Re-assessing the potential of waste in Senegal: Landfills an opportunity to fill in the gap in energy production for developing countries

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ABSTRACT

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Zeinab Sadiya Sow

This thesis examines the environmental, human, social and economic issues related to the issues of waste management in Senegal (and almost every country from the Global South).
It is a challenge that the local governments are still grappling with. Studies have shown that by implementing a sustainable and operational framework grounded in strong and effective policies that take into account both the people and the environment, two other challenges that a lot of developing countries face can be addressed by ricochet. The first is energy issues – as the methane generated from the landfills can be converted to produce energy – electricity, also mitigating methane emissions and thus addressing climate change. The second is the creation of jobs through a circular economy, which is ground-breaking in a country where the unemployment rate is at a staggering 16.51%.

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Chapter 1: Introduction

"Nothing is lost, nothing is created, everything is transformed."
Antoine Lavoisier, French Chemist, 1743-1794

According to the United Nations Department of Economics and Social Affairs, the world population is expected to reach 8.5 billion people by the year 2030. More than half of that population will be living in developing/emerging countries; located mainly on the African and Asian continents. An increase in the human population to that level will subsquently translate into overpopulation and competition for the access to the shared and already scarce resources. A signicant increase in the human population will also acceralerate the consumption of those resources placing an extremely heavy burden on the environment, thus resulting in its degradation (Cassils,2004).

John Wilmoth, the United Nations' Director of Economics and Social Affairs stated:

> The concentration of population growth in the poorest countries presents its own set of challenges, making it more difficult to eradicate poverty and inequality, to combat hunger and malnutrition, and to expand educational enrolment and health systems, all of which are crucial to the success of the new sustainable development agenda (United Nations, 2015).

With the consumption of resources, it is tacitly implied that waste will be generated as a byproduct. The waste produced can be solid or liquid, and sometimes hazardous, which poses a threat not only for human health, but also for the environment if not disposed of following the rules and regulations implemented by environmental and health stakeholders.

Unfortunately, for developing countries, the disposal and management of waste is, to this day, a conundrum for which they have yet to find effective solutions to. The contrast between how developed nations are able to handle their waste issues in comparison with developed nations is

absolutely striking. Developed nations have been "quite" successful in addressing their waste issues, because they've put the concepts "cradle-to- cradle" and "cradle-to-grave" at the core of the handling and disposal of their solid waste. The imagery and thought process used to describe both concepts are simple: every product from its conception (cradle) to the moment it's no longer usable and useful therein "dies" (grave) needs to be able to be reused, repurposed and offered a chance at a "second" life through the recycling of either its biological nutrients and/or technical components (Sustainable Dictionary, 2017).

I cannot fail to mention that the majority of the world's most contaminated and "worse" dumping sites are located in developing countries, specifically on the African and Asian continents--Kibera (Kenya), Bisasar (South Africa), Mbeubeuss (Senegal), Okhla and Ghazipur (India), just to name a few. Yet these only represent a tip of the iceberg--the list goes on. The above observation brings forth a series of questions that ought to be answered:

1. What could be the reason(s) and/or factor(s) that could explain why there are such major differences in how developed and developing nations address their waste issues?
2. What is the Global North doing right?
3. What is the Global South doing wrong?
4. What lessons – if any could the Global North teach the Global South to help them address waste issues effectively and effeciently?

It is also worth mentioning that the common denominator for all those dumping sites is their location: they are, for the most part, often placed next to disadvantaged/unprivileged neighborhoods, home to the poor and those who were driven away by the excessive housing prices in the city. I cannot help but ask myself if it is simply fate or a convenient coincidence? If analyzed under Clapp's concept named "distancing of waste", it is not a mere coincidence.

Indeed, the concept explains that societies have grown to delocalize the waste produced outside of the “richer spaces” and next to the “remote, poorer spaces of urban geography” where people of meager means and resources also live (Clapp, 2002).

Indeed, poor and marginalized populations live on lands that are definitely unsuitable to live on and are in close proximity to waste that puts their health at risk, making them more susceptible to contracting diseases like malaria and cholera. These people do not have access to the basic sanitary infrastructure wealthier populations take for granted such as latrines and access to clean and potable water. Analyzed under the scope of environmental justice (or rather injustice in this case), it is imperative to find sustainable solutions to the waste issues in developing countries for two main reasons. First of all, no one should have to live in such inhumane and precarious conditions. Second, beyond the social/human questions connected to the issue, the environment is also greatly suffering from it.

In order to understand why the disposal and management of Municipal Solid Waste (MSW) varies greatly between developing and developed countries, I first examined how the issue is seen/perceived by both. For developed nations, the term "landfill", a designated operational site where waste is disposed of is more commonly used. Indeed, "landfilling" is the primary technique used by developed nations such as the United States, the countries of the EU, China and Japan to dispose of waste (Thermelis et al., 2006). However, landfills can pose serious environmental and health hasards if they are not regulated and managed effectively and efficiently. Because landfills may come into direct contact with the surrounding environment (See Figure 1), hazardous chemicals and other materials from the landfill can seep into the surrounding soils and water and are almost in direct contact with groundwater and surface water that can affect not only the environnment but also its biodiversity. The liquid formed by the

chemicals and other materials penetrates the soils and goes deep enough to reach the water table is called landfill leachate. Landfill leachate can be a source of groundwater and surface water pollutions (Salam et al., 2014). In order to keep leachate levels at an acceptable treshold at saniatary landfills, a precautionary procedure of taking samples is required and is monitored thoroughly. The leachate can also be in contact with fecal matter present at the landfill; in case it percolates and reaches the grounwater, it can seriously impact human health through the contraction and transmission of diseases like cholera (Vibrio cholerae), salmonellosis (Salmonella sp) and dysentery (Shigella sp.) (Santamaria et a., 2003). In addition, landfills and dumps are the third largest emitters of anthropogenic methane, a greenhouse gas three times more potent than carbon dioxide (Kumar et al., 2004). Therefore, it is of utmost importance to find a way to address and curb its emissions.

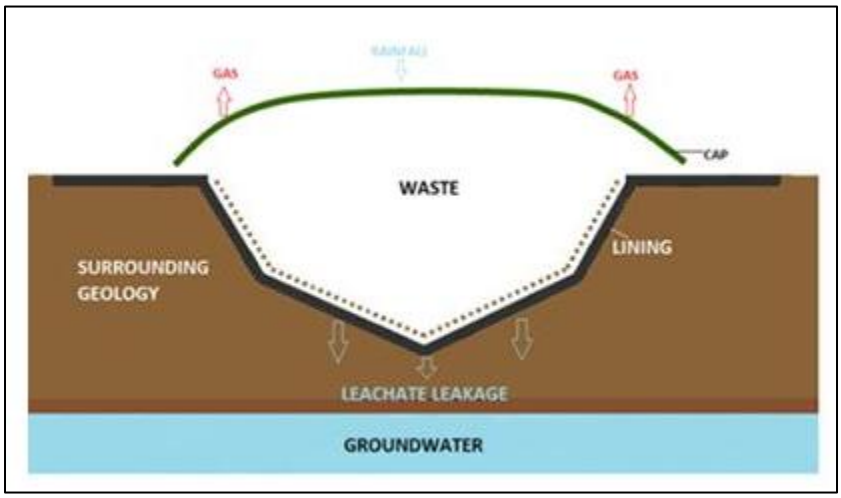

Figure 1: Cutaway View of Engineered Landfill

Source: Research project: Transport of toxic metals in clay landfill linings: influence of nanoparticles, University of Southhampton, Accessed August 10, 2017 from https://www.southampton.ac.uk/oes/research/projects/transport_of_toxic_metals_in_clay_landfill_linings.page

The call to effectively and effeciently regulate the disposal and management of MSW stems from a strong will of members of the public and the U.S. Environmental Protection Agency (USEPA) to manage, thus protecting and conserving natural resources. In that effect, a regulatory bill was introduced on October 9, 1999 to redefine and revise the requirements and criteria for the concepts of municipal solid waste and landfills (Themelis et al., 2006). The revised criteria now mandated that landfills be equipped with liners and a leachate collection sytems, which are two preventative measures to make ensure that water pollution is successfuly avoided. In addition, gas pipes and wells (whether vertical or horizontal) were now to be added to the landfills' infrastructures so as to collect the gas generated by the waste. The gas could be ultimately used to produce heat and/or electricity (Themelis et al., 2006).

