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PERSPECTIVES OF PROJECT ENGINEERING IN THE DISPOSAL OF SOLID WASTE IN COLOMBIA AND POSSIBILITIES OF ENERGY USE AND VALUATION

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Abstract:
An analysis is made of the importance of engineering and conceptual analysis for the study of waste treatment and management alternatives. A review of the history of waste disposal in the Valley of Aburrá region of Colombia, allows to discuss the and problems of application of the project engineering and the lessons learned. Proposals are made as a contribution to the potential use of waste to energy methods of waste managing for the region and the country as a sustainable and effective tool for the management of solid waste.

Keywords: WTE; Solid Waste; Planning; History; Engineering; Cost-Benefit.

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1. Introduction

With almost 47 million people (2018), the population of Colombia concentrates mainly on the highlands of the Andes and on the Caribbean coast, with 31 cities of more than 200,000 inhabitants and 65 with more than 100,000. Bogotá, the capital is a city of 8.2 million; Medellín and Cali are 2.5 million cities and there are 10 other cities with more than 500,000 inhabitants. Colombia is now one of the most urbanized countries in the region, Latin America, with an estimated urban population of 76%.

The average national unemployment rate in 2017 was 9.4%, but informality is a big problem. The per capita gross domestic product in 2017 was US $6,472. As in other countries with high levels of poverty, these conditions are associated with informal waste recycling practices. In most large cities, there are landfill systems relatively well organized, so that informal recyclers cannot enter them to recover materials from the waste being discharged from trucks. But in some other less populated cities, this still happens. About 20 people per 10,000 inhabitants work in Colombia in recycling activities, 3.9 of them organized in collective groups; 5.7 as operators separation schemes. According to a study by the OPS (Organización Panamericana de la Salud, Panamerican Health Organization), (Tello et al, 2010), Colombia generates waste at a rate slightly lower than the average in Latin America. Considering an average generation of 0.54 kg/day per inhabitant, it can be estimated that the total is about 26,000 tons per day of waste.

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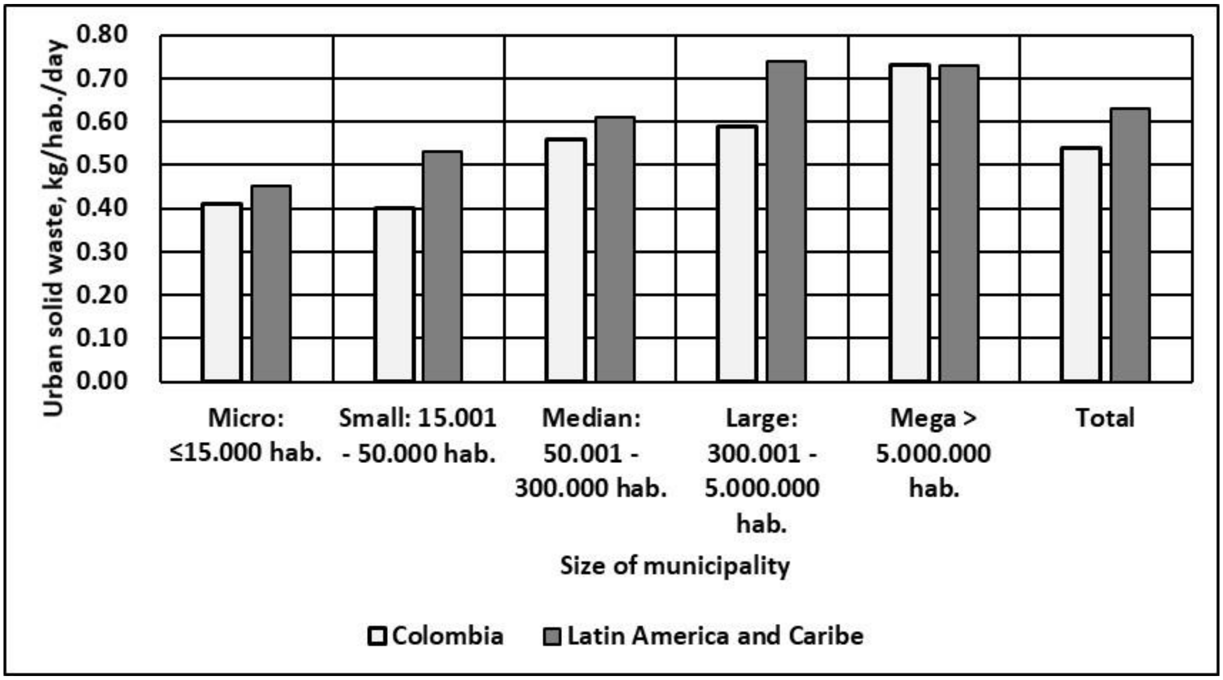

