessment indicates that there is enough waste to produce a reasonable amount of gas.

5.33 The WIPM was developed from data on gas recovery projects in the United States. The model relates gas production to the quantity of waste in the facility, but does not consider the aging of the waste and the changing rate of gas production over time. The model is as follows:

$LFG = 2 * (4.32 + 2.91 * W – 1.1W * D)$

Where:

- LFG = total landfill gas generated in a current year (cubic meters)
- W = total waste in place that is less than 30 years old (tons)
- D = aridity factor (1 when rainfall is less than 635 millimeters per year and 0 otherwise).

For Dakar, D = 1 and LFG = 18,219,022 cubic meters.

5.34 ***Potential collectable gas.*** Not all LFG generated can be collected. Some of the gas generated in the landfill will escape. According to the landfill guidelines, a reasonable assumption for a new collection system, which will operate for energy efficient recovery, is within the range of 70–80 percent CER. The estimate from the WIPM should then be multiplied by the CER to determine the potential collectable gas from the landfill. This study considers the worst-case scenario of 70 percent CER. This rate of production can be sustained for 5–15 years, depending on the site, and it is worth noting that estimating the gas potential is critical in determining the technical specifications of the project and assessing its economic feasibility**.**

$PCLFG = LFG * CER$

With:

PCLFG = potential collectable landfill gas.

For Dakar, PCLFG = 12,753,315 cubic meters.

5.35 To evaluate W, the total LFG generated in a current year, we use the WIPM with the indicator D to be equal to 1 (when precipitation is less than 635 millimeters per year). As already explained, Dakar does not meet the requirement for annual precipitation and, because of that, D is equal to 1. As a result, there is a substantial reduction in LFG generated.

5.36 ***Potential electricity production.*** Figure 4.1 on page 25 presents the process of electricity production from LFG. The process consists of two parts: (a) the collection and treatment of gas to make it suitable for combustion (see the section above on potential collectable gas) and (b) the combustion in an internal combustion engine and production of electricity through a generator.

5.37 Depending on how far the power station is from the load center, the electricity produced could also be fed into a transformer for transmission. The next section determines the amount of electricity that can be produced by the generator.

5.38 To evaluate PCLFG, a CER of 70 percent was used, which is the worse-case scenario.

5.39 ***Assumptions.*** For the calculation of the potential electricity production (PEP),

5.40 the following assumptions were made: (a) the raw LFG is 50 percent methane by volume and has a low heating value (LHV) of 16.8MJ per cubic meter; (b) the gas is burned in an internal combustion engine, which has an overall 33.0 percent electricity conversion efficiency (ECE) and an overall availability factor (AF) of 95 percent.

5.41 The following calculations were made:

PEP = PCLFG * LHV * ECE

LFG-IC = PEP/(number of hours during a year * AF)

With LFG-IC = landfill gas installed capacity

LFG-IC = PEP/(number of hours during a year * AF)

For Dakar, PEP = 70,704 MWh
and LFG-IC = 8.50MW.

5.42 Table 5.4 summarizes the parameters calculated for Dakar.

Table 5.4: Potential LFG-Generated Electricity in Dakar

W (tons)	5,032,877
LFG (cubic meters)	18,219,022
CER (%)	70.0
PCLFG (cubic meters per year)	12,753,315
LHV (MJ per cubic meter)	16.8
GHV (MJ)	214,255,694
ECE (%)	33.0
PEP (MWh per year)	70,704
AF	0.95
LFG-IC (MW per year)	8.50

5.43 Forecasting the quantity and quality of LFG available for present and future energy production can be uncertain. More reliable prediction will need field data and further testing for potential collectable gas.

5.44 The level of methane concentration in LFG (generally assumed to be within the range of 35–50 percent) is generally acceptable for use in a wide variety of equipment, including the internal combustion engine and gas turbine for electricity generation. However, gas turbine use requires a stringent filtering process to avoid the deterioration of the turbine blades.

5.45 LFG recovery and LFG-to-energy technologies are generally well developed and commercially available in most countries. The internal combustion engine, which needs less gas flow than the gas turbine and can be easily turned on and off, is more suitable when the electricity loads are changing during the day.

Initial Appraisal Result and Conclusion

5.46 The initial appraisal screening criteria aimed at determining if the landfill of Dakar has the characteristics that generally support economically viable LFG recovery projects. The strategy already developed for Conakry is applied in the following section.

Energy shortage

5.47 Based on the supply and demand forecast, Dakar will need additional capacity to meet electricity demand; a gas recovery project may be highly desirable as a source of energy for the area.

High energy cost

5.48 Dakar depends mainly on thermal generation for its electricity supply. As such, electricity prices are high in Dakar (average US¢11 per kWh), and this environment would favor—and even potentially support—profitable gas recovery projects.

Initial appraisal results from the guidelines' checklist

5.49 The guidelines provide four questions, each of which can be answered "yes" in the case of Dakar:

- Are there landfills or large, open dumps (currently receiving waste or closed recently) that could be potential candidates?
- At the potential candidate sites, are there prospective uses for the energy recovered?
- Does the candidate site have more than 1 million tons of waste in place?
- Does the candidate site contain primarily MSW?

5.50 The affirmative answers to these questions mean that there are promising options for gas recovery in Dakar. After this step, technical and economic or financial feasibility of gas recovery of the candidate site should be thoroughly evaluated.

6

Simplified Financial Analysis for WTE Projects in Conakry and Dakar

6.1 This section evaluates the sustainability of the WTE projects in Conakry and Dakar to ensure that they meet a target level of cost- effectiveness, which is valuable to investors. Using comparable World Bank–financed projects and the EPA guidelines, the investment and project costs have been estimated, as well as operation and maintenance costs, to determine the net present value (NPV), internal rate of return (IRR), payback period, and unit energy cost.

6.2 These calculations give a good overview of the sustainable nature of WTE projects in Conakry and Dakar, but these estimates will have to be refined through detailed technical design of the gas collection system and power plant to be constructed and discussions with manufacturers and suppliers of equipment and utility operators.

Hypotheses for Financial Indicators Evaluation

- The amount of collectable LFG is considered to be constant throughout the project life, assuming that the gas from incoming waste will compensate for the decreasing gas generation from existing waste.
- A tax rate of 30 percent has been assumed, a discount rate of 12 percent, and an inflation rate of 7 percent have been considered.
- The exploitation costs include operation (with administration) and maintenance costs for running the facilities.
- All financial indicators are calculated based on a useful project life of 15 years.
- The selling tariff is US¢12 per kWh for Conakry and US¢9 per kWh for Dakar, assuming that the transmission charges represent 20 percent of the end-user electricity tariff.

Investment Costs

6.3 The investment costs for the design and construction of the LFG capture and use facility were determined through a proxy method, using data from the Methane Gas Capture and Use Facility at SIMEPRODESO in Mexico, a Global Environment Facility (GEF)project, and EPA guidelines for preliminary site assessment. The costs are presented in table 6.1.