In less developed countries, also refered to as the Global South, landfills are an abstract idea, a vague and unfamiliar concept. The term "dump" mirrors more adequately the way waste is disposed of and more than 90% of it gets disposed of in dumps (Amrithra et al., 2016; Sharloy et al., 2008). Amritha et al. reported that nearly more than half of the countries around the world use the dumping method over landfilling (Amritha et al., 2016).

Waste managment, in developing countries in general and Senegal (my home country) in particular, needs to be approached holistically rather than individually as there are different moving parts (social, economic, environment, health) that feed into and have intricate links with one another. Pope Francis said: "[W]e are not faced with two separate crises, one environmental and the other social but rather one complex which is both social and environmental" and that is how waste issues ought to be thought of.

For the purpose of this thesis, I will be using Mbeubeuss, Senegal's most well-known and prominent dumping site, as a case study. I analyze it from three angles. First and foremost, I

look at the obvious and heavy human/social implications that are associated with landfills. Second, I probe the groundwater pollution/deterioration and the health impacts on the populations living close to the site. Third, I delve into a discussion pertinent to methane emissions and the importance of addressing them as they contribute to global warming. Then, I turn to the opportunities that landfill waste presents and the feasability of harnessing and converting methane from the landfills to produce electricity and/or heat. Last but not least, I formulate policy development and recommendations for Senegal, with the hope that they can serve as a blueprint for any developing country that struggles with addressing both electricity production and the management of MSW.

This thesis is all the more important as it aligns with the vision of Senegal's current President, Macky Sall. Indeed, in 2015, His Excellence Mr. Sall has come up with a roadmap called Plan Senegal Emergent (PSE), which, just as its name implies, is an ambitious plan to help the country transition from its status of emerging to developed country. A strong emphasis on the protection of the environment and the production of clean, green and renewable energy sources such as solar, wind and hydro translate the President's goal to shy away from fossil-fuel dependent energy production, as agreed at the Conference of Parties in Paris in 2015 (COP21).

Currently, a lot of developing/emerging countries still grapple with waste management issues for two main reasons. First of all, the costs to dispose of waste are very high. Therefore, the high costs of waste management may not necessarily fit into the municipalities' budgets (Guerrero et al., 2013). It becomes then easier for them to dispose of the waste in areas outside of the main cities, specifically in low-lying areas because it is significantly cheaper and less labor intensive (Kumar et al., 2004). However, with the implementation of strong and effective policies that take into account both the people and the environment, that challenge could turn into a great

opportunity because it will answer/mitigate climate change, propulse and boost the creation of clean energy (landfill gas to electricity projects) and it will also create jobs.

I hope this thesis serve as a trailblazer and exemple for any developing country to re-assess their relationship with waste and realize that landfills, if managed sustainably can be a gold mine.

Chapter 2: Presentation of Mbeubeuss.

Figure 2: Geographic Map of Mbeubeuss

Source: Google Images

Mbeubeuss is located in Malika, 30 kilometers (18 miles) outside of Dakar, the capital of Senegal, between the latitudes 14°17' and 14°50' North and the longitudes 17° 16' and 17° 20' West (Essouli, 2005). It is situated in the district of Pikine, one of Dakar's and West Africa's poorest and most overpopulated neighborhoods (Judell, 2012). The dumping site was first open in 1968, and was inhabited at the time. But as Dakar grew, so did its population and soon people with meager resources and not enough money to afford living in the hub of the capital slowly started to relocate around areas close to the dump site (VoaNews, 2009). Soon, the cities of Tivaoune Peulh, Keur Massar, Pikine were established and the population numbers grew exponentially (Gueye, 2017; Judell, 2012).

The site, about 75 hectares in size, sits on what used to be Lake Malika, which has dried up

since Mbeubeuss was implemented (Vidal, 2014). Because of its rather advantageous topographic position, the soils are very fertile and rich; and for that reason a lot of small scale farms have frantically sprouted over the course of the years (Judell, 2012). Unfortunately, as a result from the proximity with the dump, the waters and soils are also heavily polluted, making the food and meat poultry grown there defintely not appropriate for consumption. The site welcomes not only the Municipal Solid Waste (MSW) waste generated by the region of Dakar, but also all the waste produced by the industrial and manufacturing companies situated close by (IAGU, 2011).

For better operational efficiency (n.b I use the term efficiency quite loosely here), the dump has been divided in 4 sections: (1) Gouye Gui (the Ouolof term for a massive tree), (2) Baol (named after a former Senegalese kingdom), (3) the main platform where all the waste is dumped and triaged, and last but not least (4) the compost recuperation area (Judell, 2012).

Table 1: Four Sections at Mbeubeuss

Source: Adapted from Judell, 2012

Name of Section	Operational Structure
Gouye Gui	- Industrial waste is recycle there (plastic, glass bottles, non-ferrous metals, electronic waste - about 100 workers
Baol	- Turf of seasonal workers - industrial waste is recyled here as well
Platform	- Main operational epicenter ; operates day and night with 100 workers
Compost Recuperation area	- Workers look for rich soils and sediments they resell to their netwrok of farmers in Dakar.

Originally, the site was chosen for waste disposal because of its convenient location: it is far away enough from the beautiful and effervescent epicenter of the metropolitan city (again the concept of distancing of waste as previously stated above). With an "out of site, out of mind" concept, it is almost easy to get fooled by the aesthically pleasing and appealing face that the city presents to visitors. The reality is, unfortunately, quite the opposite: the ugly truth is that Mbeubeuss is an environmental, social and economic imbroglio with very complex repercussions. Therefore, Mbeubeuss has now joined the infamous list of the world's "worst

dumping sites" alongside Indonesia, India, Ghana,Brazil, China et cetera (Vidal, 2014). Local and international ecologists have dimmed the light and brought forth the problem and even gone so far as to comparing Mbeubeuss to a "ticking timebomb" (Vidal, 2014).

The impacts on the public health are quite alarming. A study on the populations living in proximity to the landfill have been tested and traces of lead were detected in their blood and urine samples (Cabral et al., 2012). The population of Mbeubeuss is mainly comprised of children; their exposure to lead can cause irreversible damages to their respiratory, neurologic and reproductive systems (Cisse, 2012). In addition, the time-bomb metaphore makes all the more sense and is all the more appropriate considering the accidents, sometimes resulting in deaths, that occur over the course of the years: just at the end of year 2016, three people perished in a fire (Soumare, 2017; Cisse, 2012).

Mbeubeuss--the name alone sounds terryfing; guttural appelation which ressembles any hairy, scary monster straight out of any children's book. It is not a monster per se, but from an environmental standpoint, can be labelled as one. The landscape is pittoresque and offers the ideal setting to shoot a horror movie (Vidal, 2014). The ground is strewn with plastic bags, aluminum cans, organic housewaste waste, electronic appliances such as refrigerators, computers still connected to keyboards. There are pieces of furniture everywhere, cans of paint of all colors and solvents--some containers still half full. The six-square kilometer dump holds so much "stuff" that navigating through this intricate maze calls for extreme vigilance and tact. Danger is everywhere.