Figure 1: Daily per capita urban solid waste generation in Colombia and Latin America-Caribe countries according to size of municipality

Colombia has a very complete waste collection system, with coverage close to100% of the total generated according to this study. This figure, however, it is not completely real, as there are many instances in which people still throw solid waste to streams and rivers, or on the road sides or on uncontrolled terrain.

To achieve high separation rates at the source, especially in households, accompanied by the selective collection of separate materials, it is necessary to create a market demand and a will on the part of people and entities that allow to pay the additional costs that these good practices imply. This, in some way, has to do with the need to increase the fees that users must pay for collection services, which right now can be considered as very low, in such a way that there is no incentive to rationalize the production of waste, nor do they facilitate the investments in treatment systems. But as the OPS study correctly explains, there is the need for clear public leadership and a greater spirit of community engagement and involvement, backed by appropriate educational campaigns to stimulate the three R's (reduction, reuse and recycling).

Although organic matter represents a very high percentage of the solid waste in Colombia, composting practices for the treatment of this fraction have not been yet developed in proportion to the amounts generated and it can be said that are almost non-existent, although there are some good initiatives undertook by pioneering companies and communities in this field.

In Colombia, recycling has been in practice for years and employs about 100,000 people, with about 30% associated in128 cooperatives. There is even a National Recycling Association (NRA), while the rest of the recyclers works independently and probably informally. Colombia it is the Latin American country with the highest number of recyclers per capita. The relative progress in the organization of these people has been favored by the existence in the country of a regulatory

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framework, that recognizes them as actors with the capacity to assume legal and institutional commitments. Colombia is a model in the region in the recycling of paper and paperboard, with a recovery rate of 57%. This has to do with the existence of industrial plants capable of using these materials in their process, which has favored a well-organized recycling scheme.

Currently in the country (Min Ambiente, 2016), the recycling rate of waste such as paper, cardboard, glass, metals and plastics is 17%, and for 2018 the objective will be to achieve a recycling goal of 20%. The remainder of the waste is destined to landfills or sanitary fillings, as there are no waste to energy (WTE) or similar treatment facilities in the country. According to the OPS report, 81.8% of unrecycled waste goes to landfills. Out of these facilities, very few ones have leachate treatment plants or burning systems for the methane being generated. Required land for these disposition systems is becoming a growing problem and, in this sense, environmental concerns are becoming more important. Also, the available land is located at distances far away from populated centers. They are often located in areas of high rainfall and hilly and complex geology, crossed by streams and ravines.

The country could use WTE (waste to energy) systems as an effective means of preventing waste from being carried over to landfill systems. In this sense, it is worth learning from the experience of many countries, not only in the most developed regions (Europe, Japan, United States), but also in countries like China and India. WTE projects should be considered as a valid alternative. To contribute in this sense, it is important to conceive integral protocols for the evaluation of the costs and benefits for the alternatives being considered when planning solid waste treatment systems. This, to appreciate and take into consideration the great advantages of these systems, based in the environmental benefits they have, as compared to the preferred systems in Colombia, which are landfills. It is very possible that environmental authorities will be verycautious when considering large WTE systems, given the lack of local experience with them and the bad fame incineration has. However, these systems are not simple incinerators, but very complete and sophisticated mass burning systems with associated emission control equipment and subjected to strict regulations. There is enough and growing experience around the world which indicates that they work very well from an environmental point of view, to the extent that the necessary measures are considered. This can be seen consulting the documentation of WTERT (Waste to energy research and technology, earth science, Columbia University), available freely online (Themelis et al, 2016), which has been specifically prepared to analyze the case of the application of WTE systems to Latin America and has been developed with the sponsorship of the BID (Inter-American Development Bank).

