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I - Introduction

I.1 - Background of the study

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 & MLW). At the same time, in most cities and suburbs in Africa, fuelwood contributes to more than 85-90% of the total energy supply. Consumption of modern energy is low.

Utilization 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 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.

In African cities, where population growth rate exceeds 3% per annum, municipal waste (always a function of population) will increase proportionally, and provide more feedstock for the 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/implement the right policies to promote the use of municipal waste for energy.

I.2 - Objectives of the study

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 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.

The report will concentrate on MSW as opposed to 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 It is based on published and unpublished material on the potential and possible energy recovery options from MSW.

I.3 - Analytical Approach and limitation

Relevant data to the objectives of the study was compiled through desk review. Most of the information was obtained from various publications, technical data from design reports, journals, technical papers, books, 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.

Because of time and resource constraints, no site visit or survey has been conducted, which would have been critical in order to obtain reliable and accurate data. The estimates, findings, and conclusions in this report should not then be taken as an appraisal study for landfill gas projection and utilization. This note 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 dump in SSA.

II – Waste Management Practices

The municipal solid waste (MSW) is a heterogeneous mixture of materials that has 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 healthcare waste are by definition not MSW. Demolition and construction waste are also not considered MSW.

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.

II.1 - Open dump method of solid waste disposal

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.

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

II.2 - Landfill method of solid waste disposal

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

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, compaction of the waste, covering of the waste and installation of landfill environmental monitoring and control facilities, Landfill control facilities include liners, landfill leachate collection and extraction systems, landfill gas collection and extraction systems and daily final cover layers.

II.3 – Landfill Gas

Landfill gas 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

III - Initial screening for identifying opportunity cities

III.1 - Screening hypotheses

The objective of this section is to present the practical steps taken to select some cities in SSA for LFG recovery purpose. The methodology used (ref. Fig 1) is progressive and integrates recommendations from various sources, including the World Bank Landfill Gas Recovery Project – Summary Matrix, the United States EPA Guide for Methane Mitigation Project and the Environment Canada (EC) Guidance Document for Landfill Gas Management.

The following guiding principles were adopted:

- We focused on the capital cities of SSA countries (Table A.1 – Annex) for several reasons: (i) These cities usually have the largest population of a country and because they have substantially developed in a short period of time, they face substantial waste management problems, (ii) Leaders give them great interest in terms of projects development.
- Countries where landfill gas capture and utilization projects are already operational were not included: e.g. South Africa and Tanzania.
- Countries with political instability or in a post-conflict situation, were not also considered.
- We applied the above-mentioned EPA and EC guidelines and the World Bank matrix data recommendations and took into account population, average precipitation requirement, electricity price. This led us to the following selections:

  a) Cities with more than one million habitant (Table A.2 – Annex)

  b) Cities with precipitation higher than 635mm/year (Table A.3 – Annex)

  c) Cities with electricity price higher than 7 USc /kWh (Table A.4 - Annex)

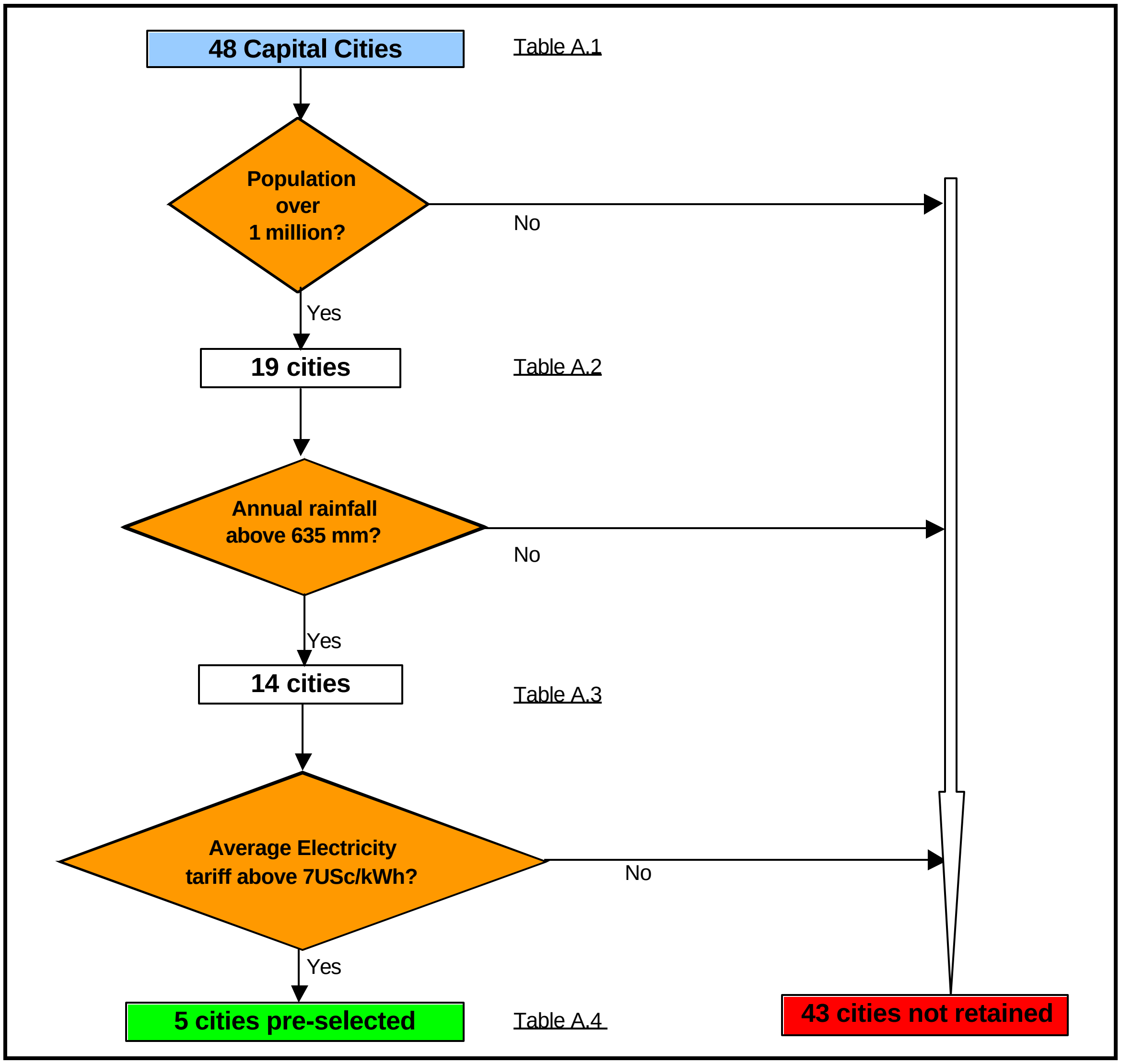

Figure 1: Initial Screening Methodology

III.2 - Step by step analysis and results

III.2.1 - Quantity of waste: LFG as a function of city size (population > 1million)

The quantity of waste in a landfill or that a landfill receive 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 the 1999 Lars Mikkel Johannessen *"Guidance Note on recuperation of Landfill gas from Municipal Solid Waste Landfills"*, for commercial recovery of generated LFG, a landfill should receive at least 200 tons/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 our screening will be the selection of cities with more than 1 million population. This choice of cities does not mean that landfill gas capture for commercial use is not possible with less population: cities with small population but with more organic content in MSW could generate as much landfill gas as a large city.

III.2.2 - Moisture content and ambient temperature :LFG as a function of annual average rain fall > 635mm/year

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 small quantity of methane. The amount of precipitation influences the moisture content of landfilled waste and this has a direct relationship with the amount of methane produced witch subsequently will influence the potential amount of electricity. A higher ambient air temperature will enhance the biodegradation processes. The second level of selection led us to cities with an annual average rainfall greater than 635mm. However, a city with a large population can also generate a substantial amount of landfill gas with less rain.