The air is filled with a pestilential smell of rotten eggs, which is explained by the carcasses of dead animals, laying further down, in advanced stages of putrefaction. The smell is also explained in part by the amputed body parts that are found amidst the decor; due to a lack of

adequate infrastructures that allow a safe disposal of biomedical and clinical waste, hopsitals do not have any choice but to dump them there. Wild dogs are chasing each other, feasting on those. Giggles and laughter sometimes interrurpt the defeaning silence, as a group of children are playing , hide and seek, barefoot, completely oblivious to the dangers they face. Those dangers range from piles of waste falling on them, getting stung and potentially infected by the syringes and/or needles on the ground, and, last but not least, being ran over by the few trucks that dump their loads fretentically, ready to hit the road for another round.

The workers

Self-claimed and self-employed recycling workers process all the waste at Mbeubeuss. The term "boudjouman" is used to describe them. The more socially acceptable translation of the term would be "scavengers", originally used to designate an informal worker, but now having gained a more peojorative meaning. Indeed, the job-title has now been claimed and used as a "passe-partout" identity by all the unemployed younsters living at the landfill. As a matter of fact, it has been estimated that 10% of the workers are early teenagers (12 years old and up), 25% are women and 65 % are men of a certain age (Judell, 2012).

Although many of them do work there and make an honest living, scavenging through the waste and reselling it to third parties manufacturers, Mbeubeuss sadly also harbors deliquants, thieves, and drug addicts. As a matter of fact, beyond constiting threats to the environement and public health, landfills are usually the theater of human and social tragedies: due to the lack of control/law-enforcement and disorganized setup, it offers an ideal setting for rapes, murders, abductions, and more (Burrows, 2015). This is confirmed by the President of the Association of scavengers, Mr Pape Ndiaye, who has deplored the fact that Mbeubeuss offers the perfect

"hideout for crooks and hooligans" (Sy, 2006).

As of 2006, there were about 1000 workers which lived on site with their families. A little over a decade has gone by and that number has obviously increased for two main reasons: urbanization, econonomics and demographics. These three key factors need to be analyzed simultaneously, rather than separately. Later in this thesis, I will analyze them in more detail.

The Occupational Safety and Health Adminstration (OSHA) is a part of the United States Department of Labor. Per international standards, it sets forth rules and regulations that ensures the well-being and the protection of all workers. Among those rules is the mandatory use of Personal Protective Equipment also known as (PPE). PPE is worn to :

> minimize exposure to hazards that cause serious workplace injuries and illnesses. These injuries and illnesses may result from contact with chemical, radiological, physical, electrical, mechanical or other workplace hazards. Personal protective equipment may include items such as gloves, safety, glasses and shoes, earplugs or muffs, hard hats, respirators, or coveralls, vests and full body suits (OSHA, 2017).

At Mbeubeuss, the "boudjoumen" work for their own account and they do not have access to PPE. First of all, they are propably not aware of internional standards they need to follow and or how to use the equipment to efficiently protect themselves. Second, PPE is very expensive and with the low wages they make from selling the salvaged material from the landfills, they are not able to afford them. Subsequently, they've become very good at finding ingenious ways to create their own version of PPE. Handkerchieves, sunglasses and rubber gloves are what they are using. Indubitably, those are insufficient layers of protection and for that same very reason, workers find themselves subject to serious physical injuries ranging from fractures to severe burns, and exposed to irreversible respiratory diseases, human feces, infectious diseases.

Mbeubeuss is a voracious ogre and has over the course of the years claimed the lives of many

workers. The most recent deaths date back to December of 2016. A pile of waste caught on fire and soon enough, the fire spread. Two workers died, calcinated and a third went missing. (Soumare, 2017). Unregulated/open dumps and even sanitary landfills are very suceptible to catching on fire. Fires usually start because of the presence of combustibles like plastics, paper, cardboard et cetera. For example, if there is are hot ashes or a rising tempatures on a warm day, that could be enough to get a fire started. A hastily discarded match may also spell trouble in a landfill (U.S. Fire Administration, 2001).

Besides risks of fire, cases of lanslides are also frequent not only at Mbeubeuss, but also at other dumps. Engineering analyses of such catastrophes indicate that differences in the moisture content of the various layers of the landfill might be one of the causes of landslides (the more recently added waste tends to be wetter) (Yin et al., 2015). Unfortunately, those trying to eke out a living on the landfill have no understanding of these scientific principles at work. The dumps are both a workplace and home for a lot of people; their aim is their survival and that's why the human casualties are always high.

Figure 3: A worker scavenging through the waste

Source: https://www.sencms.com/news/Societe/lendemain-de-tabaski-dakar-ploie-sous-les-ordures-et-la-mauvaise-odeur_n_148.html

Figure 4: A group workers at the Mbeubeuss dump

Source: http://globalrec.org/2017/01/02/a-massive-fire-

Figure 5: workers waiting for truck to unload waste so they can start sorting through it

Source: http://www.thisisplace.org/i/?id=c0653950-8ff7-4312-baad-fbf2a32a690a

Figure 6: Aerial photo of the Dump : a threat to the environment and the public

Source: http://www.alamy.com/stock-photo/landfill.html?pe=001&so=20

Figure 7: Piles of Waste Adjacent Modern Buildings

Source: http://www.seneweb.com/news/Societe/reportage-nbsp-un-laquo-nbsp-mbeubeuss-nbsp-raquo-rsquo-niche-au-c-oelig-ur-de-dakar_n_188196.html

On March 12th 2017, Ethiopia woke up in horror: 113 people living at the Koshe landfill had perished in a landslide. The name of the landfill Koshe literally translates into "dust", already giving away the nature of the accident. Some people have taken up residence on site, living in "houses" made out recycled material (Duggan et al., 2017). The unstability of the land and the poor quality of the building materials are two ingredients that make the ideal recipe to a accidents like that. A similar scenario has occured in China in 2015 killing 58 people (Duggan et al., 2017). As at Koshe and in China, the social implications that are associated with unregulated dumps come at a very heavy price: when there are accidents or catastroophes of any nature, the

toll is usually very high because the number of people living on the premises is usually important. By some esimates, 15 million people live on dumpsites and landfiflls around the world (England, 2017). Protecting the "workers" for the government of those countries seldom mean relocating them to a new area and that process usually takes time and requires a lot of money. In addition, for those living on the dumps scavanging is a more honorable means of providing for a family than begging or turning to crime.

Figure 8: Koshe landslide Ethiopia (The similarities between Koshe and Mbeubeuss are striking)

Source: http://www.cnn.com/2017/03/15/africa/ethiopia-trash-landslide-death-toll/index.html

Figure 9: A house at Mbeubeuss dump

Source: https://www.idrc.ca/fr/article/la-decharge-de-mbeubeuss-creuset-dexperiences

Chapter3: Discussion Increase in Municipal Solid Waste (MSW) Generation in developing countries

Municipal Solid Waste (MSW) is the amount and quantity of waste generated by households, industrial, commercial businesses in any given municipality (Cointreau, 1982). In both developed and developing countries, municipalities bear the burden of disposing of MSW (Guerrero et al., 2013). However, both the management and disposal of MSW are becoming a major problem in developing countries and their capitals because of a signifcant increase in the population and subsequently, the amount of waste generated. Indeed, with urbanization and globalization, living in the city offers more professional, economonic, social opportunities and advantages to people from the countryside. Cities and capitals in developing countries have been witnessing a rapid and constant increase in its population--approximately 4-7% per year (Cointreau, 1982). Dakar, Senegal has become a major metropolitan city and is one of the most populated cities in the country, with a population of three million people (Agence de la Presse Senegalaise, 2017).

The urban exodus can be explained by the general assumption that moving to the city is usually synonymous to an opportunity to make a better living, thus increasing a person's buying and spending power and also equates to a significant increase in social status (Kaushal et al., 2012; Kumar, 2016). This then translates into more waste generated per person per kilogram per day due to the direct correlation between an increase in salary (or access to better living conditions) and the quantity of waste generated (Bello, 2016). It is estimated that 7.6 million tons of MSW are generated per day in developing countries (Nagendran et al., 2006).