2. The Importance of Engineering in the Study of Alternatives for waste Treatment and Management. Historical Errors and Lessons to be Learned

The establishment of waste-treatment systems implies significant investments and should be carefully examined, with enough time and resources to study the alternatives. Although the city of Medellin and its metropolitan region of the Valle de Aburrá have a very good tradition of public policy and planning, with long-term vision and very professional and powerful organizations that have implemented projects of high community impact in the provision of their public services, a review of the history of solid waste treatment in the region shows that the decisions that have been made in the past have failed to take into account sufficiently comprehensive visions to achieve

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sustainability and the best possible outcomes. Fortunately, there has been enough resilience and leadership to provide the services that the community requires, within the constraints that permitted collecting fees rates and available resources allow, and this shows that the corresponding public service entities and the municipal authorities have acted in a constant and effective manner. But this must not obscure the difficulties that have been experienced, the costs incurred and the investments that have been lost. It is important to establish, for future developments, processes that fully consider all engineering stages, especially those related to the analysis of alternatives and conceptual engineering, but without leaving aside the basic, detailed and execution engineering stages. All of this applies also to the whole of Colombia.

A recount of what has happened in the recent history of the disposal of solid waste in Medellín and the region of the Aburrá Valley will be described.

Let the River Take Away the Waste

This was the preferred strategy until well into the second half of the 20th century. Taking advantage of the Medellín River, which has a relatively high and stable flow and fast currents, it was considered for years that urban waste could be dumped into the river. Fortunately, this practice was suspended in the decade of the years 70s. But this was done in a reactive way, when it was evident that these things could not be done, without having at the time a clear analysis of alternative and sustainable routes to dispose of waste (AMVA, 2006). The municipality was suddenly confronted with the need of getting a waste disposal site, at higher costs, requiring more personnel and additional equipment to handle waste.

It seems that this method of disposition should not even be mentioned, because in appearance it is a thing of a past, that should be forgotten. However, there is still a propensity for some people belonging to the communities located on the banks of the abundant streams that come down from the mountains of the Aburrá Valley, to throw all kinds of rubbish to them. This is evident when walking along around them and it is painfully experienced in a recurrent way, when the channelized streams are clogged in times of rain, giving rise to damage and flooding. (Ortiz, 2018), (Loaiza,2016), (Universidad Nacional, 2018), (Concejo de Medellin, 2008). For example, according to the Medellín environment authorities, in 2018, they intervened 32 points in the streams, extracting 1,130 cubic meters of rubble and sediments and 78 tons of rubbish. This despite the fact that the city sanitary services entity, Emvarias, provides an excellent collection and transportation service for all types of solid waste in residential and non-residential sectors of the city and despite the fact that there is a friend line to call and ask for the collection of old furniture, appliances and mattresses and that there is a system of onerous fines for throwing waste into public and stream spaces. This is a problem that is evidenced in many parts of the country and that eventually leads to the pollution of great rivers and the coasts.

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Figure 2: Collage of photographs showing that there is still the custom of throwing solid waste to the water streams and the river itself at Medellín (taken from El Colombiano city daily newspaper)

Here the lesson learned is that it is not enough to have sophisticated collection systems and to have coercive tools and norms. It is very important to develop educational and cultural activities, but it is also necessary to have very effective presence, surveillance and monitoring systems. On the other hand, the region does not yet have waste collection systems, based on appropriate containers located in designated locations in different streets and urban areas, being the usual method for people to place garbage in plastic bags that are placed on the street sides, waiting for the passing of the collecting trucks. In this way, the population still has the daily image of accumulations of rubbish in different places, including the shores of streams and ravines. Another aspect to improve is to have separate waste collection systems at the source, which would be a great cultural stimulus to create management discipline.

Improvising on Open Land as Waste Disposal Site

From 1977 on, the urban waste stopped being dropped into the river and began to be deposited in a depressed terrain located in a sector known as Moravia, quite close to the city central zone. This was an emergency decision, although with the goal of building a proper landfill site. However, the necessary steps to achieve this were not followed. What was done was simply to throw waste without much control, whereupon the site became a dark lunar of the city and a source of air and water pollution, since the dump generated visible fumes and particulate matter emissions, which affected even the campus of the main local university, situated in its vicinity. Very soon, a waste mountain was formed, with the daily 500 tons of waste, which reached 40 meters in height. A huge social problem originated also, as a sizable number of persons and their families settled on the site or nearby, to derive their livelihood from what they could salvage from waste. When the city saw its international image deteriorating after appearing in a photographic report in The National Geographic, there was, again, the urgent need to change things.