III.2.3 - Electricity price > 7c/kWh

The gas recovered from landfill can be used on site or sold to nearby facility through gas distribution grid. This approach however will be difficult to implement in most SSA countries because of the lack of gas distribution system. Another way of using this gas is generation of electricity and distribution through the power grid. This has a direct implication as peri-urban population do 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 have a cost of kWh generated less than 7USc/kWh.

III.2.4 - Results

Based on the above initial screening tests, we are left with 5 potential cities (Table 1), Conakry, Bamako, Abidjan, Kinshasa, Yaounde, which could be considered for further analysis to gauge their suitability for landfill gas recovery. The political situation in Abidjan (Cote d'Ivoire), the absence of waste in the new landfill of Bamako, the lack of data on Kinshasa resulted in the elimination of these three cities. Out of the remaining two from our screening test, only Conakry has all the required information to finalize the analysis.

Countries	Capital	Population	Average Precipitation (mm)	Growth rate %	Electricity price (USc/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**
Cameroun	**Yaounde**	**1,239,100**	**1,555.0**		**9.20**
Congo, Dem. Rep.	**Kinshasa**	**6,301,100**	**1,358.0**	**3.15**	**8.20**

Table 1 - Potential candidates for waste-to-energy projects.

Based on different interviews and the data availability, the city of Dakar could be retained as a potential candidate despite the fact that Dakar failed the average rainfall test. For the second part of the analysis (Figures 2 and 3), we will then include Dakar as a substitute to Yaounde.

Countries	Capital	Population	Average Precipitation (mm)	Growth rate %	Electricity price (USc/kWh)
Senegal	**Dakar**	**2,476,400**	**542.0**	**2.60**	**11.00**

Table 2 - Selected data on Dakar.

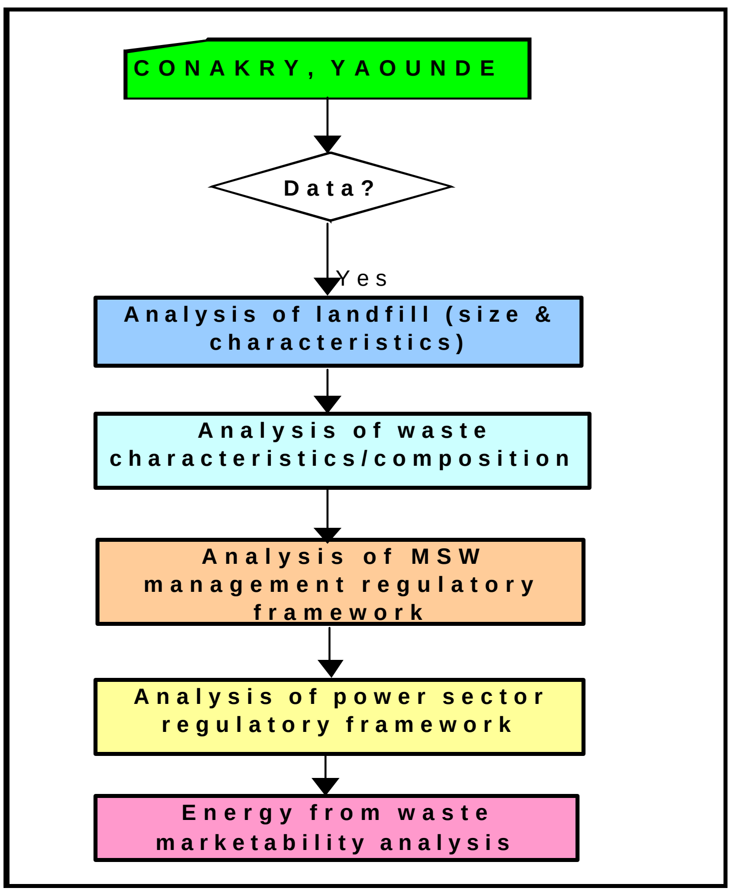

Figure 2 - Group 1 Analysis

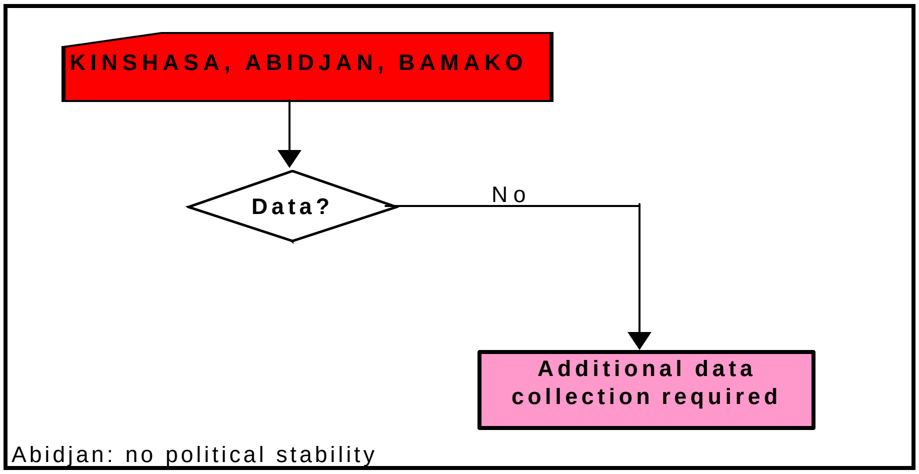

Figure 3 - Group 2 Analysis

IV - Potential of Energy from MSW in Conakry

IV.1- Country Background (see Country at Glance in Annex)

IV.1.1 - General presentation

Guinea, located in West Africa, is surrounded in the North by Guinea-Bissau, Senegal and Mali, in the East by Côte d'Ivoire, in the South by Liberia and Sierra Leone and in the West by the Atlantic Ocean. The country is rich in natural resources, both in terms of 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; mono-seasonal-type rainy season (June to November) with southwesterly winds; dry season (December to May) with northeasterly harmattan winds

Since 1996 Guinea has experienced a Gross Domestic Growth (GDP) real growth of 4.4% in 1995, with major growth originating from the primary sector, namely agriculture and mining. This has been a result of the implementation of various structural adjustment reforms with the help of the World Bank and the International Monetary Fund (IMF) which have included the following: (i) elimination of price controls; (ii) liberalization of foreign exchange; (iii) improvements in tax revenues with the introduction of Value Added Tax (VAT); (iv) emphasis on private sector initiative; (v) financial sector and monetary policy reforms.

The country possesses over 30% of the world's bauxite reserves and is the second largest bauxite producer. The mining sector accounted for about 75% 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.

IV.1.2 - Urban energy demand and supply

Some 70 percent of Guinea’s 7.58 million-population live in rural areas. Overall, less than 5% of the population has access to electricity: about 35% of urban households including the capital Conakry and large prefectures and less than 1% of rural households (districts or sous-prefectures). Many rural households have no prospects of receiving electricity services in the foreseeable future.

Private pico-generators are being used by few wealthy and small businesses. At least 10 different types of generators below 5kVA can be found in Conakry’s hardware stores. The power company EDG, supplies electricity to the capital, 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 peri-urban areas, there are still thousands of potential consumers who are not connected to the grid for technical and/or financial reasons, who use batteries to run their TVs and light.

Guinea has an installed capacity of 127 MW and the electricity generation breaks into 63.8% fossil fuel and 36.2% hydro.

IV.1.3 - Municipal waste as a renewable energy

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. 90% of the waste is delivered at the local disposal site.

IV.2 - Regulatory framework and marketability analysis

IV.2.1 - Regulatory framework of waste management

The waste management framework in Conakry is currently evolving. Through the 3rd Urban Development Project, the World Bank provides assistance to solid waste management in Conakry with the following key objectives: (i) increase the solid waste collection rate, (ii) improve the solid waste disposal system and protect the environment, and (iii) enhance the managerial and operational capacity of the participating private sector and the public service (SPTD) in charge of the solid waste transfer to the sanitary landfill.