A study conducted in Qatar looked at how an increase in salary promotes behavioral and new lifestyle choices/changes (Bello, 2016). The authors found that the more money and resources

one has access to, the greater their spending power, and the more waste will be generated. Although Senegal is not as wealthy as Qatar, similar trends are currently happening and can be seen in the more affluent neighborhoods of the capital Dakar- like Almadies, Point E, Ngor, and Fann Residence. A decade ago, 2.9 billion residents produced 0.64kg (roughly 1.4 lbs) of MSW (World Bank, 2012). As of today, there are 3 billion people generating 1.2 kg (2 lbs) of MSW, which equates to 1.3 billion of tons of MSW a year. The World Bank's 2012 report entitled "What a waste: A Global Review of Solid Waste Management" takes a closer look at the trends amount of MSW. Experts project that by the year 2025, 4.3 urban residents will produce 1.4kg (3 lbs) of MSW per person per day (World Bank, 2012).

All these factors strongly play in favor of a signficant increase in the amount of MSW. A report by Kawai and Tasaki, entitled "Revisiting estimates of municipal solid waste generation per capita and their reliability", provided the per capita waste generation of countries around the globe. Although it was very difficult to obtain accurate and reliable data for developing countries, they were able to come up with a figure for Senegal: 0.52 kg per person per day for Senegal. The value for OECD countries was listed at 1.34 kg per person per day. Based on the data given, the global median can be calculated at 0.94 kg per person per day. Given all the issues and challenges currently faced, could Senegal even handle 0.94 kg per person per day of waste? Would it be ready to deal with such an increase ?

At its creation, Mbeubeuss received 475,000 tons of waste per year. In 2011, that value reached 500,000 tons of waste per year and by 2015 that volume was well over 519,000 tons per year (Mbengue et al.,2015) The waste received at the dump is comprised approximately of 45% of fine particles and 20% of rotten/decaying material and the remaining 35% are solid materials (CRDI- IAGU, 2011). The rest of the waste is made up of aluminium cans, plastics bottles,

glass, textiles,eletronics appliances and even synthetic hair weave.

The primary reason why MSW constitutes a major problem for municipalities in developing countries is because it is not placed high on their list of priorities; other issues such as public health, education, construction / pavement of roads are put first at the detriment of MSW (Nagendran et al., 2006). The mistake made by municipalities in regards to addressing MSW stems from a fact of not understanding the deep repercussions that a poor management of MSW can have both on the public health and the environment. As stated earlier, they need to be analyzed simultenously instead of separately because open dumps create environmental nuisances that in turn affect the health of the people living at the dump and that of the people living nearby.

Methane emissions from unregulated dumps

Both natural and anthropogenic (man-made) sources emit methane. In 2000, 286 million tonnes of methane were emitted, according to the U.S. Environmental Protection Agency (USEPA). Of those 286 million, dumps and sanitary landfills produced 36 million tonnes (Themelis et al., 2007).

Landfill gas (LFG), the gas emitted by dumps and landfills is predominantly composed of methane (CH4) and carbon dioxide (CO2) (Kumar et al., 2016). LFG results from the anaerobic decompostion of organic matter (food and yard waste primarily) (Matthews et al., 2007). It is a very powerful greenhouse gas (GHG), 21 times more powerful at sequestering heat in the atmosphere than carbon dioxide over a 100-year time frame (Johanssen et al., 1999). For that reason, in terms of impact on climate change, landfill gas can be considered more powerful and dangerous than carbon dioxide (Yip et al., 2008). It contributes significantly to the

acceleration of the global warming mechanism every year. In fact, the context of global warming, MSW from dumps and landfills produces 15% of the yearly global methane emissions budget (West et al., 1998).

A widening gap exists between developed and developing nations in how the former addresses the production of LFG as opposed to the latter. To mitigate the production of methane from landfills, developed nations have invested heavily in capturing the LFG and use it to produce both electricity and heat. The gas either can be flared or even burned to recover energy (Yip et al., 2008). Despite the heavy economic and financial investments required to put such LFG systems in place, both strategies have proven to be successful in mitigating methane emissions and producing electricity and heat (Matthews et al., 2007). In California for example, landfill gas projects produce almost 250 MW of electricity (California Energy Commission, 2017).

Groundwater Pollution

According to the World Health Organization (WHO), more than 340.000 children die around the world yearly after contracting diseases from consuming or playing in contaminated waters (Min, 2015). Landfills and dumps are one source of contaminated water. Open dumps are also the source of environmental catastrophes and a direct threat to public health for many other reasons. They receive a myriad of different waste types, including industrial material (such as batteries, electronic appliances and paints) whose content in heavy metals is extremely high (Cabral et al., 2012). The most common types of heavy metals found in dumps include lead (Pb), arsenic (As), chromium (Cr), zinc (Zn), copper (Cu), mercury (Hg) and nickel (Ni) (Wuana et al., 2011). Heavy metals are extremely dangerous if not handled and disposed of carefully. In

adults, lead exposure can cause anemia, headaches, and memory problems. In children, lead poisoning can result in development delays (reproductive) and hearing loss (Mayo Clinic, 2017). Mercury exposure can lead to vision, cognitive impairement and tremors; arsenic is known to cause skin lesions that can evolve to skin cancer (Mayo Clinic, 2017).

In developing countries, the challenge of supplying clean water preventing its contamination by heavy metals is exarcerbated by a notable defiency, inedquacy and lack of infrastructures and facilities to not only treat the waste but also contain it. If effective containment measures were put in place, they would help prevent human contact with these toxic substances, thus avoiding preventable diseases and deaths.

Leachate is the liquid that accumulates at the bottom of the landifll, gathering both suspsensed and dissolved particles along the way (Raghab et al., 2013). Leachate can be also be a vector of carcinogens (Sambou, 2008). Through percolation, the leachate passes through the water table and then reaching the aquifers below. The populations living on the site at the dumps and those that live nearby rely heavily on that water source for their daily needs; often times they are aware that the water is not fit for consumption. In truth, they don't have any other choice.

In developed countries, sanitary landfills are required to have liners that prevent the leachate from reaching the water table, thus containing the population. The liners can either be made of plastic, clay or a composite (a mix of plastic and clay) (ejnet.org). Coupled with a lack of latrines or toilets, infrastructure taken for granted in many parts of the Global North, populations residing near dumps in the Global South are highly susceptible to contracting cholera, dysenteria, and malaria. The populations live in close quarters and in promiscuity: in case of an outbreak, the disease spreads much more rapidly than in other settings.

As mentionned earlier, Mbeubeuss sits on what used to be a dried up lake. Beause of that, the

soils are very rich and fertile due to their high contents of sediments, making them appear suitable for agriculture and raising poultry and pork. In order to cut down on their expenses, the animal breeders use the organic waste and leftover foods found at the dump to feed the animals (Sambou, 2008). Unfortunately, animals started getting sick due to the food and water they were fed with--traces of polychlorinated biphenyl (PCB) were found in their bloodstream (Sambou, 2008). After the animals are slaughtered and sold to the general public, it becomes a domino-effect and people start getting sick. Exposure to PCBs in humans is known to increase deaths from cancers of the gastrointestinal tract, liver, and organs involved in the production of blood (Greenfacts, 2017).

Clean Development Mechanim and Landfill Gas (LFG) Projects

The Kyoto Protocol, an international agreement signed between developed and developing nations on December 11, 1997, was one of the first promising steps taken on a global scale to address climate change. Although climate change is a global concern that will ultimately affect both developed and developing nations, the Protocol placed a significantly heavier burden on developed nations to take affirmative and concrete actions to significantly reduce their share of GHG (United Nations Framework on Climate Change, 2014). The authors of the Kyoto Protocol ackowledged that developing/emerging nations have less of a participatory/active role in the emission of GHG. As a result, they drafted different guidelines that Annex I countries (developed countries) and non- Annex I parties (developing/emerging countries) would follow in order to curb GHG emissions thus addressing global warming (Ellis et al., 2007). These emission comittments hold both groups accountable while still allowing non-Annex I countries to continue to aim towards economic growth/ development, while still shying away from fossil-

fuel based technologies.