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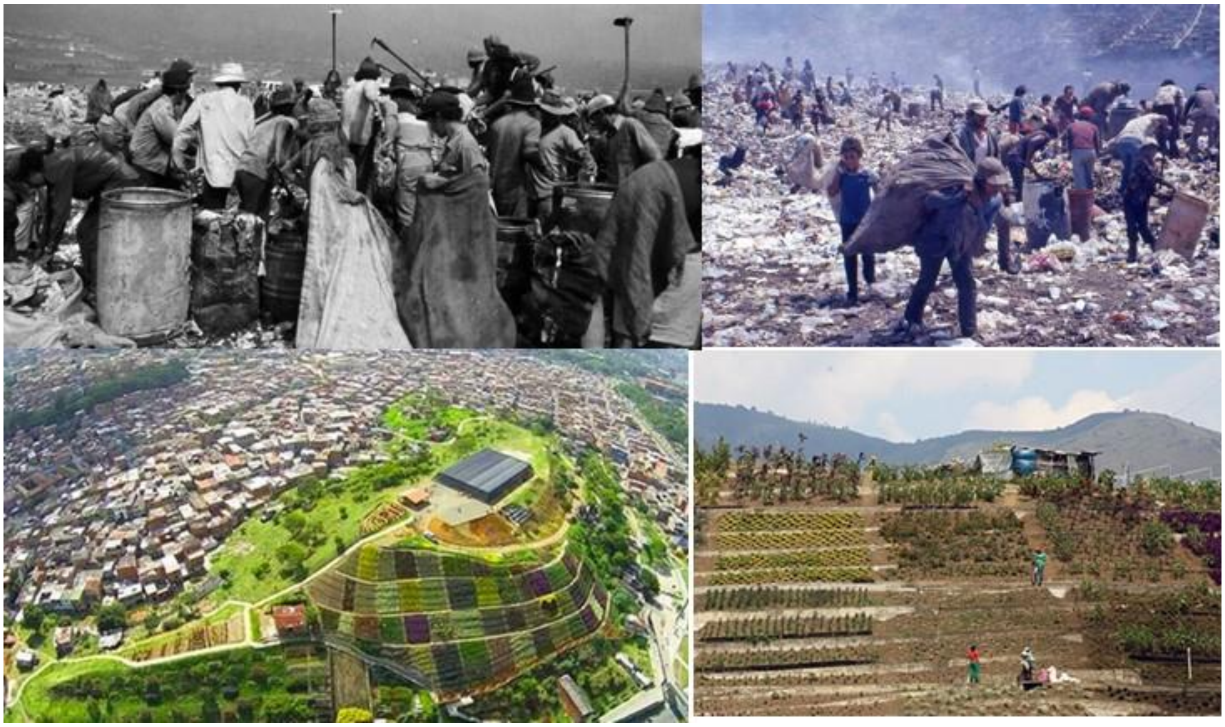

Figure 3: Collage of photographs showing the old Moravia dumping site, before 1978 (top) and the transformation achieved (taken from Viviren el Poblado newspaper)

Still today, 20 years later, some informal settlements remain in the artificial mountain of Moravia, although the place has been largely converted into an urban garden of novel design, for which they have had to do works to collect leachates and to manage biogas emissions. Neighboring areas, which are flat and potentially valuable, lost value and became informal settlements, their inhabitants in general working in recycling activities and where the authorities have developed many actions for social inclusion and urban renewal, with still much to be done. Undoubtedly, the improvised actions that were undertaken have been very costly from the social, economic and the environmental point of views. Here, of course, the lessons learned have to do with the need to act in a planned, holistic way, which considers social, environmental and economic aspects at the time of adopting a solution. It is necessary to have a project with schedules, resources, activities, analysis of impacts and other aspects, for which it is essential to have complete engineering. Cities should be able to respond to the urgency, without improvisation, in such a way that the problems do not accumulate and get to become complex situations very difficult to solve.