The solid waste sub-component of the World Bank Project includes several activities related to the pre-collection and the transfer of garbage to the sanitary landfill, the supervision and monitoring of the SMEs interventions, cleaning of the streets and public places, enhancing the capacity of SPDT and the SMEs. Decision-makers in Conakry consider the overall design and operation of a disposal site a high priority.

A - 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 31st December 2001, 31 contracted small and medium enterprises (SMEs) provide solid waste collection service to the whole metropolitan area and collect approximately 90% of the solid waste generated in Conakry. The waste is being disposed in 39 small transfer stations by the SMEs from where it is transported in bulk by SPTD to the sanitary landfill.

B - 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, etc.).

C - Policies and structure

In Conakry, the key actors in waste management are mainly the Government (also key decision maker), the municipalities, and the private sector/SMEs involved in the street cleaning in the 5 municipalities of Conakry and the waste collection from households. The World Bank is involved, through the urban waste project development, in the establishment of legal and institutional mechanisms to facilitate SMEs' access to local banks' credits.

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IV.2.2 - Regulatory framework of electricity sector

A - Laws and regulation for foreign participation in Energy project development

In June 1998, the government of Guinea promulgated the law 97/012/AN, which allows the financing, construction, management of infrastructure assets by the private sector.

B - Power sector reform status and future plan

In 1997, the Government had contracted out for 10 years system operations to a foreign private operator, SOGEL, under an "Affermage" agreement. SOGEL mandate is to operate in urban areas already connected to the main grid or receiving electricity supply, thus leaving rural and peri-urban areas without service. In 2001, the "Affermage" (lease) agreement has fallen through due to 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.

The Government has reiterated its commitment to reform and to launch a new reform process in the power sector. The government strategy for the power sector reform that was endorsed by the World bank is aimed at (i) ensuring a reliable electricity supply to support economic activity; (ii) adopting and enforcing effective economic tariff; (iii) mobilizing private sector financing for the generation, transmission and distribution of electricity; (iv) promoting decentralized electricity supply; and (v) limiting the government's activities to policy making and regulation of energy sector.

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

IV.2.3 - Marketability of LFG

The purpose of this section is to assess whether there is a suitable use for the gas recovered and if a landfill gas recovery project can be attractive in the context of Conakry.

A - Energy supply and demand balance

Due to 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 landfill gas, there is a large potential for further investments through expansion of electricity generation source.

B - Use of energy recovered and access to market

The landfill of Conakry is located within the city and within 1km from the local power grid. The following checklist below is a quick proof that the energy use criterion is satisfied for initial screening purpose according to the landfill guidelines:

- There are residential areas nearby that could use a supplemental source of electricity;
- There are industrial facilities nearby (approximately within 10km radius) that can use medium quality gas and/or electricity;
- There is a power distribution system that can be supplied from a landfill.

We can reasonably conclude from the above that there is an attractive market for electricity use option in Conakry. A better assessment would need 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.

IV.3 – Better characterization of urban waste to energy option in Conakry

IV.3.1 - Study approach

In this section, we will analyze and calculate parameters, which have great implications in the potential landfill gas 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, either through flaring or through recovery and utilization. It is advisable to consider LFG recovery projects during the appropriate life cycle of the landfill and waste biodegradation to expect large quantity of gas production.

IV.3.2 - Landfill size analysis

This section aims at analyzing the landfill characteristics, including the approximation of the total waste in place and received by the Conakry landfill CET (*Centre d'enfouissement technique*).

Landfill characteristics	**Conakry**
Landfill Type	Sanitary landfill
Capacity (m3)	1,330,000
Actual Depth of Waste (meters) - Filling Status	5 to 20
Final Depth of Waste (meters)	62 to 110
Remaining time to closure (years)	3 to 6
Waste in Place: Time Since Landfilled (years)	20
Daily Cover Type	Sand
Average Annual Temperature (C degrees))	27
Precipitation (mm annually)	3,828
Leacheate Management	Yes
Gas Management	Yes
Surround ing Fence	Yes

Table 3 - Landfill characteristics in Conakry

A - Age of the landfill

Conakry has a sanitary landfill, converted from an open dump site which is **20 years** old, and is still receiving 90% of the waste generated in the 5 municipality of the city.

B - Leachate management

The sanitary landfill of Conakry is equipped with 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. Re-circulating the leachate in a landfill adds moisture to the disposed waste and thereby enhances the biodegradation process in the waste.

C - Estimated quantity of waste landfilled:

Assumptions

For the calculation of the total waste landfilled over the most recent 20-year period, we made the following adjustment: to calculate the quantity of waste landfilled every year, (i) we considered the population growth rate (PGR) and the waste generation rate (WGR) to be constant over the period of landfilling; (ii) we assumed that the fraction of waste landfilled is constant and equal to 0.65 (source: WB report) from 1983 to 2000 and 0.90 (source: WB report) for the period 2000-2003; (iii) for every year, we applied the constant growth rate to calculate the urban population. The various parameters are computed as follows:

$$\text{Total Waste Landfilled} = W = ?\, WL_I = ?\, \left(UP_I * WGR * FWL_I\right)$$

- ✍✍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%;
- ✍✍WGR = Waste Generation Rate (kg/person/year);
- ✍✍FWL_I = Fraction of Waste Landfilled during the year I;

For Conakry, W = 1,978,729 Tons

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

Table 4 – Total Waste Landfilled in Conakry

IV.3.3 - Waste characteristics analysis

A - Waste composition:

Table 5 presents the composition of the waste in Conakry. The waste landfilled has an approximate 58% of organic content, which produces the methane in an anaerobic environment.

Nature	Content (%)
Organic waste	**58.0**
Textiles and cloth	4.0
Paper and card board	9.0
Metallic ferrous	1.0
Plastic	4.0
Glass	1.0
Leather	1.0
Other – stones	4.0
Fine(d<2.5)	18.0
Total	100.0

Table 5 – Waste Composition in Conakry

IV.3.4 - Preliminary site assessment

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

A - Potential landfill gas 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/composition, and collection system designs.

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

Method of "Waste In Place Model (WIPM)": The WIPM model 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 other 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 (m^3);
- W = Total Waste In Place which is less than 30 years old (tons);
- D = Indicator for arid conditions (1 when rainfall < 635mm/year and 0 otherwise)

For Conakry, D = 0 and LFG = 11,516,214 m^3

Potential collectable gas

It should be noted that not all landfill gas generated could 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 efficiency recovery, is within the range of 70-80 % collection efficiency ratio (CER). The estimate from the WIPM should then be multiplied by the CER to determine the potential collectable gas from landfill. For this study, we will consider the worst-case scenario of 70% of CER. This rate of production can be sustained for 5 to 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 gas from landfill.

For Conakry, PCLFG = 8,061,350 m^3

B - Potential electricity production

Figure 4 presents the process of electricity production from landfill gas. The process consists clearly of two sections: (a) the collection and treatment of gas to make it suitable for combustion (see section on potential collective gas – above) and (b) the classic combustion in an internal combustion engine and production of electricity through a generator.

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 following section is to determine the amount of electricity that can be produced by the generator.