With climate change being a global concern and a challenge that will adversely affect both developped and developing nations, it quickly became apparent that a consensus needed to be reached in order to address global emissions. The Green Fund Development (GFD) was developed for countries to meet their designated target emissions by funding mitigation projects in the developing world (Lecoq et al., 2007). However, it received a lot of push -back from Annex I countries who were very weary of the financial penalties iimposed when they did not meet their emissions reductions goals. After discussions to find a fair compromise that would encompass all parties' needs and expectations while still holding true to the primary objective of the Kyoto protocol, Article 12 of the agreement was finally incorporated on December 11th 1997. The implementation of the Clean Development Mechanism (CDM) marked one of the turning points of the Kyoto Protocol agreements.

The CDM acknowledges that there are clear differences between the Global North (Annex I countries) and the Global South (non-Annex countries) when it comes to GHG emissions and that's the reason why a cooperation (to reach development without compromising the climate and jeapodizing the environment) between the former and the latter had to be strongly encouraged (Ellis, 2007). The CDM then allows developed countries to purchase emission reduction credits by financing and supporting mitigation projects and programs in developing countries. The purchase of credits also helps the developed countries which have exceeded their allowed emission quotas to offset emissions by financing sustainable projects in the developing world.

One of the main focuses and sub-components of the CDM has been tailored to the solid waste industry, more specifically the MSW. It has been developed with the idea of assisting

developing countries in the process of implementating a more sustainable framework in the management of their solid waste by harvesting the LFG to produce electricity. For example, in China, 26 LFG projects have been implemented, with a production capacity of 56. 8 MW, as a result of the CDM (Chen et al., 2010).

LFG Projects – an opportunity to boost electricity production in developing countries

It is estimated that a staggering 1.3 billion people around the world do not have access to electricity ; 85% of those live in the countryside and rural areas (The Economist, 2010). Because access to electricity has been used as a proxy for development and economic growth by international organizations like the United Nations, it should not come as a surprise that most of the people without electriticy access live in Sub-Saharan Africa and South-East Asia (Economic Consulting Associates, 2014).

As previously stated, developed and developing countries have reached a consensus to gradually decrease their use and dependence on fossil fuels to produce and meet electricity needs. The production of energy in developing countries constitutes a challenge because it requires a lot of infrastructure and building that infrastructure requires vast financial resources. Even so, if the methane generated from the already existing landfills in the developing world can be captured and successfully converted to energy, it could answer the ever-lasting questions and challenges of energy production and access in those countries (Scarlat et al., 2015; CDM Investment Letter, 2008).

Apart from their environmental benefits, LFG projects also embed social and economic benefits that can positively impact the lives of both the workers and the communities living nearby. Among those benefits are the creation of jobs, a successful transition from the status of

unregulated landfills/ dumps to sanitary landfills, access to affordable electricity, and a boost in the economy. The only disadvantage that the municipalitlies and waste companies need to take into consideration when implementing these projets is the displacement of all the workers who both live and work on the dumps. A thoughtful planning should incorporate a relocation and a reinsertion/ reconversion into the sanitary landfills so that they do not lose their only way of making a decent and honest living.

Chapter 4: Methods

The primary method used for the research of the thesis was a thorough review of the current literature pertinent to the current issues related to the handling and disposal of MSW in developing countries. First of all I analyzed documents written by international instances such as the World Bank and looked at the socio-economic mechanims such as urbanization, globalization, occidentalization and how they contributed significantly to the increase in MSW. Second, I analyzed the literature about the techniques used by developing and developed nations to dispose of waste. I focused on the terminology used to differenciate the widening gap exisiting between the two: landfilling for developed countries and dumping for developing countries. For the second half of the thesis, I then analyzed the environmental issues that are associated with dumping waste instead of adequately disposing of it (methane emissions, contamination of the groundwater, contraction of diseases such as cholera, dysenteria). Then, I studied the literature written about the Clean Development Mechanism, an instrumental tool in helping to implement Landfill Gas Project, a technique to recover and put to good use the methane generated from MSW. For that purpose, I looked at landfill mining to recover materials in open dumps. In order to address and mitigate methane emissions, I looked at policies related to landfill gas extraction for energy. Finally, based on all the information found, I formulated recommendations and informed policies that could be used as guidelines for Mbeubeuss. An aborted process to implement an LFG project was started a decade ago but it was never carried out.

Chapter 5: Landfill Mining

"Can implementing the three R's- reduce, recycle, reuse, save you money ? If you only implemented the three R's in your kitchen, you would save money."

Catherine Pulsifer

Commodities such as plastics, metals, glass, paper, and food are constantly discarded into in landfills. Often times, those commodities are relatively new and could potentially be offered a new life if refurbished and fixed. Landfill mining, the practice of sorting out, digging and reclaiming materials that have been thrown away can also be a great source of revenue for developing countries (Asotin County, 2017).

In addition, landfills can be mined for their metals. There are two categories of metals: rare and precious ones. Zinc, copper, silver, gold, cobalt et cetera are juxtaposed with the adjective precious for a reason that already gives it away; they have a very high monetary value because they are always in high-demand (Krook et al., 2012). Rare earth metals (REEs), a group of seventeen chemical elements, are of tantamount importance to manufacturing companies and are used in daily products consumers use such as cell phones, computers, and tablets. From an ecological and environmental standpoint, there are less damages to the environment when extracting and recuperating what is already "out there" and at arm's reach rather than finding and producing new supply sources (Wagner & Raymond, 2015; Dutta et al., 2016). By repurposing the metals buried at the landfills, water and energy are sources are also preserved and conserved. Furthermore, computer and cellphone manufacturers have been outsourcing the rare and precious metals from developing countries like the Democratic Republic of Congo (DRC). In the DRC, the majority of the workers extracting cobalt used in manufacturing computers are children, who work in absolutely inhumane and horrible conditions: no PPE,

long days of work for very minimal revenue (Kelly, 2016). Therefore, by favoring landfill mining over producing and extracting new supply sources, manufacturingcompanies can stop supporting child labor.

Another added benefit that is also important to take into account is the cost savings associated with the extraction/recuperation process as opposed to the development of new supply sources; the fomer being cheaper than the latter, which requires a lot of financial expenditure.

With access to higher education still being a challenge for poor people, the chances of making a decent living become ipso facto very slim. The only viable alternatives for the uneducated youth are jobs from the informal sector, including working at Mbeubeuss selling precious metals and other valuable commodities to manufacturing companies. The informal sector brings a non-negligible contribution to Senegal's national G.D.P, accounting for 41.6% (Asoko Insight, 2015)

However, that success is over-shadowed by preventable accidents and/or deaths that occur at the site. According to Abdoulaye Gueye, Chief of Staff to the Minister of Labor:

> despite its contribution to the national economy, it is marked by severe deficits, such as" the precarious working conditions which are unsuitable and dangerous" and, the exclusion from formal social security system and laws governing health, safety and motherhood" (Agence de Presse Senegalese, 2015).

Landfill mining is already a reality at Mbeubeuss. However, it needs more attention from both the municipalities and the Senegalese government. In other words, for Mbeubeuss to be stripped off its unfortunate "ecological timebomb" badge of shame that has drawn negative international attention and scrutiny, the opportunities and assets it could present need to be presented as such. Mbeubeuss and other unregulated dumps/landfills need to be looked as "reservoirs of econonomically valuable resources" (Krook et al.,2012). For example, the workers there make between $600 - $725, which is significantly higher than some of the

educated positions (Sy, 2002). Mbeubeuss injects approximately 13 million francs CFA into the economy every month, according to its coordinator. Due to the significant revenues it generates, if strong policies, coupled with accompanying/preventative measures to better protect the workers, landfill mining in Senegal could be an added bonus to the electriciy generated from the waste. Additionally, landfill mining can help "increasing landfill space, reclaim land, extract methane gas" (Krook et al., 2012; Astosin, 2017).