Table 6.1: Investment Costs for Methane Gas Capture and Use in Conakry and Dakar

		Mexico	Conakry	Dakar
	Installed capacity (MW)	7.0	5.4	8.5
Gas recovery cost (US$)				
	Gas recovery equipment	1,946,160	1,501,323	2,363,194
	Gas cleaning equipment	54,000	41,657	65,571
Gas use cost (US$)				
	Complete system for electricity generation			
	Engine house	43,200	33,326	52,457
	Engines	6,456,024	4,980,361	7,839,458
	Electrical substation (34.5 kilovolts)	828,360	639,021	1,005,866
	Interconnection line	432,000	0	0
Contingencies (10%physical; 7% price)		1,665,582	1,223,267	1,925,513
	Subtotal		8,418,955	13,252,059
Other cost (US$)				
	System design cost		1,262,843	1,987,809
	Training	37,800	100,000	100,000
Total investment costs (US$)		11,463,126	9,781,799	15,339,868

Results Analysis

6.4 Table 6.2 presents the NPV, IRR, and unit energy costs for Conakry and Dakar.

Table 6.2: NPV, IRR, and Unit Energy Costs in Conakry and Dakar

	Mexico	Conakry	Dakar
Installed capacity (MW)	7.0	5.4	8.5
Discount rate	10.0%	12.0%	12.0%
Inflation rate		0.0%	0.0%
Tax rate	35.0%	30.0%	30.0%
Electricity tariff (US¢/kWh)	8.75	12.00	9.00
Investment costs (US$)	11,463,126	9,781,799	15,339,868
NPV over 15 years (US$)	2,231,844	8,371,146	5,166,809
IRR over 15 years	13.4%	27.3%	18.2%
Unit energy cost (US¢/kWh)		4.41	4.12
Ratio of NPV to investment costs	19.5%	85.6%	33.7%

6.5 The NPV is positive for both projects and represents a substantial proportion of the investment costs for Conakry (85.6 percent) and Dakar (33.7 percent). It indicates that the scheme used is financially viable.

6.6 The IRR is very useful for an investor with few opportunities. It tells the investor the annual rate of return on monies while they remain tied up in the project. The value of the IRR for both projects is greater than the discount rate used (12 percent). If all the money has to be borrowed, the IRR will guide investors as to what maximum interest rate they could use to borrow money and run the project successfully.

6.7 Table 6.3 presents a discounted cash flow analysis for the two projects, which shows that the payback period is between five and six years for the Conakry project and between eight and nine years for the Dakar project.

Table 6.3: Payback Periods for the Conakry and Dakar Projects

	Cumulated Cashfow (US$)	
Year	Conakry	Dakar
Year 0	-9,781,799	-15,339,868
Year 1	-7,374,568	-12,733,684
Year 2	-5,225,255	-10,406,735
Year 3	-3,306,225	-8,329,101
Year 4	*-1,592,806*	-6,474,071
Year 5	*-62,967*	-4,817,794
Year 6	1,302,960	-3,338,975
Year 7	2,522,538	-2,018,601
Year 8	3,611,447	*-839,696*
Year 9	4,583,687	*212,898*
Year 10	5,451,758	1,152,714
Year 11	6,423,664	2,300,524
Year 12	7,291,438	3,325,355
Year 13	8,066,235	4,240,383
Year 14	8,758,019	5,057,372
Year 15	9,375,683	5,786,826

Sensitivity Analysis

6.8 A sensitivity analysis was also performed to assess the effect of uncertainty in the electricity price and discount rate on the results of the financial analysis. This was done by changing each of the parameters over a specific range and performing the financial analysis as previously.

6.9 Table 6.4 presents the sensitivity of the NPV and unit energy cost to changes in discount rates.

Table 6.4: Sensitivity of the NPV and Unit Energy Cost to Changes in Discount Rates for the Conakry and Dakar Projects

	NPV (US$)		Unit energy cost (US¢/kWh)	
Discount rate	Conakry	Dakar	Conakry	Dakar
8.0%	13,483,081	10,768,964	3.75	3.47
10.0%	10,659,705	7,664,611	4.07	3.79
12.0%	8,371,146	5,166,809	4.41	4.12
14.0%	6,501,914	3,143,027	4.76	4.47
16.0%	4,964,140	1,492,649	5.12	4.82
18.0%	3,690,435	*138,686*	5.49	5.19
20.0%	2,628,715	*-978,224*	5.87	5.57
22.0%	1,738,425	-1,904,194	6.27	5.96
24.0%	987,751	-2,675,305	6.66	6.35
26.0%	*351,557*	-3,319,989	7.07	6.76
28.0%	*-190,152*	-3,860,803	7.48	7.16
30.0%	-653,391	-4,315,764	7.89	7.57

6.10 Table 6.5 presents the sensitivity of the NPV and IRR to changes in the electricity price.

Table 6.5: Sensitivity of the NPV and IRR to Changes in the Electricity Price for the Conakry and Dakar Projects

	NPV (US$)		IRR	
Tariff (US¢/kWh)	Conakry	Dakar	Conakry	Dakar
7	-1,141,104	-852,665	9.7%	10.9%
8	761,346	2,157,072	13.5%	14.7%
9	2,663,796	*5,166,809*	17.1%	*18.2%*
10	4,566,246	8,176,546	20.5%	21.7%
11	6,468,696	11,186,283	23.9%	25.1%
12	*8,371,146*	14,196,020	*27.3%*	28.4%
13	10,273,596	17,205,757	30.6%	31.8%
14	12,176,045	20,215,495	33.8%	35.0%
15	14,078,495	23,225,232	37.1%	38.3%

6.11 Figures 6.1 and 6.2 present, respectively, the sensitivity of the NPV to the discount rate and the IRR to the electricity price.