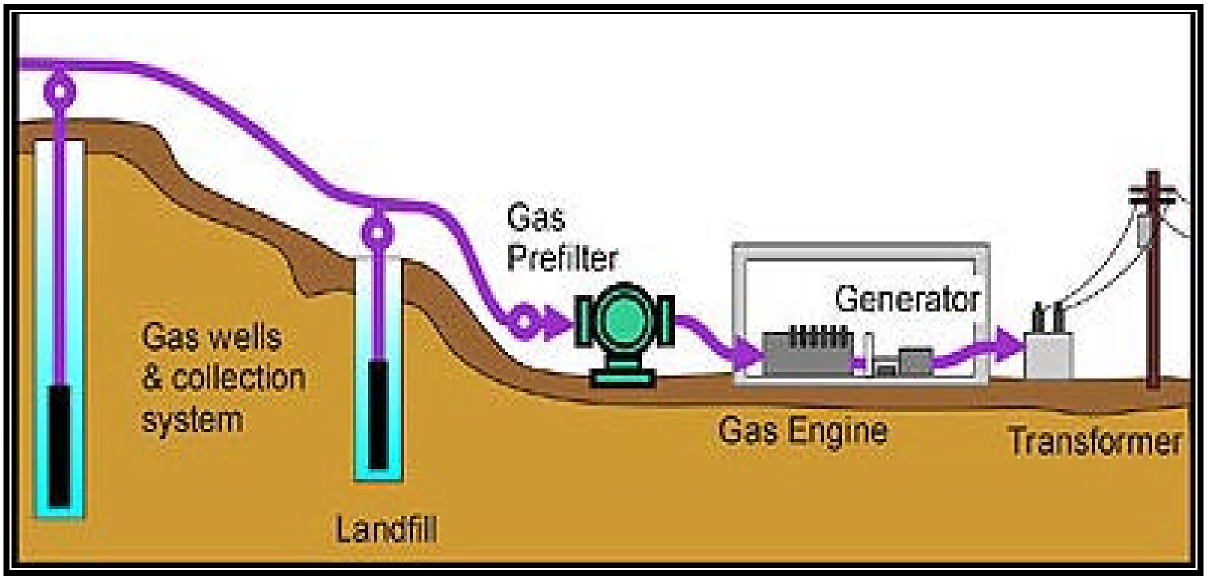


Figure 4 - Electricity production from landfill gas

Assumptions

For the calculation of the potential electricity production (PEP), we made the following assumptions: we considered (i) the raw LFG has 50% of methane by volume and has a low heating value (LHV) of 16.8MJ/m^3; (ii) the gas is burned in an internal combustion engine, which has an overall 33.0% of electricity conversion efficiency (ECE) and an overall availability factor (AF) of 95%.

We then have the following:

PEP = PCLFG * LHV * ECE

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

- With LFG-IC = landfill gas installed capacity

For Conakry, we have a potential PEP = 44,682 MWH and LFG-IC = 5.37 MW.

Table 6 summarizes the calculations for Conakry.

W (tons)	**1,978,729**
LFG (m^3)	**11,516,214**
CER (%)	70%
PCLFG (m^3)	**8,061,350**
LHV (MJ/m^3)	16.8
GHV (MJ)	**135,430,673**
ECE(%)	33.0%
PEP (MWh)	**44,692**
AF	0.95
LFG-IC (MW)	**5.37**

Table 6 – Potential of LFG generated electricity in Conakry

Forecasting the quantity, 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.

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

Landfill gas recovery and landfill gas 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.

IV.4 - Initial appraisal result and conclusion

The initial appraisal screening criteria aim at determining if the landfill of Conakry has the characteristics that generally support economically viable gas recovery projects. To conduct this evaluation, we will follow the guideline recommendations.

IV.4.1 - Energy shortage

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

IV.4.2 - High energy cost

Currently, electricity prices are very high in Conakry (Average 15.15 USc/kWh) and this environment would favor, and even potentially support profitable gas recovery projects.

IV.4.3 - Initial Appraisal Results from the guideline checklist

The guideline points to a series of four questions recorded below, with the answers in case of Conakry:

- Are there landfill or large open dumps (currently receiving waste or closed recently) that could be potential candidates? **Yes**
- At the potential candidate sites, are there potential uses for the energy recovered? **Yes**
- Do the candidate site have more than 1 million tons of waste in place? **Yes**
- Do the candidate site contains primarily Municipal solid waste? **Yes**

The answer "**Yes**" to all the above questions means that there are promising options for gas recovery in Conakry. After this step, technical and economic feasibility of gas recovery of the candidate site should be thoroughly evaluated. This will be conducted in the following phase of this study.

V - Potential of Energy from MSW in Dakar

V.1 – Country background (see Country at Glance in Annex)

V.1.1 - General presentation

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) together with natural gas and light petroleum in the 1960s at Diamnado Kabor, near Dakar. However such discoveries show no signs of becoming part of a broad range of inter-fuel substitution schemes.

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

V.2.2 - Urban energy demand and supply

The energy sector in Senegal could be described as diversified in spite of its modest energy resource base.

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

Traditional fuels are much more difficult to estimate either in terms of potential or production. In 1980, Senegal's forestland in 1980 was estimated at 12 million hectares, 60% of the country's area. According to studies, it is also estimated that Senegal should be able to cover its needs in woodfuels if sustainable management schemes are conducted 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 represented 53%, petroleum fuels 34%, electricity 12% and agricultural residue 1%. In Dakar alone charcoal consumption is estimated at 150,000 tons, and total consumption of wood at 1.5 million tons in 1992, of which 86% is consumed in rural Senegal.

The power company SENELEC, supplies electricity to the capital, Dakar, and a number of small towns. Some other companies and large consumers generate electricity for their own use.

V.1.3 - Municipal waste as a renewable energy

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.

V.2 - Regulatory framework and marketability analysis

V.2.1 - Regulatory frame work of waste management

A - Collection and transfer

Collection is provided by the municipality and private operators on a fee basis to households and commercial establishments. The city of Dakar has an established municipal waste collection system. Collection rate is approximately 77% 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 while collections from residential areas and of street sweepings are made at dawn.

B - Disposal

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

Mbeubeuss is actually located in an area where market gardening is regarded as one of the main activities. Indeed, market gardening activities are unable to flourish due to hazards caused by waste. The closure of the site has been discussed but the main problem is related to finding a suitable replacement. In other words, there are not enough infrastructures to facilitate the closure of the site and put in place a new dumping site.

Recently an agreement has been signed between a Swiss company (Alcyon) and the Senegalese government with regard to the processing of household and industrial waste.

C - Policies and Structure

The responsibility for waste management lies with local authorities through the Dakar Urban Community (**the CUD**), a department that is common to the three main towns, Dakar, Pikine and Rufisque. It is this department that is responsible for the co-ordination of all the activities linked to waste management in the Dakar region. It has at its disposal the relevant personnel and the logistics to carry out the operation.

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

In Dakar, the collection of waste is done depending of the practicability of the road. When and where roads are in reasonable condition, heavy-duty refuse collection vehicles with built-in compressors conducted a door-to-door waste removal.

V.2.2 - Regulatory framework of electricity sector

A - Laws and regulation for foreign participation in energy project development

One of the major objectives of the future reform plan is to foster private sector participation and introduction of innovative financial mechanism.

B - Power sector reform situation and future plan

The private sector was active in electricity development with a 25-year concession agreement for system operations to a foreign consortium in 1998. In 2000, the concession agreement has fallen through due to a failure to achieve one of the main goals of power sector reform i.e. the improvement of supply/demand balance. The Government and the consortium decided to put an end to their partnership in SENELEC with the government yet reassuring its options for privatization and liberalization of the power sector. This paved a way to a second attempt but not completed yet with SENELEC being a vertically integrated state owned utility. There is no open access to the utility transmission lines in Senegal.

Regulatory barriers are key obstacles facing potential landfill gas recovery projects. Landfill gas-to energy projects must comply with local, state and national regulatory and permitting requirement. In the city of Dakar, alternative energy prices are relatively high and landfill gas cost may be attractive.

V.2.3 - Marketability of LFG

The purpose of this step is to assess whether there is a suitable use of 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.

A - Energy supply and demand balance

The excessive energy prices and the willingness of the government to favor renewable energy sources offer opportunities for landfill gas 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.