Although landfill mining stems from concepts of preservation, effective resource management and conservation, the sustainability component had yet to be fully incorporated. Indeed, the term Enhanced Landfill Mining (ELFM) was not coined until the year 2000 (Asotin, 2017). ELFM focuses on the recovery of the materials both as a source of energy and an economic stream (resell raw materials) (Wolfsberg et al., 2014; Krook et al., 2012; Asotin, 2017).

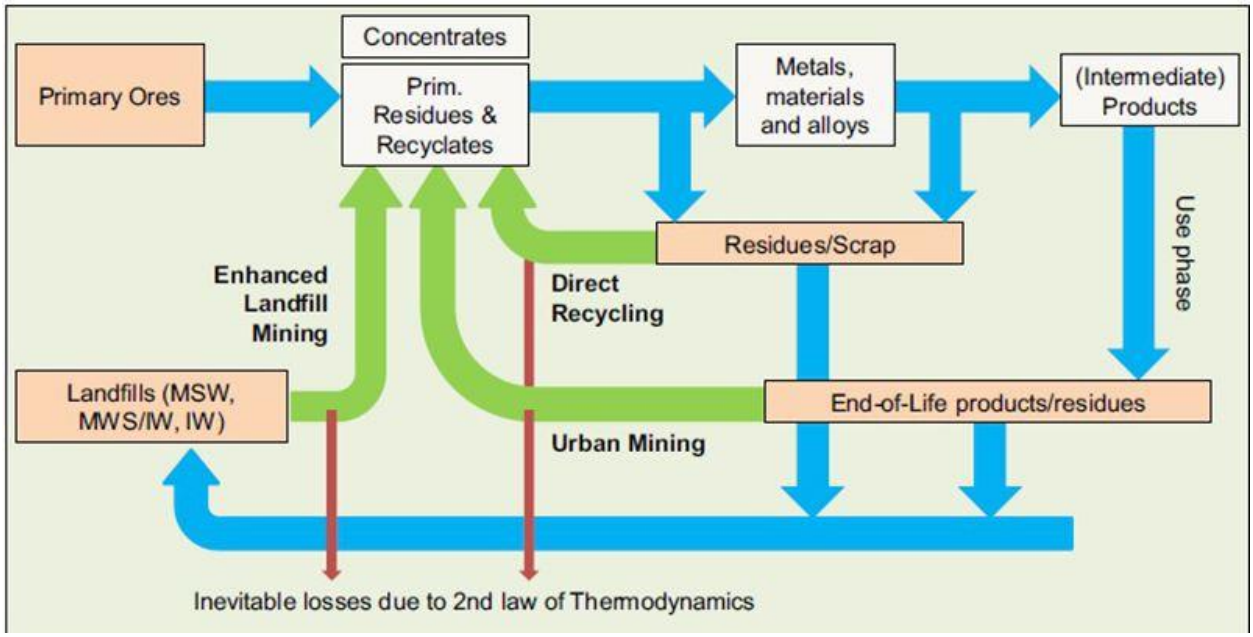

Figure 10: Enhanced Landfill Mining

Source: Jones et al., 2011

With all the benefits listed, landfill mining presents a lot of attractive benefits that developing countries ought to incorporate into the managerial policies and procedures of their landfills and

open dumps.

Landfill Gas Extraction for Energy

To understand how landfill gas (LFG) can be captured and turned into a reliable source of energy, it is necessary to understand how methane is generated at a landfill. The Landfill Methane Outreach Program, a component of the U.S. EPA, is a nationwide group of volunteers who has teamed up with experts from the solid waste industry to educate the general public about methane emissions from landfills. In June 2017, the Landfill Methane Outreach Program published a handbook called the *LFG Energy Development Handbook*, to help the general public understand the driving mechanisms behind the production of methane at landfills. The primary goal of the handbook is to raise awareness about the global warming potential from MSW and to incite the public to take a more active stand by looking at what they throw away.

With that specific puprose in mind, the handbook covers the process of converting methane into electricity in depth. The gas from MSW is produced in four distinct phases. During the first one, aerobic bacteria (bacteria that only lives in the presence of oxygen) is present. The bacteria gradually breaks down the chains of lipids, proteins and carbohydrates until there is no more oxygen available. At that stage, the bacteria in the landfill produce carbon dioxideand three other byproducts methane, ethanol, and now hydrogen (Landfill Outreach Methane Program, 2017). At the third stage, the organic acids that were produced during the second stage combine to produce acetate which, in turn, enables the formation of additional methane. During the last phase, LFG is formed, with a composition of about 50% methane, 45% carbon dioxide and about 2 - 5 % of other gases (Landfill Outreach Methane Program, 2017).

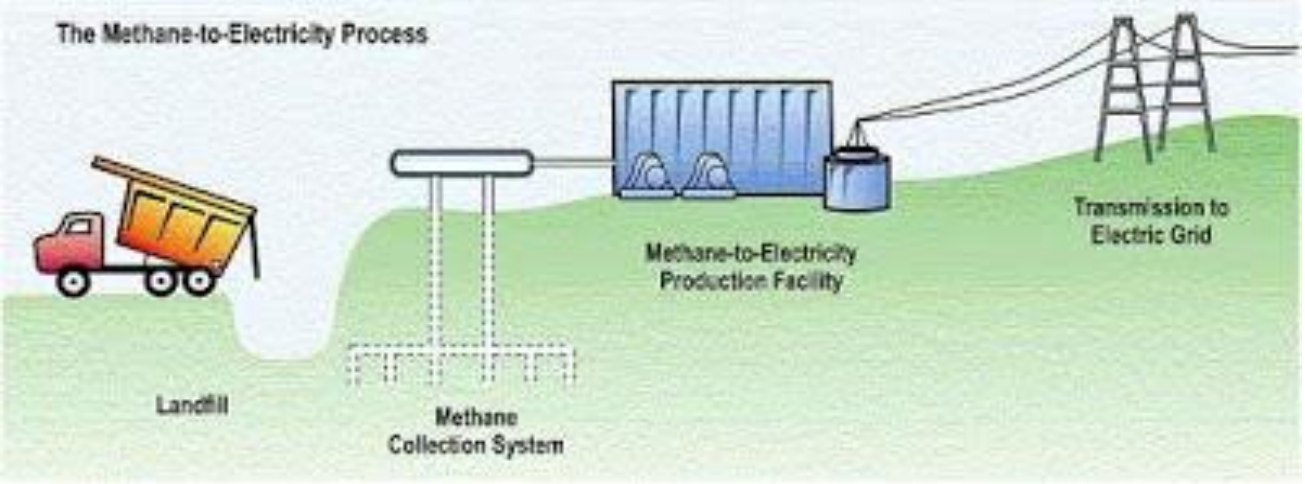

Figure 11: A simplified diagram of the methane to electricity production from the deposit stage at the landfill to the conversion and production and transmission through the electric grid. Source: http://landfillwaste.blogspot.com/

The process of extracting and recuperating LFG to produce both and electricity and heat in the developed world has asserted itself as one of the promising techniques to progressively stop the heavy reliance on fossil-fuels which has been one of the driving forces and mechanisms behind industrualization. As of this writing, there are about 955 landfills in the world that have LFG projects in their energy production portfolios. The majority of the projects are housed in the United States, followed by Europe (Germany and the UK) (Yip et al., 2008).

It is estimated that one million tons of MSW can produce roughly 300 cubic feet of LFG (Landfill Methane Outreach Program, 2017). In 2005 alone, it was estimated that the LFG projects around the world generated nine billion KWH of energy (Yip et al., 2008). Energy production from LFG is all the more promising because it is a sustainable process, and can still be a viable source of energy even 20 - 30 years after the waste has been landfilled.