Figure 6.1: Sensitivity of the NPV to the Discount Rate

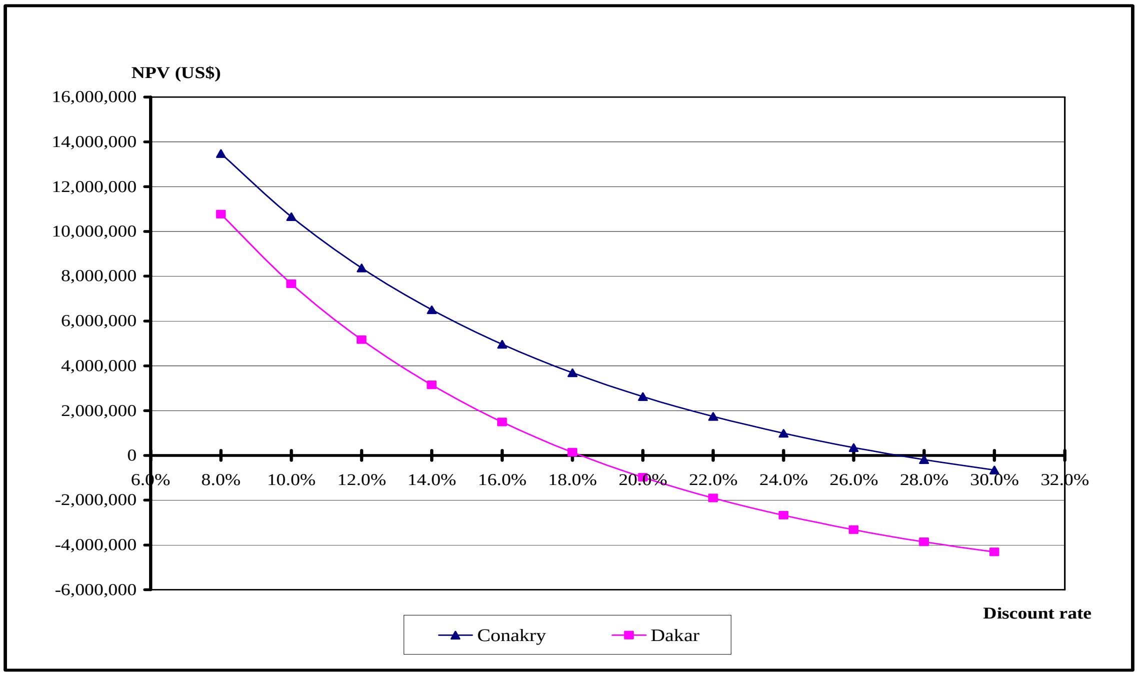
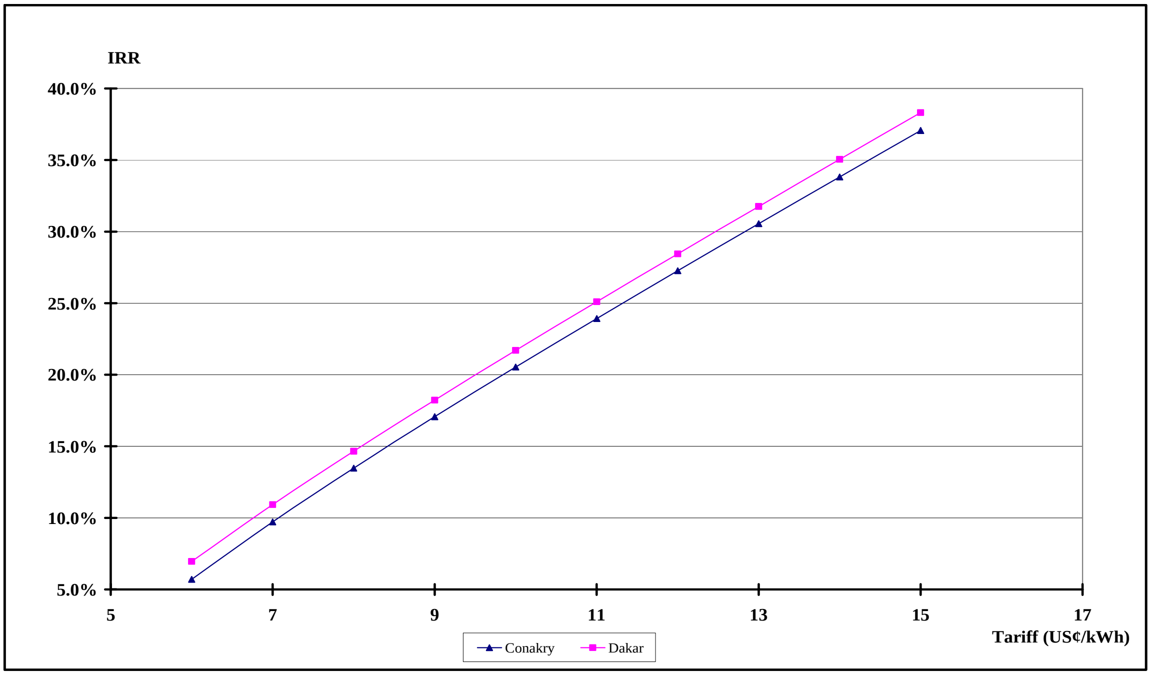


Figure 6.2: Sensitivity of the IRR to the Electricity Tariff



Conclusion of the Financial Analysis

6.12 After weighing the investment costs, unit energy costs, IRR, NPV, and payback period, the WTE projects in Conakry and Dakar can be considered cost-effective projects on a purely commercial basis. If one takes into consideration environmental benefits, such as greenhouse gases reduction, the projects can receive emission credit from the Carbon Fund or a grant from GEF, making them more attractive.

7

Ongoing LFG Projects in Africa

7.1 This section presents some major experiences in LFG capture and use projects and draws or reinforces preliminary conclusions for the feasibility of WTE projects in SSA cities. Two different experiences, from which lessons and recommendations can be drawn to benefit future LFG projects in Africa, are presented below:

- Takagas: A LFG project that did not take off. Why?
- Durban: An ongoing carbon finance LFG project, which includes a best practice that could be economically attractive in some SSA cities with high electricity prices and in some other SSA cities with low electricity price through use of the carbon finance (for example, in Lagos, Nigeria, and Accra, Ghana).

Takagas: An LFG Project that Did Not Take Off. Why?

7.2 The Takagas project aimed at treating municipal solid waste in Dar-es-Salaam, Tanzania, for the purpose of generating biogas, electricity, and fertilizer. The project was to handle about 60 tons of waste per day. The project development objective was to reduce the amount of methane and carbon dioxide emitted to the atmosphere through the reduction of uncontrolled aerobic and anaerobic digestion of organic waste. Controlled generation and use of methane for power production was also envisaged to contribute to reducing the consumption of fossil fuels. Because of various reasons, the project had to be terminated before commencement of the biogas plant's construction.

7.3 The project's physical implementation did not go far beyond the plant design, and the construction stage was not reached, however, about 19 percent of project funds were already spent. The reasons for terminating the project encompass inadequacy of the project's pre-investment study, delays in the project's plot acquisition, absence of a reliable solid waste delivery system for the proposed plant, absence or inadequate enforcement of waste management legislation, and failure to raise additional funds when the project proved to be more expensive than was originally planned.

7.4 Based on events that led to closure of Takagas Project, the following recommendations need to be given careful thought when planning to implement a project similar to Takagas: (a) ensure that the proper enabling legislation is in place, (b) carry out exhaustive feasibility studies and (c) be logical in planning and selecting technologies.

Durban LFG-to-Electricity: a Clean Development Mechanism (CDM) Project

7.5 The Durban project involves an enhanced collection of LFG at three landfill sites in Durban, South Africa, and the use of the recovered gas to produce electricity. The produced electricity will be fed into the municipal grid and replace electricity that the municipal electric company is currently buying from other suppliers. The primary purpose of the project is electricity generation, and it is characterized as a municipal autogeneration project. The project is also environmentally positive: it will result in emission reductions that would not occur otherwise, because the project does not present an economically attractive investment opportunity. Given that energy generation by the proposed project costs more than the continued purchase of electricity from the national utility company, ESKOM, the project sponsor is unlikely to invest in the project in the absence of carbon finance.