Given the large quantity of waste in place and the composition of the waste in Dakar, potential opportunity that land fill gas recuperation may have, there is a large potential for further investments through expansion of electricity generation source

B - Use of energy recovered and access to market:

The landfill of Dakar is located within 30 km from the city downtown and the local power grid is less than 1 km far from the open dump. The following checklist below is a quick proof that the energy use criterion is satisfied for initial screening purpose according to the landfill guidelines:

(i) There are residential areas nearby that could use a supplemental source of electricity.

(ii) There are industrial facilities nearby (approximately 20km radius) that can use medium quality gas and/or electricity.

(iii) There is a power distribution system that can that can be supplied from the landfill

We can conclude that there is an attractive market for electricity use option in Dakar. A better assessment would need discussion with energy planners in the ministry of energy and local power supplier, SENELEC.

V.3 - Better characterization of urban waste to energy option in Dakar

V.3.1 – Study approach (see section IV.3.1)

In this section, we will analyze and calculate parameters, which have great implications in the potential landfill gas 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, either through flaring or through recovery and utilization. It is advisable to consider LFG recovery projects during the appropriate life cycle of the landfill and waste biodegradation to expect large quantity of gas production.

V.3.2 - Landfill size analysis

Landfill characteristics	Dakar
Landfill Type	Large open dump
Capacity (m3)	-
Actual Depth of Waste (meters) - Filling Status	-
Final Depth of Waste (meters)	-
Remaining time to closure (years)	1 to 3
Waste in Place: Time Since Landfilled (years)	25
Daily Cover Type	No
Average Annual Temperature (C degrees))	35
Precipitation (mm annually)	542.0
Leachate Management	No
Gas Management	No
Surrounding Fence	Yes

Table 7 - Landfill characteristics in Dakar

A - Age of the landfill

Dakar has a large open dump called Mbeubeuss; which is 25 years old and is still receiving 77% of the waste generated in the city. Landfill gas is still being produced.

B - Leachate management

There is no leachate treatment or re-circulation in the Mbeubeuss open dump. Re-circulating the leachate in a landfill adds to moisture to the disposed waste and thereby enhances the biodegradation process in the waste. If the leachate re-circulation is optimal for example, the organic load in leachate will be significantly reduced and greater amount of LFG will be produced. This needs to be considered for implementation in Dakar when considering a LFG project.

C - Estimated total waste landfilled

The methodology followed is similar to the one for Conakry (see section IV.3.2) and will not be repeated here, PGR = 2.6%. Table 8 presents the calculation of total waste landfilled.

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

Table 8 - Total Waste Landfilled in Dakar

V.3.3 - Waste characteristics analysis

A - Waste composition

Table 9 presents the waste composition in Dakar.

Nature	Content (%)
Organic waste	**50.1**
Textiles and cloth	5.2
Paper and card board	9.7
Metallic ferrous	3.4
Plastic	2.7
Rubber	1.5
Glass	1.1
Wood	0.2
Leather	0.3
Nail and ceramic	2.4
Other - stones	4.3
Fine(d<2.5)	19.1
Total	100.0

Table 9 – Waste Composition in Dakar

B - Moisture content

Dakar does not have enough rainfall to wet the waste and therefore enhance the biodegradation to produce more gas. As Dakar is a big city with many on-going waste management initiatives, the arid condition could be overcome.

V.3.4 - Preliminary site assessment

The methodology is similar to the one used in the case of Conakry (see section IV.3.4).

A - Potential gas production

As said before, the amount of gas that can be collected depends on several factors including the amount of waste in place, waste characteristic and collection system designs. There are several approaches for estimating current and potential future gas production. The most reliable one is to drill test wells into the waste.

To evaluate W, the total landfill gas generated in a current year, we use the WIPM with the indicator for arid conditions D to be equal to 1 (when precipitation is less than 635 mm/year). As already explained, the city of 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 landfill gas generated.

B – Potential electricity production

To evaluate PCLFG, the potential collectable gas, we use a CER of 70%, which is the worse case scenario.

To evaluate PEP, the potential electricity production, we use the same CER of 70% as in Conakry, and to evaluate the IC-LFG (MW), the availability factor is set to 0.95.

Table 10 summarizes the parameters calculated for Dakar.

W (tons)	**5,032,877**
LFG (m^3)	**18,219,022**
CER (%)	70.0%
PCLFG (m^3)	**12,753,315**
LHV (MJ/m^3)	16.8
GHV (MJ)	**214,255,694**
ECE (%)	33.0%
PEP (MWh)	**70,704**
Availability factor	0.95
LFG-IC (MW)	**8.50**

Table 10 – Potential of LFG generated electricity in Dakar

V.4 - Initial appraisal result and conclusion

The initial appraisal screening criteria aimed at determining if the landfill of Dakar has the characteristics that generally support economically viable gas recovery projects. We use the same strategy as the one already developed for Conakry.

V.4.1 - Energy shortage:

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

V.4.2 - High energy cost:

Dakar depends mainly on thermal generation for its electricity supply. As such, electricity prices are high in Dakar (Average 11 UScents /kWh) and this environment would favor, and even potentially support profitable gas recovery projects.

V.4.3 - Initial Appraisal Results from the guideline checklist:

The guideline points to a series of four questions recorded below, with the answers in case of Dakar:

- Are there landfill or large open dumps (currently receiving waste or closed recently) that could be potential candidates? **Yes**

- At the potential candidate sites, are there potential uses for the energy recovered? **Yes**
- Do the candidate site have more than 1 million tons of waste in place? **Yes**
- Do the candidate site contains primarily Municipal solid waste? **Yes**

The answer "**Yes**" to all the above questions means that there are promising options for gas recovery in Dakar. After this step, technical and economic/financial feasibility of gas recovery of the candidate site should be thoroughly evaluated.

VI – Simplified financial Analysis for WTE projects in Conakry and Dakar

The purpose of this section is to evaluate the sustainability of the waste-to-energy projects in Conakry and Dakar and 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; we estimated the investment/project costs, operation and maintenance costs to determine the Net Present Value (NPV), Internal Rate Return (IRR), payback period (PB), and the unit energy cost.

While these calculations give a good overview of the sustainable nature of WTE projects in Conakry and Dakar, 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/suppliers of equipment and utility operators.

VI.1 - Hypotheses for financial indicators evaluation

- The amount of collectable landfill gas 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.
- We assumed a tax rate of 30%, a discount rate of 12%, and an inflation rate of 7%.
- 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 12 UScents/kWh for Conakry and 9 UScents/kWh for Dakar assuming that the transmission charges represent 20% of the end-user electricity tariff.

VI.2 – Investments Costs

The investment costs for the design and construction of the LFG capture and use facility were determined through a proxy method using the data for Methane Gas Capture and Use Facility at SIMEPRODESO in Mexico, a GEF Project, and EPA guidelines for preliminary site assessment. The costs are presented in Table 11 below.

	Mexico	Conakry	Dakar
Installed Capacity (MW)	7.0	5.4	8.5
Gas Recovery Cost (US$)			
Gas recovery equipment	1,946,160	1,501,323	2,363,194
Gas cleaning equipment	54,000	41,657	65,571
Gas Utilization Cost (US$)			
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 kV)	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**

Table 11 - Investment Costs for Methane Gas Capture and Use in Conakry & Dakar

VI.3 – Results Analysis

Table 12 presents the NPV, IRR and Unit Energy Costs for Conakry and Dakar.