The collection of LFG can be done using two different processes: vertical and horizontal drill trenches. Each method is used depending on the conditions and nature of the site. For exaample, horizontal drilling and wells are implemented in deeper landfills (Landfill Outreach Methane Program, 2017). Vertical wells are the most widespread technique to collect LFG and that is in part due to its rather simple requirements: the wellheads are hooked to lateral pipes which then carry the gaz to a tank through the use of a blower to propulse it (See Figures 12 and 13) (Landfill Outreach Program, 2017).

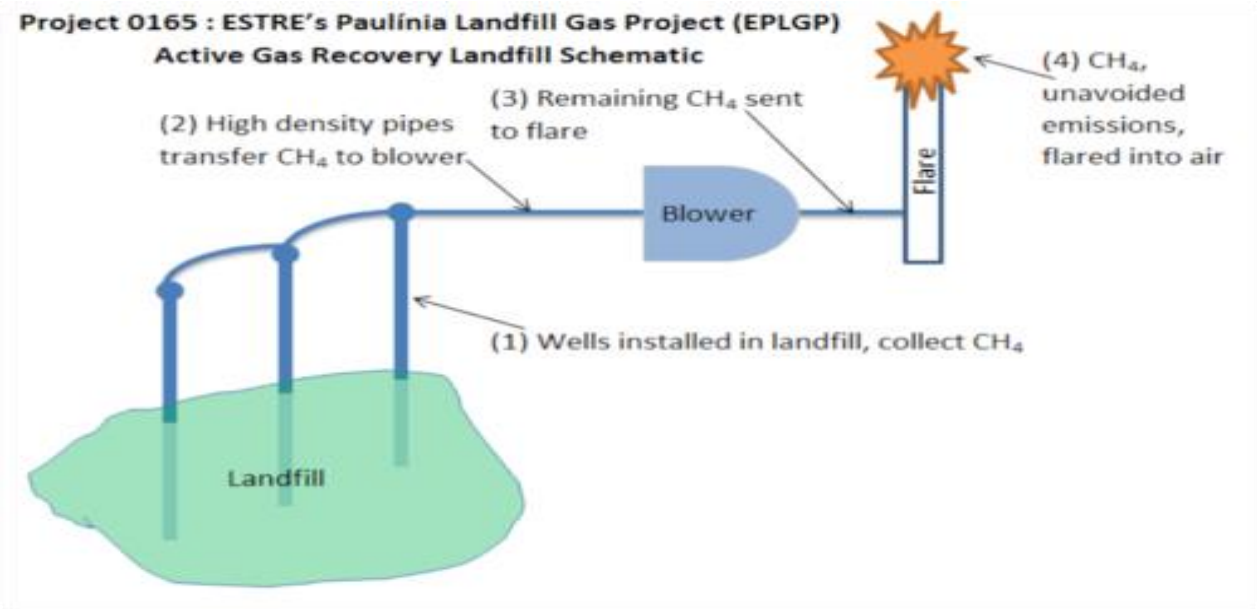

Figure 12: Vertical LFG well collection

Source: https://en.wikipedia.org/wiki/Landfill_gas_emission_reduction_in_Brazil

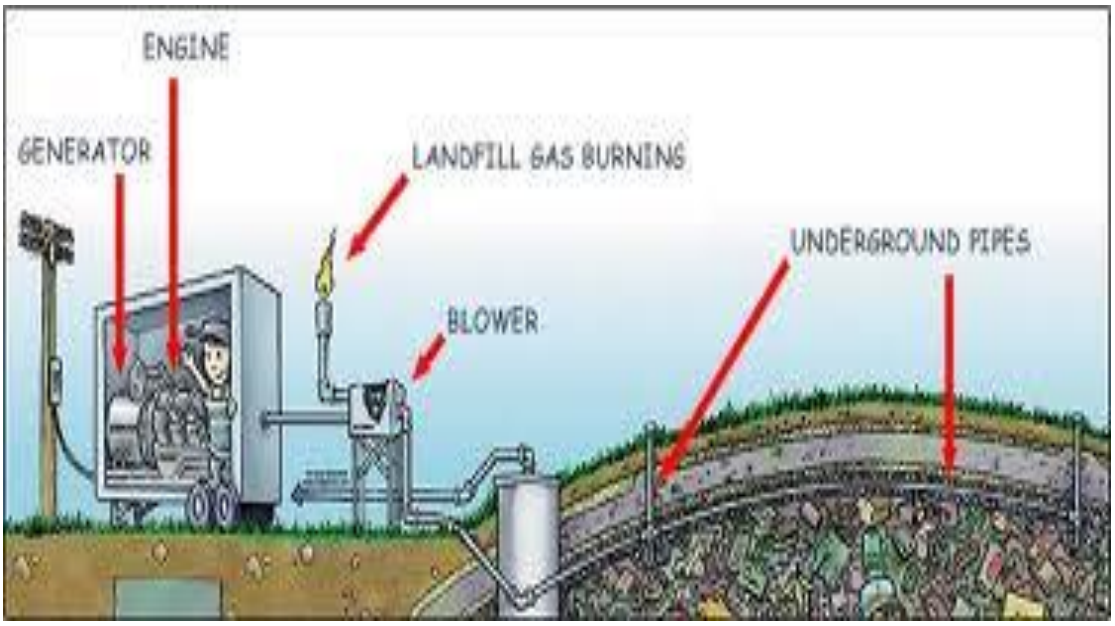

Figure 13: Horizontal LFG collection

Source**:** http://rcrcommodities.com/?page_id=598

For the commercial recovery of LFG, a landfill should: (1) recive at the minimum, 200 tons of waste per day, and (2) have a minium capacity of 500,000 tons (Johannessem, 1999; Ouedraogo, 2005).

Compared to other clean and renewable energies, LFG is significantly cheaper. The "Capital Cost Review of Power Generation Technologies" written by the Western Electric Council actually looks at various renewable energy technology production and analyzes the capital cost of energy (kW) produced per dollar amount. In other words, the report compared methods to determine which was cheaper to implement. The LFG capital cost were estimated to be around $2,800/kW whereas hydrothermal was coined at $5,900/kW (Western Electric Council, 2014). In the case of Senegal, I would expect relative cost comparisons to be similar although the exact figures might be different. And, with Mbeubeuss, there will be a ready fuel supply.

Chapter 6: Recommendations for Mbeubeuss : Why it makes sense to implement a Landfill Gas-to-Energy project at the landfill.

Recurrent power outages in Senegal

I established the correlation between access to energy and poverty at the beginning of this thesis. They go inevitably go hand in hand, and sustainability, whether economic, social or environmental, cannot be achieved without electricity. The United Nations defined access to electricity as one of the Millenium Development Goals (MDG), setting an optimal target for everyone in developing countries to have access to electricity by the year 2030 (Karekezi et al., 2009)

During the summer of 2012, power outages in Senegal spurred national riots and the problem has only worsened since then. The youth descended in the streets, ransacking and destroying public goods to express their anger and frustration about the constant outages, outages that could last 48 hours and sometimes even longer. SENELEC (Societe Nationale d' Electricite du Senegal), the electrical power company owned by the Senegalese government, issued a statement that there were two main reasons for the outages. First of all, SENELEC faced challenges in meeting the voracious demand from a constantly growing population and second, they were struggling with the oil purchases, due to its very high prices. (It should be noted that the country's current electric power supply and generation primarily comes from imported fossil fuels (World Bank, 2015). In addition, their equipment was old and defective (Causes.com). That situation negatively impacted not only the country's economy but also the health and well-being of the populations.

Indeed, many of the public hospitals are not equipped with power generators in case of electricity outages. The generators need fossil fuels to run and with the high prices associated with them, the health institutions often find themselves unable afford those back up supplies of

electricity. For that reason, a few cases of deaths had been noted among premature babies who were connected to eletrical equipment to keep them alive and who unfortunately died when the power went out (Seneweb, 2010).