7.6 The project will generate 10 MW of electric power from methane, which will displace coal-fired energy purchased from the grid. The expected cost of electricity generation by the project is calculated at US$0.0422 per kWh, and Durban currently pays a tariff of US$0.0156 per kWh for peak-load power and US$0.00694 for off-peak periods.

7.7 It is estimated that the project will reduce an estimated 3,204,032 tons of carbon dioxide in the first seven years' crediting period. The emission reductions from the Durban project will result from:

- Avoided landfill methane emissions due to collection, use, or flaring, and conversion to CO_2 of the methane in the landfill gas
- Avoided CO_2 emissions due to displacement of grid electricity with LFG-generated electricity.

7.8 From an investment point of view, the autogeneration option, using the LFG, is not an economically attractive course of action for the municipality of Durban now or in any foreseeable future. However, in the context of the CDM of the Kyoto Protocol, the avoided $C0_2$ emissions will be sold and therefore make this project attractive. Some SSA countries with low electricity cost and large population could take advantage of the carbon finance initiative. Lagos, with more than 13 millions people, will be a good candidate. The purchase price ranges between US$2.50 and US$4.0 per ton of CO_2.

8

Conclusion

8.1 The Durban LFG project is not economically attractive without carbon finance mechanism in the context of South Africa, where electricity costs are very low. However, it could be a sustainable and economically viable project in some SSA cities with high energy costs, such as Conakry, Yaoundé, Kinshasa, and Dakar (see table A.4, annex). The WTE project, combined or not with the carbon finance initiative, could be an innovative solution to some of the most pressing electricity shortage problems in certain SSA countries, as well as to pollution and waste disposal problems in the Region. The lessons from the Takagas failure demonstrate the need for reliable data in planning LFG projects.

8.2 To choose cities that offer good opportunities for LFG capture, we applied a methodology, tailored specifically for this study, which integrates different sources of information. This methodology is summarized in two consecutive steps presented by figure 3.1 (page 12) and figure 3.2 (page 15).

8.3 The first two criteria adopted (population of more than 1 million, annual rainfall of more than 635 millimeters) do not mean that cities with less population or rainfall could not be eligible for LFG capture projects: cities with a small population but more organic content in MSW could generate as much LFG as a large city. A city with a large population can also generate a substantial amount of LFG with less rain (Dakar, for example).

8.4 From the overall screening process, we can conclude that (a) Conakry is a good candidate for an LFG capture project and has a potential of 5.4 MW; (b) Dakar is also a good candidate and has a potential of 8.5 MW, even when taking into account the aridity condition; (c) for Yaoundé, further investigation or data collection, including a site visit, is needed to make a better assessment of the situation.

8.5 In addition, the simplified financial analysis (pages 41–47) leads to interesting results: (a) Conakry has an IRR of 27.3 percent and a ratio of NPV to investment costs of 85.6 percent; (b) Dakar has an IRR of 18.2 percent and a ratio of NPV to investment costs of 33.7 percent; (c) the payback period for both projects is fewer than nine years.

8.6 This study is an initial step to a larger program that could contribute to poverty reduction in SSA, especially in terms of diversification and increase of periurban or rural electrification options or both. Several approaches could be adopted:

- The first one would be to analyze the required steps for the implementation of an LFG capture project for periurban electrification in the selected cities, that is, in Conakry and Dakar. This would include a review of the policies that can affect project design and implementation and a proposal for the suitable environment for such project.
- The second approach would be to conduct a technical and economical feasibility study on LFG capture for electricity generation in Dakar and Conakry. This study would include contributions from World Bank experts from the SSA Region and other interested units.
- The third option would be to develop a guidance note for LFG recovery for periurban electricity initiatives in SSA. This last approach would extend the study to other cities in SSA, with site visits for reliable data collection and gas capture opportunity assessment. The findings would be analyzed and presented in a handbook and other adequate formats for knowledge sharing and dissemination.

Annex 1

Tables and Guinea and Senegal at a Glance

Table A.1: SSA Countries and Capital (or Major) Cities

Country			*Capital or major city*		
Name	Population	Annual pop growth rate (%)	Name	Population	Share of country population (%)
Angola	13,510,000	3.1	Luanda	2,200,000	16.3
Benin	6,440,000	2.9	Porto-Novo	223,025	3.5
Botswana	1,700,000	2.8	Gaborone	225,000	13.2
Burkina Faso	11,550,000	2.4	Ouagadougou	960,000	8.3
Burundi	6,940,000	2.2	Bujumbura	331,000	4.8
Cameroon	15,200,000	2.5	Yaoundé	1,239,100	8.2
Cape Verde	450,000	2.5	Praia	95,000	21.1
Central African Republic	3,770,000	2.4	Bangui	567,896	15.1
Chad	7,920,000	3.0	N'Djamena	626,639	7.9
Comoros	570,000	2.6	Moroni	24,000	4.2
Congo, Dem. Rep. of	52,350,000	3.3	Kinshasa	6,301,100	12.0
Congo, Rep. of	3,100,000	3.1	Brazzaville	950,000	30.6
Côte d'Ivoire	16,410,000	3.1	Abidjan	3,395,976	20.7
Djibouti	640,000	2.9	Djibouti	360,000	56.3
Equatorial Guinea	470,000	2.6	Malabo	53,722	11.4
Eritrea	4,200,000	2.7	Asmara	429,316	10.2
Etiopía	65,820,000	2.3	Addis Ababa	2,300,000	3.5
Gabon	1,260,000	2.8	Libreville	509,323	40.4
Gambia, The	1,340,000	3.4	Banjul	43,687	3.3
Ghana	19,710,000	2.4	Accra	2,269,437	11.5
Guinea	7,580,000	2.6	Conakry	1,800,000	23.7
Guinea-Bissau	1,230,000	2.3	Bissau	220,000	17.9
Kenya	30,740,000	2.6	Nairobi	2,312,300	7.5
Lesotho	2,060,000	1.9	Maseru	173,700	8.4
Liberia	3,210,000	2.5	Monrovia	630,600	19.6
Madagascar	15,980,000	3.0	Antananarivo	1,245,181	7.8
Malawi	10,530,000	2.0	Lilongwe	499,200	4.7
Mali	11,090,000	2.5	Bamako	1,069,242	9.6
Mauritania	2,750,000	2.9	Nouakchott	800,000	29.1
Mauritius	1,200,000	1.2	Port Louis	148,024	12.3
Mozambique	18,070,000	2.2	Maputo	1,100,000	6.1
Namibia	1,790,000	2.4	Windhoek	177,470	9.9
Niger	11,180,000	3.5	Niamey	723,200	6.5
Nigeria	129,870,000	2.8	Lagos	13,500,000	10.4
Rwanda	8,690,000	2.0	Kigali	338,398	3.9
SãoTomé and Principe	150,000	2.6	São Tome	50,310	33.5
Senegal	9,770,000	2.7	Dakar	2,476,400	25.3
Seychelles	80,000	1.5	Victoria	79,715	99.6
Sierra Leone	5,130,000	2.3	Freetown	971,679	18.9
Somalia	9,080,000	2.0	Mogadishu	1,219,000	13.4
South Africa	43,240,000	2.0	Pretoria	1,600,000	3.7
Sudan	31,690,000	2.3	Khartoum	1,244,500	3.9
Swaziland	1,070,000	3.1	Mbabane	67,200	6.3
Tanzania	34,450,000	2.8	Dar es Salaam	2,421,900	7.0
Togo	4,670,000	2.7	Lomé	658,100	14.1