	Mexico	Conakry	Dakar
Installed Capacity (MW)	7	5.4	8.5
Discount Rate	10.0%	12.0%	12.0%
Inflation Rate		7.0%	7.0%
Tax Rate	35.0%	30.0%	30.0%
Electricity Tariff (UScents/kWh)	8.75	12	9
Investment Costs (US$)	11,463,126	9,781,799	15,339,868
NPV Over 15 Years (US$)	2,231,844	17,752,452	16,246,029
IRR Over 15 Years	13.4%	35.2%	26.2%
Unit Energy Cost (USc/kWh)		4.95	4.54
Ratio NPV to Investment Costs	19.5%	181.5%	105.9%

Table 12 – NPV, IRR and Unit Energy Costs in Conakry & Dakar

The NPV is positive for both projects and represents a substantial proportion of the investment costs: Conakry (181.5%) and Dakar (105.9%). It indicates that the scheme used is financially viable.

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

Table 13 presents a discounted cash flow analysis for the two projects; which shows that the payback period is between 4 and 5 years for the Conakry Project and between 6 and 7 years for the Dakar Project.

	Cumulated Cashfow (US$)	
Year	**Conakry**	**Dakar**
Yr 0	-9,781,799	-15,339,868
Yr 1	-7,374,568	-12,733,684
Yr 2	-5,036,593	-10,183,927
Yr 3	-2,768,875	-7,694,496
Yr 4	-571,934	-5,268,432
Yr 5	1,554,126	-2,908,024
Yr 6	3,609,556	-614,910
Yr 7	5,594,908	1,609,834
Yr 8	7,510,986	3,765,617
Yr 9	9,358,809	5,852,265
Yr 10	11,139,573	7,869,961
Yr 11	13,051,460	10,127,878
Yr 12	14,877,994	12,284,995
Yr 13	16,622,987	14,345,813
Yr 14	18,290,078	16,314,629
Yr 15	19,882,746	18,195,552

Table 13 – Payback periods for Conakry & Dakar Projects

VI.4 - Sensitivity Analysis

A sensitivity analysis was also performed in order 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.

Table 14 presents the sensitivity of NPV and Unit Energy Cost to changes in Discount Rates.

	NPV (US$)		Unit Energy Cost (USc/kWh)	
Discount Rate	**Conakry**	**Dakar**	**Conakry**	**Dakar**
2.0%	21,780,618	37,328,176	3.65	3.21
4.0%	16,229,198	28,077,487	3.87	3.44
6.0%	11,937,899	20,919,209	4.11	3.69
8.0%	8,595,097	15,336,623	4.37	3.95
10.0%	5,972,096	10,950,403	4.65	4.24
12.0%	3,899,702	7,479,830	4.95	4.54
14.0%	2,251,753	4,715,511	5.27	4.86
16.0%	933,453	2,500,058	5.60	5.20
18.0%	-126,956	714,282	5.94	5.54
20.0%	-984,192	-732,734	6.29	5.90
22.0%	-1,680,273	-1,910,836	6.66	6.27
24.0%	-2,247,685	-2,874,053	7.03	6.64
26.0%	-2,711,719	-3,664,463	7.41	7.03

Table 14 – Sensitivity of NPV and Unit Energy Cost to changes in Discount Rates for Conakry & Dakar Projects (Electricity Tariff is 7 Uscents/kWh)

Table 15 presents the sensitivity of NPV and IRR to changes in Electricity Price.

	NPV (US$)		IRR	
(USc/kWh)	**Conakry**	**Dakar**	**Conakry**	**Dakar**
5	-1,641,398	-1,286,368	9.3%	10.7%
6	1,129,152	3,096,731	13.7%	15.0%
7	3,899,702	7,479,830	17.7%	18.9%
8	6,670,252	11,862,930	21.5%	22.7%
9	9,440,802	**16,246,029**	25.1%	**26.2%**
10	12,211,352	20,629,128	28.5%	29.7%
11	14,981,902	25,012,227	31.9%	33.0%
12	**17,752,452**	29,395,327	**35.2%**	36.4%
13	20,523,001	33,778,426	38.5%	39.7%
14	23,293,551	38,161,525	41.7%	42.9%
15	26,064,101	42,544,624	44.9%	46.2%

Table 15 – Sensitivity of NPV and IRR to changes in Electricity Price for Conakry & Dakar Projects

Figures 5 and 6 present respectively the sensitivity of NPV to Discount rate and IRR to Electricity Price.