In 2013, former President Barack Obama, created the intitiative Power Africa with the aim to propulse and bolster Africa's energy production and access to electricity for its populations. Power Africa's primary mission is to:

> . . .add more than 30.000 megawatss of cleaner, more efficient electricity generation capacity and 60 million new home and business connections. Power Africa works to unlock the substantial power of wind, solar, hydropower, natural gas and geothermal resources on the continent] (USAID, 2016).

Power Africa's main mission is completely en phase with the implemention of LFG projects. It could also be a viable source of financial support that the Senegalese government could look into to support the project.

Senegal has about 731 MW of energy production available and ready to go and needs approximately 864 MW to be self-sufficiant and meet the national demand. However, that amount is considerable smaller than what is necessary to serve the needs of the population (see Figure 14 below) (USAID, 2016). In contrast to the nine billion MW that the LFG can generate,

which is a significant difference.

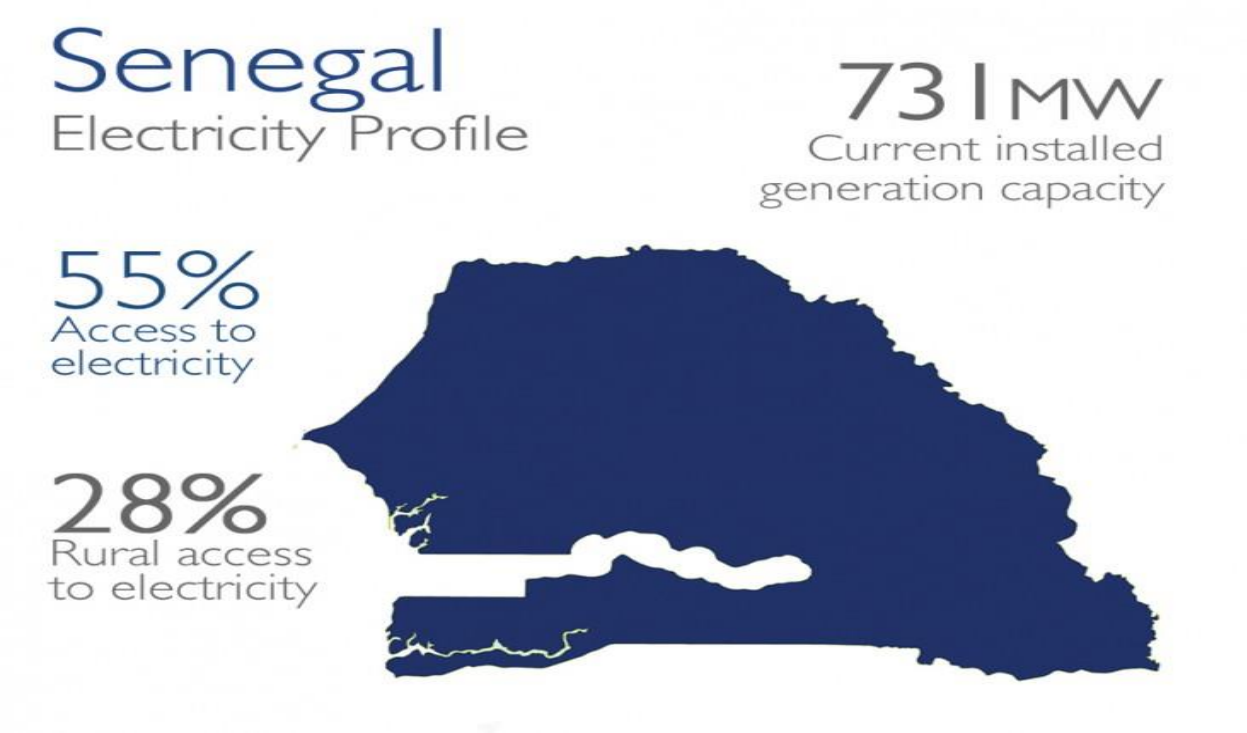

Figure 14: Senegal's Electrical Energy Productivity and Access Profile

Source: https://www.usaid.gov/powerafrica/senegal

Plan Senegal Emergert: strong emphasis on clean and green energy

The Senegalese government has come to the realization that in order to attain development and economic growth, there has to be a switch from the dependency on imported fossil fuels to clean, green and renewable energy sources. The Plan Senegal Emergent, a vision that President Macky Sall began to think about soon after his election, has sustainability at its core (Plan Senegal Emergent, 2014). The economic roadmap has a budget of about 9700 billion francs CFA and it is heavily grounded in the development of the six following axes– each of which has been allocated a budget and has been ranked per its importance.

1. Infrastrucutre and transport services (621 billion CFA)

2. Energy (304 billion CFA)

3. Agriculture (261.8 billion CFA)

4. Education and training (257.3 billion CFA)

5. Drinking water and sanitation (251.6 billion CFA)

6. Health (124.6 billion CFA)

Source: Ministry of Economy, Finance and Planning, 2014

Two things are worth mentioning when it comes to the choice of the priority each item has on the list. The energy sector has been ranked second on the agenda and allocated a signifcant portion of the funding. This indicates the importance it has for the country: sustainable development in any shape or form cannot be reached without a significant shift in the way energy is produced. It also conveys the message that the Senegalese government has the firm intention to follow through and say true to all the committments made during the COP21 (Department of Economy, Finances and Planning, 2014). The objectives completely feed into each other and, like a ripple effect, have profound positive repercussions on each other. Transitioning from fossil fuels to clean energy sources will not only be able to solve the everlasting problem of electricity production and access, but it will also create steady and good-paying jobs and create a better and healthier environment for all. In addition, through educational programs added in the national curriculu, it will raise awareness, thus allowing the country to address the issue from a bottom-up approach (education is where it needs to happen).

As of August 9, 2017, the Senegalese government and the World Bank have signed a 60 million dollar partnership agreement to effectively and effectiently transition Mbeubeuss from an ecological catastrophe to a ‘green lung’. The goals of the partnership are to structurize

Mbeubeuss by delocalizing the landfill, find integrated solutions to address the environemental and economic issues that are related to it. Most importantly, it is also imperative to find socio-economic solutions to palliate to the 2000 informal workers who make a living by salvaging the material and reselling it.

Chapter 7: Conclusion

Landfills--whether they are sanitary or even open dumps--represent an incredile source of energy wealth if exploited to their full potential. To effectively implement a landfill-to-energy project at the Mbeubeuss dump in Senegal requires that several mechanism occur organically and simultaneously. First of all, the population must be educated about waste; a significant shift in the relationship between the population and waste needs to take place. In other words, people need to stop viewing waste as useless, dirty and smelly and instead see it as a "gold mine" with all the environmental, economic and social benefits it can bring into a community. As part of that education, municipalities and the Senegalese government must implement recycling and composting programs in the national curriulum, to engage students in the establishing healthy and sustainable habits.

The second step would be to restructure Mbeubeuss; not necessarily transform it with the latest state-of-the-art equipment, but rather to make use of what is already out there and make improvements, changes that will accomodate not only the workers but also the populations living nearby. A business partner would gradually start constructing the facilities and equipment for the landfill-to-energy operation. To ensure that funds stay within the country and have positive impacts on the local economy, preference would be given to companies using local manufacturing and with local employees. The partner could provide or arrange for training for those living near the site.

The World Bank has already committed to financing 60 million dollars to work on the project. However, Senegalese businessmen should also invest in the project so as to decrease the loan from the bank, to show their support for energy production from waste, and to boost the local economy.

In the end, by implementing this project at Mbeubeuss, Senegal could become the pioneer and

leader in West Africa in an effective management of MSW and LFG project. It will be able to support and meet the demand of the growing population and perhaps in the future could sell electricity generated to its neighbors (Gambia, Mali, Mauritania).

As journalist Rose George beautifully stated: "waste is a resource we are wasting". With LFG being implemented at Mbeubeuss, this a chance to change things around and for Senegal to write a new page in its environmental stewardship book.

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