Uganda	22,790,000	3.1	Kampala	953,400	4.2
Zambia	10,280,000	2.6	Lusaka	2,218,200	21.6
Zimbabwe	12,820,000	2.1	Harare	1,864,400	14.5

Table A.2: Cities with Population of More than 1 Million

Country			*City*		
Name	Population	Annual pop. growth rate (%)	Name	Population	Share of country population (%)
Nigeria	129,870,000	2.8	Lagos	13,500,000	10.4
Congo, Dem. Rep. of	52,350,000	3.3	Kinshasa	6,301,100	12.0
Côte d'Ivoire	16,410,000	3.1	Abidjan	3,395,976	20.7
Senegal	9,770,000	2.7	Dakar	2,476,400	25.3
Tanzania	34,450,000	2.8	Dar es Salaam	2,421,900	7.0
Kenya	30,740,000	2.6	Nairobi	2,312,300	7.5
Ethiopia	65,820,000	2.3	Addis Ababa	2,300,000	3.5
Ghana	19,710,000	2.4	Accra	2,269,437	11.5
Zambia	10,280,000	2.6	Lusaka	2,218,200	21.6
Angola	13,510,000	3.1	Luanda	2,200,000	16.3
Zimbabwe	12,820,000	2.1	Harare	1,864,400	14.5
Guinea	7,580,000	2.6	Conakry	1,800,000	23.7
South Africa	43,240,000	2.0	Pretoria	1,600,000	3.7
Madagascar	15,980,000	3.0	Antananarivo	1,245,181	7.8
Sudan	31,690,000	2.3	Khartoum	1,244,500	3.9
Cameroon	15,200,000	2.5	Yaoundé	1,239,100	8.2
Somalia	9,080,000	2.0	Mogadishu	1,219,000	13.4
Mozambique	18,070,000	2.2	Maputo	1,100,000	6.1
Mali	11,090,000	2.5	Bamako	1,069,242	9.6

Table A.3: Cities with Population of More than 1 Million and Annual Rainfall of More than 635 Millimeters

Country	*Capital city*	*Population*	*Average precipitation (mm)*
Guinea	Conakry	1,800,000	3,869.6
Nigeria	Lagos	13,500,000	1,828.8
Cameroon	Yaoundé	1,239,100	1,555.0
Côte d'Ivoire	Abidjan	3,395,976	1,421.0
Madagascar	Antananarivo	1,245,181	1,367.5
Congo, Rep. of	Kinshasha	6,301,100	1,358.0
Ethiopia	Addis Ababa	2,300,000	1,236.0
Mali	Bamako	1,069,242	1,018.2
Zambia	Lusaka	2,218,200	838.2
Zimbabwe	Harare	1,864,400	838.2

Mozambique	Maputo	1,100,000	768.3
Kenya	Nairobi	2,312,300	760.3
Ghana	Accra	2,269,437	736.6
South Africa	Pretoria	1,600,000	704.1
Tanzania	Dar es Salaam	2,421,900	550.6
Senegal	Dakar	2,476,400	542.0
Somalia	Mogadishu	1,219,000	431.8
Angola	Luanda	2,200,000	330.2
Sudan	Khartoum	1,244,500	155.5

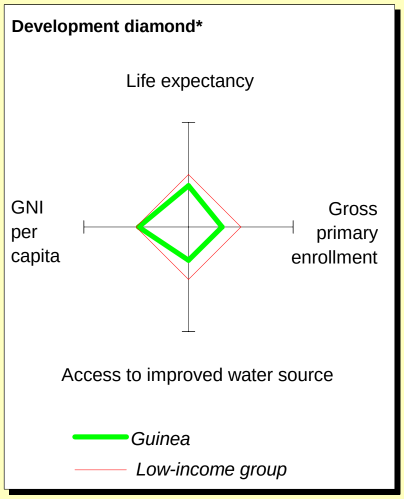
Table A.4: Cities with Population of More than 1 Million, Annual Rainfall of More than 635 Millimeters, and Electricity Price of More Than US¢7/kWh

Country	*Capital city*	*Population*	*Average precipitation (mm)*	*Electricity price (US¢/kWh)*
Mali	Bamako	1,069,242	1,018.2	16.88
Guinea	Conakry	1,800,000	3,869.6	15.15
Côte d’Ivoire	Abidjan	3,395,976	1,421.0	9.40
Cameroon	Yaoundé	1,239,100	1,555.0	9.20
Congo, Dem. Rep. of	Kinshasa	6,301,100	1,358.0	8.20
Senegal	Dakar	2,476,400	542.0	11.00
Madagascar	Antananarivo	1,245,181	1,367.5	6.76
Ghana	Accra	2,269,437	736.6	6.75
Kenya	Nairobi	2,312,300	760.3	6.27
Ethiopia	Addis Ababa	2,300,000	1,236.0	5.83
Nigeria	Lagos	13,500,000	1,828.8	5.70
Zimbabwe	Harare	1,864,400	838.2	5.24
South Africa	Pretoria	1,600,000	704.1	4.85
Mozambique	Maputo	1,100,000	768.3	3.15
Zambia	Lusaka	2,218,200	838.2	2.45

Guinea at a glance

9/23/02

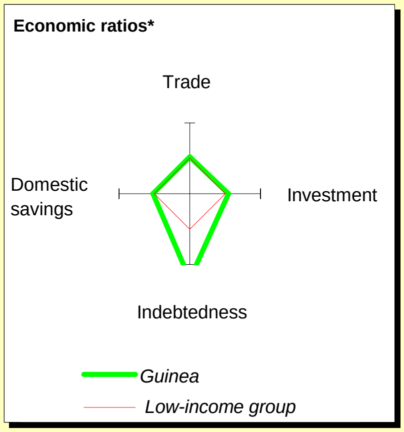
POVERTY and SOCIAL	**Guinea**	**Sub-Saharan Africa**	**Low-income**
2001			
Population, mid-year *(millions)*	7.6	674	2,511
GNI per capita *(Atlas method, US$)*	410	470	430
GNI *(Atlas method, US$ billions)*	3.1	317	1,069
Average annual growth, 1995-01			
Population *(%)*	2.3	2.5	1.9
Labor force *(%)*	2.1	2.6	2.3
Most recent estimate (latest year available, 1995-01)			
Poverty *(% of population below national poverty line)*	..	..	..
Urban population *(% of total population)*	28	32	31
Life expectancy at birth *(years)*	46	47	59
Infant mortality *(per 1,000 live births)*	95	91	76
Child malnutrition *(% of children under 5)*	23	..	..
Access to an improved water source *(% of population)*	48	55	76
Illiteracy *(% of population age 15+)*	..	37	37
Gross primary enrollment *(% of school-age population)*	61	78	96
Male	74	85	103
Female	49	72	88