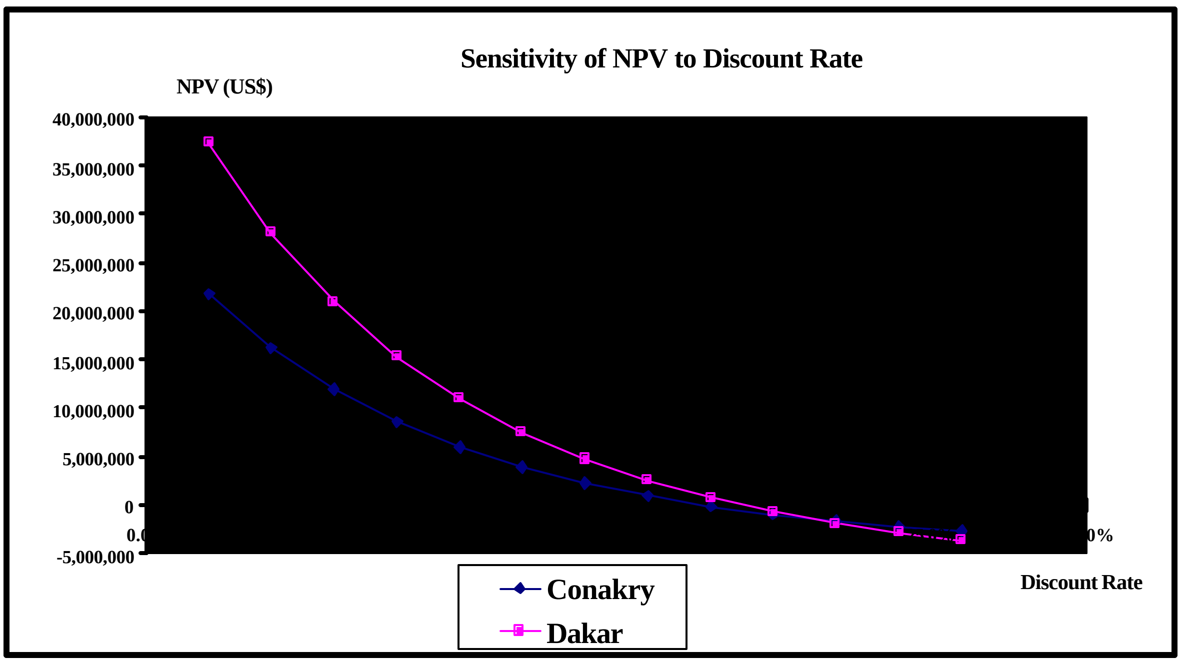


Figure 5 - Sensitivity of NPV to Discount Rate

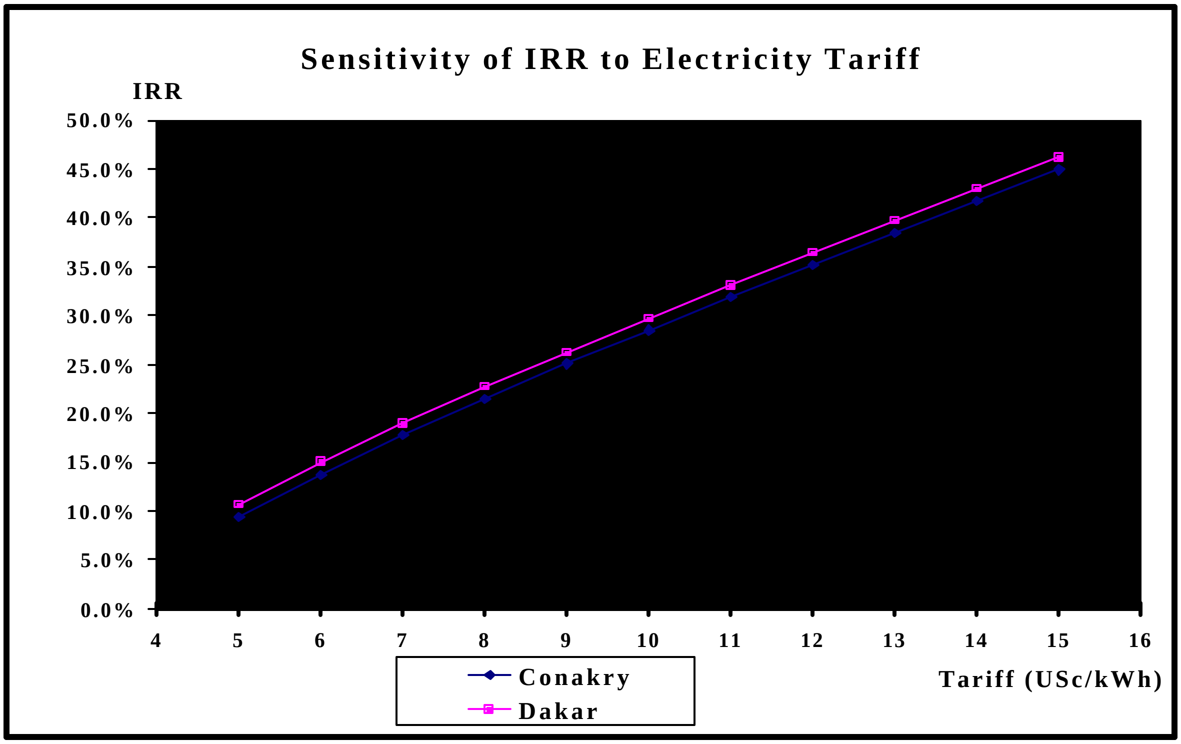


Figure 6 - Sensitivity of IRR to Electricity Tariff

VI.6 – Conclusion for the financial analysis

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

VII - Ongoing LFG project in Africa

The objective of this section is to present some major experiences in landfill gas capture and utilization projects and draw/reinforce preliminary conclusions for the feasibility of waste-to-energy project in Sub-Saharan African cities. We will thus present two different experiences/studies from which lessons/recommendations can be drawn to benefit future landfill gas projects in Africa:

- TAKAGAS: A landfill gas project that did not take off. Why?
- DURBAN: An ongoing carbon finance landfill gas project. A best practice which could be economically attractive in some SSA cities with high electricity prices and in some other SSA cities with low electricity price with the carbon finance (e.g.: Lagos, Accra).

VII.1 - Takagas: A landfill gas project that did not take off. Why?

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. The controlled generation and use of methane for power production was also envisaged to contribute in reducing the consumption of fossil fuels. Because of various reasons, the project had to be terminated before commencement of biogas plant's construction works.

The project physical implementation did not go far beyond the plant design, as the construction stage was not reached but however, about 19% of project funds were already spent. The reasons for terminating the project encompass: inadequacy of the project's pre-investment study, delays in project's plot acquisition, absence of reliable solid waste delivery system to 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 conceived.

Based on events that led to closure of Takagas Project, some concluding remarks and recommendations to be given a thought when planning to implement a project similar to Takagas. The recommendations are related to the need for enabling legislation, exhaustive feasibility studies and the need to be logical in planning and selecting technologies

VII.2 – Durban Landfill Gas-to-Electricity: a CDM project

The project consists in an enhanced collection of landfill gas at three landfill sites of the municipality of 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 auto-generation project. The project is environmentally additional because it will generate emission reductions that would not occur otherwise, since 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.

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

It is estimated that the project will reduce an estimated 3,204,032 tons of CO2 in the first 7 years crediting period .The emission reductions from the Durban Project result from:

- Avoided landfill methane emissions due to collection, utilization or flaring, and conversion to CO2 of the methane in the landfill gas;
- Avoided CO2 emissions due to displacement of grid electricity with landfill gas-generated electricity

From an investment point of view, the auto-generation option, using the landfill gas, 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 Clean Development Mechanism (CDM) of the Kyoto Protocol, the avoided carbon C02 emissions will be sold and therefore make this project attractive. Some SSA African countries with low electricity cost and large population could take advantage of the carbon finance. Lagos with more than 13 millions people will be a good candidate. The purchase price ranges between $2.5 and $4.0/tCO2.

VIII - Conclusion

The Durban landfill gas project is not economically attractive without carbon finance 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 countries with high energy price such as Conakry, Yaounde, Kinshasa, Dakar to name a few (see Table A.4 in Annex). The waste-to-energy project, combined or not with carbon finance initiative, could be an "innovative solution" to some of the most pressing electricity shortage in some SSA countries and to pollution and waste disposal problems in the SSA region. The lessons from the Takagas experience failure demonstrate the need of reliable data in planning LFG projects.

For the choice of cities that offer good opportunities for landfill gas 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 1 (page 6) and Figure 2 (page 8).

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

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

In addition, the simplified financial analysis (pages 32 to 37) leads to interesting results: (i) Conakry has an IRR of 35,2% and a ratio of NPV to Investment costs of 181.5%; (ii) Dakar has an IRR of 26.2% and a ratio of NPV to Investment costs of 105.9%; (iii) the payback period for both projects is less than 7 years.

This study is an initial step to a larger program; which could contribute to poverty reduction in SSA, especially in terms of diversification and increase of peri-urban and/or rural electrification options. Several approaches could be adopted:

- The first one would be to analyze the required steps for the implementation of a LFG capture project for peri-urban electrification in the selected cities, i.e., in Conakry and Dakar. This will include a review of the policies, which can affect the 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 will include contribution from WB experts from the Africa Region and other interested units.

- The third option would be to develop a guidance note for landfill gas recovery for peri-urban electricity initiatives in SSA. This last approach is to extend the study to the overall SSA cities, 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.

IX – Annex

Countries			Capital Cities		
Name	Population	Pop. Growth (%)	Name	Population	% Ctry. Pop.
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%
Cameroun	**15,200,000**	**2.5**	**Yaounde**	**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%
Comores	570,000	2.6	Moroni	24,000	4.2%
Congo, Dem. Rep. Of	**52,350,000**	**3.3**	**Kinsasha**	**6,301,100**	**12.0%**
Congo, Rep. Of	3,100,000	3.1	Brazzaville	950,000	30.6%
Cote 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%
SaoTome & Principe	150,000	2.6	Sao 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 Salam**	**2,421,900**	**7.0%**
Togo	4,670,000	2.7	Lome	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.1 – Sub-Saharan African Countries and Capital Cities

Countries			Capital Cities		
Name	Population	Pop. Growth (%)	Name	Population	% Ctry. Pop.
Nigeria	129,870,000	2.8	Lagos	13,500,000	10.4%
Congo, Dem. Rep. Of	52,350,000	3.3	Kinsasha	6,301,100	12.0%
Cote 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 Salam	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%
Cameroun	15,200,000	2.5	Yaounde	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.2 – Cities with population > 1 million

Countries	Capital City	Population	Capital Population Growth rate (%)	Average Precipitation (mm)
Guinea	**Conakry**	**1,800,000**	**4.9**	**3,869.6**
Nigeria	**Lagos**	**13,500,000**		**1,828.8**
Cameroun	**Yaounde**	**1,239,100**		**1,555.0**
Cote D'Ivoire	**Abidjan**	**3,395,976**		**1,421.0**
Madagascar	**Antananarivo**	**1,245,181**	**3.3**	**1,367.5**
Congo, Rep	**Kinsasha**	**6,301,100**	**3.2**	**1,358.0**
Etiopía	**Addis Ababa**	**2,300,000**	**6.0**	**1,236.0**
Mali	**Bamako**	**1,069,242**	**3.2**	**1,018.2**
Zambia	**Lusaka**	**2,218,200**		**838.2**
Zimbabwe	**Harare**	**1,864,400**		**838.2**
Mozambique	**Maputo**	**1,100,000**	**2.7**	**768.3**
Kenya	**Nairobi**	**2,312,300**	**2.9**	**760.3**
Ghana	**Accra**	**2,269,437**	**2.9**	**736.6**
South Africa	**Pretoria**	**1,600,000**		**704.1**
Tanzania	Dar es Salam	2,421,900		550.6
Senegal	Dakar	2,476,400	2.6	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.3 – Cities with population > 1 million and annual rainfall > 635 mm