KEY ECONOMIC RATIOS and LONG-TERM TRENDS

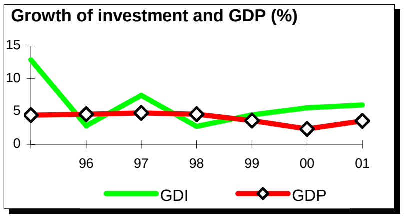
	1981	**1991**	**2000**	**2001**
GDP *(US$ billions)*	..	3.0	3.1	3.0
Gross domestic investment/GDP	..	18.1	22.1	22.1
Exports of goods and services/GDP	..	23.0	24.0	27.8
Gross domestic savings/GDP	..	18.0	16.9	20.4
Gross national savings/GDP	..	15.4	14.7	18.4
Current account balance/GDP	..	-1.8	-7.4	-3.7
Interest payments/GDP	..	1.3	1.9	1.8
Total debt/GDP	..	87.0	97.6	98.2
Total debt service/exports	..	15.0	22.4	19.9
Present value of debt/GDP	..	..	77.5	78.1
Present value of debt/exports	..	..	322.7	280.3

	1981-91	**1991-01**	**2000**	**2001**	**2001-05**
(average annual growth)					
GDP	4.1	4.3	2.3	3.6	5.2
GDP per capita	1.1	1.8	0.1	1.3	3.0
Exports of goods and services	5.6	5.1	3.0	3.3	4.1

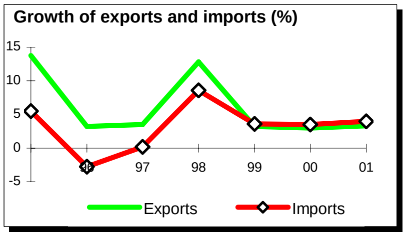


STRUCTURE of the ECONOMY

	1981	**1991**	**2000**	**2001**
(% of GDP)				
Agriculture	..	23.9	23.6	24.4
Industry	..	32.7	36.5	37.7
Manufacturing	..	4.6	4.1	4.4
Services	..	43.4	39.9	37.9
Private consumption	..	73.3	79.2	74.8
General government consumption	..	8.8	3.9	4.8
Imports of goods and services	..	23.1	29.2	29.5



	1981-91	**1991-01**	**2000**	**2001**
(average annual growth)				
Agriculture	3.2	4.1	-1.0	2.4
Industry	2.7	5.1	4.8	4.9
Manufacturing	..	4.2	7.0	5.5
Services	4.4	3.5	3.6	-1.7
Private consumption	4.0	3.4	1.7	3.1
General government consumption	-1.3	6.9	3.6	5.2
Gross domestic investment	5.0	3.3	5.6	6.0
Imports of goods and services	4.7	2.0	3.5	4.0



Note: 2001 data are preliminary estimates.

* The diamonds show four key indicators in the country (in bold) compared with its income-group average. If data are missing, the diamond will be incomplete.

Senegal at a glance

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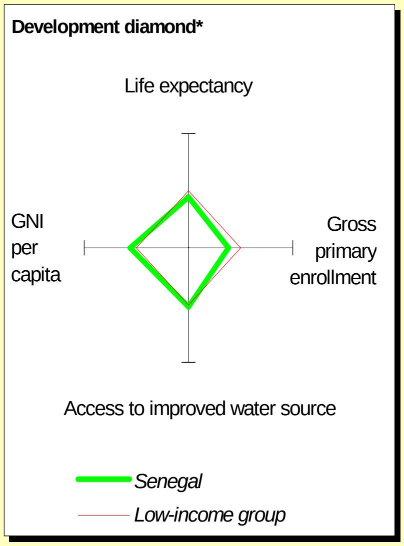
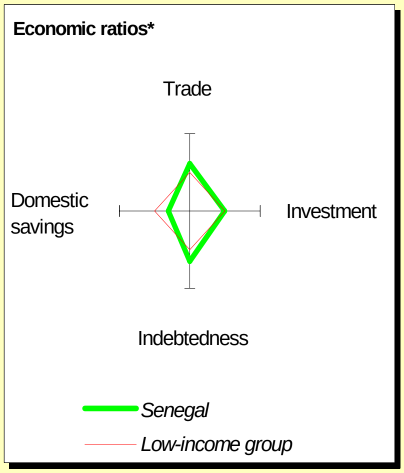
POVERTY and SOCIAL	Senegal	Sub-Saharan Africa	Low-income
2001			
Population, mid-year *(millions)*	9.8	674	2,511
GNI per capita *(Atlas method, US$)*	480	470	430
GNI *(Atlas method, US$ billions)*	4.7	317	1,069
Average annual growth, 1995-01			
Population *(%)*	2.7	2.5	1.9
Labor force *(%)*	2.8	2.6	2.3
Most recent estimate (latest year available, 1995-01)			
Poverty *(% of population below national poverty line)*	..	..	..
Urban population *(% of total population)*	48	32	31
Life expectancy at birth *(years)*	52	47	59
Infant mortality *(per 1,000 live births)*	60	91	76
Child malnutrition *(% of children under 5)*	13	..	..
Access to an improved water source *(% of population)*	78	55	76
Illiteracy *(% of population age 15+)*	62	37	37
Gross primary enrollment *(% of school-age population)*	73	78	96
Male	78	85	103
Female	68	72	88

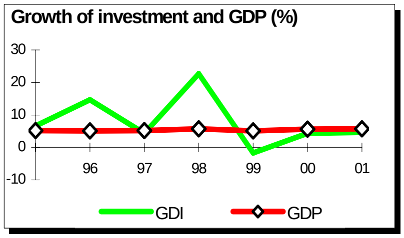


KEY ECONOMIC RATIOS and LONG-TERM TRENDS	1981	1991	2000	2001
GDP *(US$ billions)*	2.5	5.5	4.4	4.6
Gross domestic investment/GDP	12.8	12.9	19.8	20.0
Exports of goods and services/GDP	31.0	24.7	30.5	29.6
Gross domestic savings/GDP	-9.1	5.9	10.8	12.0
Gross national savings/GDP	-13.3	2.9	13.4	14.2
Current account balance/GDP	-25.1	-8.3	-6.5	-5.8
Interest payments/GDP	2.0	1.6	1.3	1.5
Total debt/GDP	67.4	64.9	77.1	..
Total debt service/exports	17.0	19.6	14.3	..
Present value of debt/GDP	..	..	55.3	..
Present value of debt/exports	..	..	151.1	..

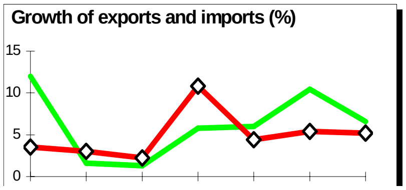
	1981-91	1991-01	2000	2001	2001-05
(average annual growth)					
GDP	2.8	4.3	5.6	5.7	4.9
GDP per capita	0.0	1.5	2.9	3.2	2.6
Exports of goods and services	3.1	4.0	10.5	6.6	5.2



STRUCTURE of the ECONOMY	1981	1991	2000	2001
(% of GDP)				
Agriculture	17.8	19.1	18.2	17.9
Industry	15.8	18.6	26.9	26.9
Manufacturing	11.5	12.6	17.8	17.6
Services	66.3	62.3	55.0	55.2
Private consumption	88.7	80.5	78.8	77.9
General government consumption	20.4	13.5	10.4	10.1
Imports of goods and services	52.8	31.6	39.6	37.6



	1981-91	1991-01	2000	2001
(average annual growth)				
Agriculture	2.3	2.8	11.5	6.9
Industry	3.8	5.6	7.3	6.8
Manufacturing	3.9	4.6	4.8	4.7
Services	2.7	4.3	3.4	5.0
Private consumption	1.8	4.2	5.1	6.0



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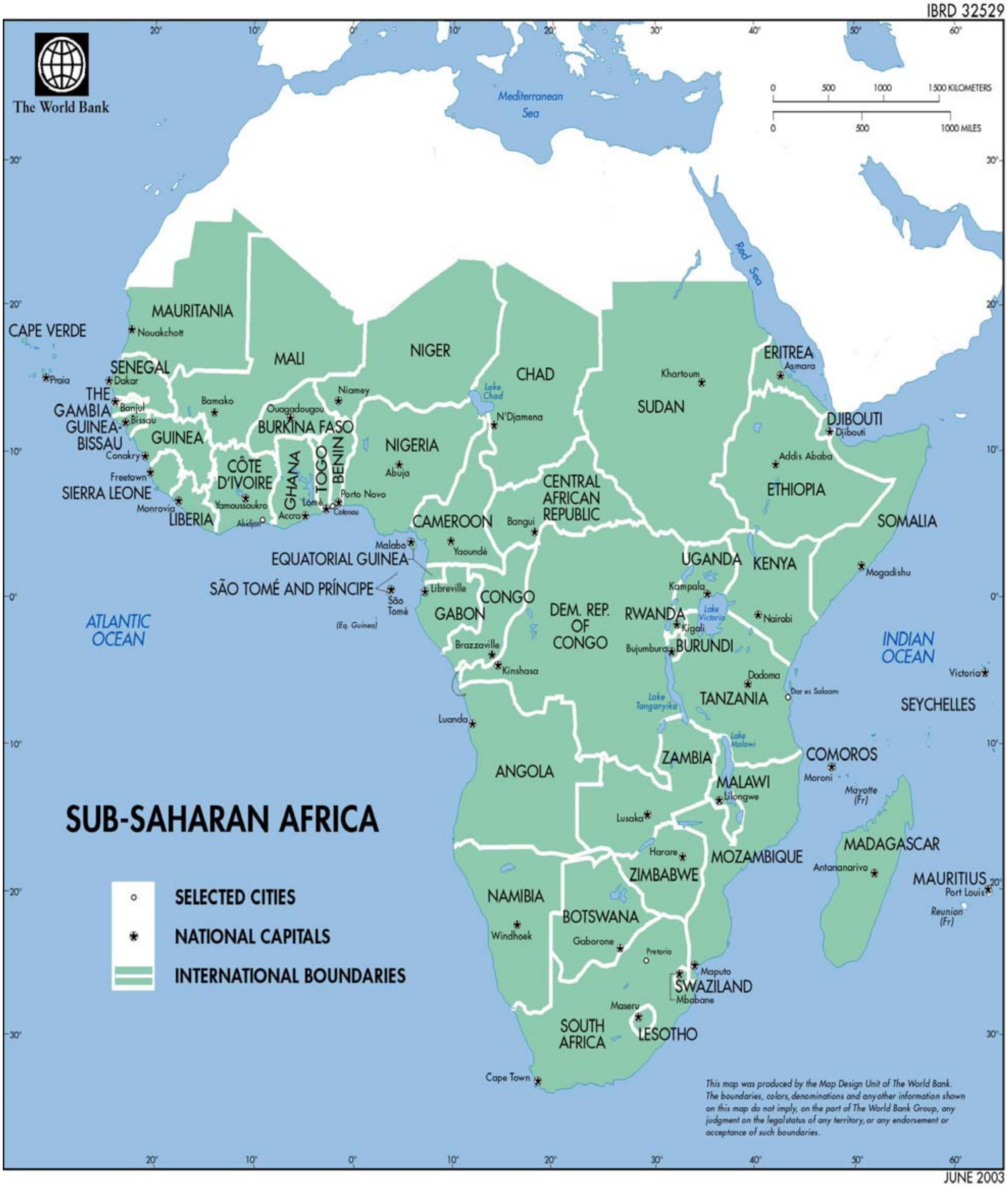

Joint UNDP/World Bank

ENERGY SECTOR MANAGEMENT ASSISTANCE PROGRAMME (ESMAP)