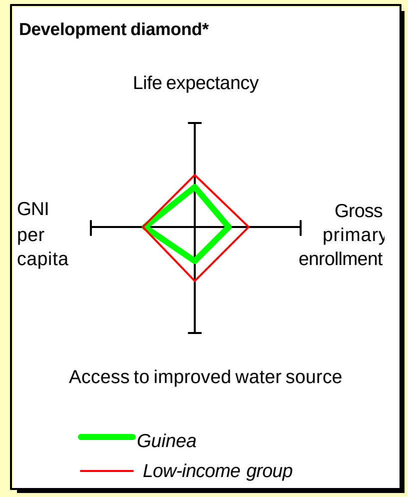
Countries	Capital City	Population	Average Precipitation (mm)	Growth rate %	Electricity price (USc/KWh)
Mali	**Bamako**	**1,069,242**	**1,018.2**	**3.17**	**16.88**
Guinea	**Conakry**	**1,800,000**	**3,869.6**	**4.89**	**15.15**
Cote d'Ivoire	**Abidjan**	**3,395,976**	**1,421.0**		**9.40**
Cameroun	**Yaounde**	**1,239,100**	**1,555.0**		**9.20**
Congo, Dem. Rep. Of	**Kinshasa**	**6,301,100**	**1,358.0**	**3.15**	**8.20**
Madagascar	Antananarivo	1,245,181	1,367.5	3.25	6.76
Ghana	Accra	2,269,437	736.6	2.87	6.75
Kenya	Nairobi	2,312,300	760.3	2.91	6.27
Ethiopia	Addis Ababa	2,300,000	1,236.0	6.00	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	2.65	3.15
Zambia	Lusaka	2,218,200	838.2		2.45

Table A.4 – Cities with population > 1 million, annual rainfall > 635 mm and electricity price > 7 USc/kWh

Guinea at a glance

9/23/02

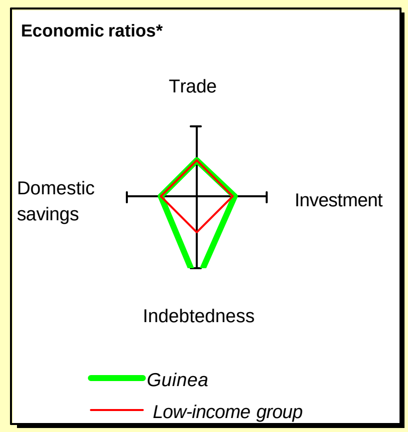
POVERTY and SOCIAL	Guinea	Sub-Saharan Africa	Low-income
2001			
Population, mid-year *(millions)*	7.6	674	2,511
GNI per capita *(Atlas method, US$)*	410	470	430
GNI *(Atlas method, US$ billions)*	3.1	317	1,069
Average annual growth, 1995-01			
Population *(%)*	2.3	2.5	1.9
Labor force *(%)*	2.1	2.6	2.3
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

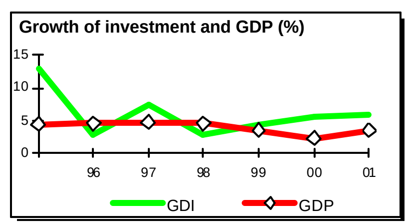
	1981	1991	2000	2001
GDP *(US$ billions)*	..	3.0	3.1	3.0
Gross domestic investment/GDP	..	18.1	22.1	22.1
Exports of goods and services/GDP	..	23.0	24.0	27.8
Gross domestic savings/GDP	..	18.0	16.9	20.4
Gross national savings/GDP	..	15.4	14.7	18.4
Current account balance/GDP	..	-1.8	-7.4	-3.7
Interest 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

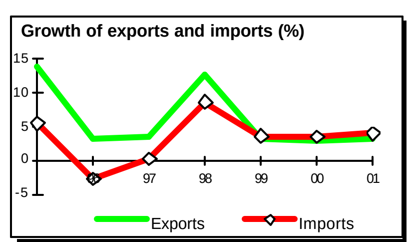


STRUCTURE of the ECONOMY

	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



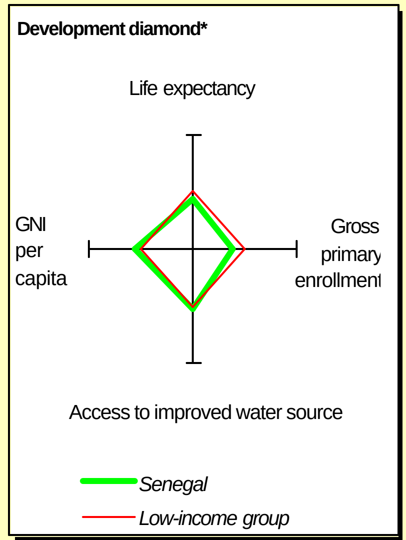
Note: 2001 data are preliminary estimates.

* 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

Sene 9/20/02

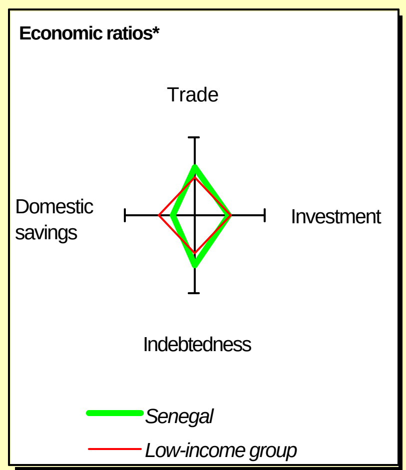
POVERTY and SOCIAL	Senegal	Sub-Saharan Africa	Low-income
2001			
Population, mid-year *(millions)*	9.8	674	2,511
GNI per capita *(Atlas method, US$)*	480	470	430
GNI *(Atlas method, US$ billions)*	4.7	317	1,069
Average annual growth, 1995-01			
Population *(%)*	2.7	2.5	1.9
Labor force *(%)*	2.8	2.6	2.3
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

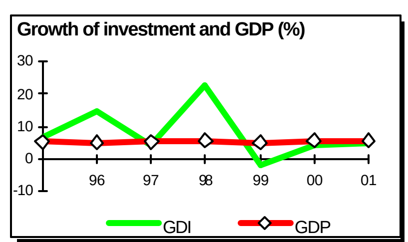
	1981	1991	2000	2001
GDP *(US$ billions)*	2.5	5.5	4.4	4.6
Gross domestic investment/GDP	12.8	12.9	19.8	20.0
Exports of goods and services/GDP	31.0	24.7	30.5	29.6
Gross domestic savings/GDP	-9.1	5.9	10.8	12.0
Gross national savings/GDP	-13.3	2.9	13.4	14.2
Current account balance/GDP	-25.1	-8.3	-6.5	-5.8
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	..

(average annual growth)	1981-91	1991-01	2000	2001	2001-05
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

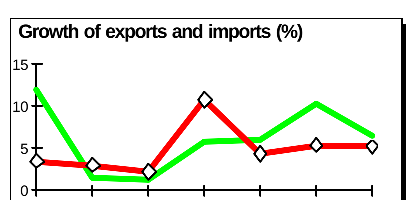


STRUCTURE of the ECONOMY

(% of GDP)	1981	1991	2000	2001
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



(average annual growth)	1981-91	1991-01	2000	2001
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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