LIST OF TECHNICAL PAPER SERIES

Region/Country	***Activity/Report Title***	***Date***	***Number***
	SUB-SAHARAN AFRICA (AFR)		
Africa	Power Trade in Nile Basin Initiative Phase II (CD Only): *Part I: Minutes of the High-level Power Experts Meeting; and Part II: Minutes of the First Meeting of the Nile Basin Ministers Responsible for Electricity*	04/05	067/05
Côte d'Ivoire	Workshop on Rural Energy and Sustainable Development, January 30-31, 2002. (French Only)	04/05	068/05
Ethiopia	Phase-Out of Leaded Gasoline in Oil Importing Countries of Sub-Saharan Africa: The Case of Ethiopia - Action Plan.	12/03	038/03
	Sub-Saharan Petroleum Products Transportation Corridor: Analysis And Case Studies	03/03	033/03
	Phase-Out of Leaded Gasoline in Sub-Saharan Africa	04/02	028/02
	Energy and Poverty: How can Modern Energy Services Contribute to Poverty Reduction	03/03	032/03
East Africa	Sub-Regional Conference on the Phase-out Leaded Gasoline in East Africa. June 5-7, 2002.	11/03	044/03
Kenya	Field Performance Evaluation of Amorphous Silicon (a-Si) Photovoltaic Systems in Kenya: Methods and Measurement in Support of a Sustainable Commercial Solar Energy Industry	08/00	005/00
	The Kenya Portable Battery Pack Experience: Test Marketing an Alternative for Low-Income Rural Household Electrification	12/01	05/01
Malawi	Rural Energy and Institutional Development	04/05	069/05
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Mauritania	Phase-Out of Leaded Gasoline in Oil Importing Countries of Sub-Saharan Africa: The Case of Mauritania - Action Plan. (French)	12/03	040/03
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	Nigerian LP Gas Sector Improvement Study	03/04	056/04
	Taxation and State Participation in Nigeria's Oil and Gas Sector	08/04	057/04
Regional	Second Steering Committee: The Road Ahead. Clean Air Initiative In Sub-Saharan African Cities. Paris, March 13-14, 2003.	12/03	045/03
	Lead Elimination from Gasoline in Sub-Saharan Africa. Sub-regional Conference of the West-Africa group. Dakar, Senegal March 26-27, 2002 (French only)	12/03	046/03
	1998-2002 Progress Report. The World Bank Clean Air Initiative in Sub-Saharan African Cities. Working Paper #10 (Clean Air Initiative/ESMAP)	02/02	048/04
	Landfill Gas Capture Opportunity in Sub Saharan Africa	06/05	074/05
Senegal	Regional Conference on the Phase-Out of Leaded Gasoline in Sub-Saharan Africa	03/02	022/02
	Elimination du Plomb dans I'Essence en Afrique Sub-Saharienne Conference Sous Regionales du Groupe Afrique de I'Quest. Dakar, Senegal. March 26-27, 2002.	12/03	046/03
South Africa	South Africa Workshop: People's Power Workshop.	12/04	064/04
Swaziland	Solar Electrification Program 2001—2010: Phase 1: 2001—2002 (Solar Energy in the Pilot Area)	12/01	019/01

Region/Country	***Activity/Report Title***	***Date***	***Number***
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	Phase-Out of Leaded Gasoline in Oil Importing Countries of Sub-Saharan Africa: The Case of Tanzania - Action Plan.	12/03	039/03
Uganda	Report on the Uganda Power Sector Reform and Regulation Strategy Workshop	08/00	004/00

WEST AFRICA (AFR)

Regional	Market Development	12/01	017/01

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China	Assessing Markets for Renewable Energy in Rural Areas of Northwestern China	08/00	003/00
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	Technology Assessment of Clean Coal Technologies for China Volume II—Environmental and Energy Efficiency Improvements for Non-power Uses of Coal	05/01	011/01
	Technology Assessment of Clean Coal Technologies for China Volume III—Environmental Compliance in the Energy Sector: Methodological Approach and Least-Cost Strategies	12/01	011/01
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	Renewable Energy Action Plan	03/02	021/02
	Vietnam's Petroleum Sector: Technical Assistance for the Revision of the Existing Legal and Regulatory Framework	03/04	053/04

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Bangladesh	Workshop on Bangladesh Power Sector Reform	12/01	018/01
	Integrating Gender in Energy Provision: The Case of Bangladesh	04/04	054/04
	Opportunities for Women in Renewable Energy Technology Use In Bangladesh, Phase I	04/04	055/04

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Russia	Russia Pipeline Oil Spill Study	03/03	034/03

MIDDLE EASTERN AND NORTH AFRICA REGION (MENA)

Region/Country	*Activity/Report Title*	*Date*	*Number*
Regional	Roundtable on Opportunities and Challenges in the Water, Sanitation And Power Sectors in the Middle East and North Africa Region. Summary Proceedings. May 26-28, 2003. Beit Mary, Lebanon. (CD)	02/04	049/04

LATIN AMERICA AND THE CARIBBEAN REGION (LCR)

Region/Country	*Activity/Report Title*	*Date*	*Number*
Brazil	Background Study for a National Rural Electrification Strategy: Aiming for Universal Access	03/05	066/05
Bolivia	Country Program Phase II: Rural Energy and Energy Efficiency Report on Operational Activities	05/05	072/05
Ecuador	Programa de Entrenamiento a Representantes de Nacionalidades Amazónicas en Temas Hidrocarburíferos	08/02	025/02
Guatemala	Evaluation of Improved Stove Programs: Final Report of Project Case Studies	12/04	060/04
Mexico	Energy Policies and the Mexican Economy	01/04	047/04
Nicaragua	Aid-Memoir from the Rural Electrification Workshop (Spanish only)	03/03	030/04
	Sustainable Charcoal Production in the Chinandega Region	04/05	071/05
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	Regional Electricity Markets Interconnections — Phase II Proposals to Facilitate Increased Energy Exchanges in South America	04/02	016/01
	Population, Energy and Environment Program (PEA) Comparative Analysis on the Distribution of Oil Rents (English and Spanish)	02/02	020/02
	Estudio Comparativo sobre la Distribución de la Renta Petrolera Estudio de Casos: Bolivia, Colombia, Ecuador y Perú	03/02	023/02
	Latin American and Caribbean Refinery Sector Development Report – Volumes I and II	08/02	026/02
	The Population, Energy and Environmental Program (EAP) (English and Spanish)	08/02	027/02
	Bank Experience in Non-energy Projects with Rural Electrification Components: A Review of Integration Issues in LCR	02/04	052/04
	Supporting Gender and Sustainable Energy Initiatives in Central America	12/04	061/04
	Energy from Landfill Gas for the LCR Region: Best Practice and Social Issues (CD Only)	01/05	065/05

GLOBAL

Region/Country	*Activity/Report Title*	*Date*	*Number*
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	Best Practices for Sustainable Development of Micro Hydro Power in Developing Countries	08/00	006/00
	Mini-Grid Design Manual	09/00	007/00

Region/Country	*Activity/Report Title*	*Date*	*Number*
	Photovoltaic Applications in Rural Areas of the Developing World	11/00	009/00
	Subsidies and Sustainable Rural Energy Services: Can we Create Incentives Without Distorting Markets?	12/00	010/00
	Sustainable Woodfuel Supplies from the Dry Tropical Woodlands	06/01	013/01
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	Knowledge Exchange: Online Consultation and Project Profile from South Asia Practitioners Workshop. Colombo, Sri Lanka, June 2-4, 2003	12/03	043/03
	Energy & Environmental Health: A Literature Review and Recommendations.	03/04	050/04
	Petroleum Revenue Management Workshop	03/04	051/04
	Developing Financial Intermediation Mechanisms for Energy Efficiency Projects – Focus on Banking Windows for Energy Efficiency	08/04	058/04
	Evaluation of ESMAP Regional Power Trade Portfolio (TAG Report)	12/04	059/04
	Gender in Sustainable Energy Regional Workshop Series: Mesoamerican Network on Gender in Sustainable Energy (GENES) Winrock and ESMAP	12/04	062/04
	Women in Mining Voices for a Change Conference (CD Only)	12/04	063/04
	Renewable Energy Potential in Selected Countries: Volume I: North Africa, Central Europe, and the Former Soviet Union, Volume II: Latin America	04/05	070/05
	Survey Results with Renewable Energy Business Community and Bank Task Managers for a Renewable Energy Toolkit	05/05	073/05

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