Use of Turnkey Solutions That Did Not Work

A common form in our midst to undertake civic projects, is to rely on some novel technology as a definitive solution to the problems, selecting, with some criterion, turnkey solutions, implemented directly by their suppliers, without the local development of previous engineering stages or designs, or activities that allow to open and understand locally the so-called "technological package". In these solutions, the supplier assumes total responsibility, including delivery of the systems in full and verified operation. These are very attractive solutions, since they can be executed in relatively short times, without the need for detailed previous studies or engineering developments. In principle, the client avoids studies and engineering, perhaps assuming higher investments. It is assumed that the technology supplier knows very well the situations for which it

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is delivering solutions, since it has demonstrable experiences of successful application of its technologies. The client can produce bidding documents, stating the requirements and the desirable conditions for the project, indicate quotation deadlines and proceed to adjudicate the work to the best of the proposals.

However, this idealized situation can fail due to different aspects:

- To select a provider who does not really have the experience, compared to others who do, but are more expensive.
- To select a provider based on criteria not always adequate and generally non-technical, such as offering less expensive offers; or apparently assuming all the investments; or promising short project times. In other cases, choosing proposals that do not include in the offer all the aspects that the competition offers and that could be essential for the good functioning of the project, or that offers less reliable guarantees. Also, accepting special commercial advantages that are not really reflected in the quality of the supply.
- To select a supplier under conditions of turnkey supply, under which the provider assumes responsibility for supplying the project in operation but does not offer to deliver any customer-supervised engineering documents and designs. Them, once the contract is signed and the work assumed by the supplier, the client starts imposing demands on the different components, during the development of the project, which result in the supplier having to elaborate designs, parts certifications and detailed studies for which he had not committed himself or for which he had not planned to make deliveries. This leads to over-costs and delays, more work, possible legal demands and postponements.

When the negative experiences with the Moravia open dump were being experienced, the city decided to deal properly with solid waste management, in ways that would avoid taking the waste to a landfill, based on the idea that all the waste could be separated, recovering materials and taking value added from them. This idea, which seems very attractive, was not the result of experiences, essays, prior knowledge, or an engineering project. What was done was to acquire a ready-made recycling plant, actually quite sophisticated, which was bought, turnkey, in Spain. This plant had several transporting bands to receive the waste, served by initial manual separation operations. After this, the materials were mechanically manipulated by means of transport equipment and mechanical and pneumatic separation, to recover plastics, papers and paperboards, metals, glass, and others, probably non-useful and disposable, leaving at the end an organic fraction, with which compost was generated. The plant was installed and started. However, after some running time, production was stopped, and the plant was abandoned and dismantled, apparently because it did not give the yields or the expected qualities. The generated compost presented smells and the presence of pieces of glass and other waste and was not marketable or acceptable to potential consumers, according to the analysis carried out by the official entity (AMVA, 2006).Then, it turned out to be a turnkey project that became technologically frustrating, probably generating economic and legal costs and losses, either for the city or for the unfortunate supplier.

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Figure 4: Collage of photographs showing aspects of the failed separation and recovery plant installed at El Guacal landfill site, now closed, (taken from a study done by the author)

It seems that these failed experiences of separation of mixed urban waste were no properly learned. Surprisingly, after this, in the country and in the region several plants have been installed under similar concepts, although somewhat simpler and more based on manual operations. They have been installed in landfills to separate the waste, recover useful materials and produce compost, trying to diminish the load to be deposited in the landfills, under the concept of the so-called Environmental Parks. At least two plants of this type that were installed in the Aburrá Valley did not function properly, despite the attempts made by the contractors which developed the respective projects.

As lessons learned, there would be a need to conceptualize the problems very well before proceeding to set up turnkey solutions. It seems obvious that the situations were not sufficiently modelled, both by the supplier and the client. The expected products were not well specified with the contracted supply, nor was there a clear idea of the operating costs that would result or the resulting qualities. It seems that there was no evidence or experience of functioning of this type of plant to treat waste like those existing in the city. In this sense, of course, it must be emphasized the importance of having previous experiences, at least of a pilot nature, that allow to examine the products generated and the nature of the costs and the operation, when such large projects are undertaken, and consider fully operational risks.

Another aspect to consider in turnkey projects, it is related to the guarantees and to the efforts that are required, in many cases, to stabilize the processes and to take them to their optimal operational points, through process adjustments, operational methods, training of people, adjustments in input materials and manipulation of components. It is very possible that these learning and adjustments, which would have saved the plant, either to adapt it, to take it to reasonable points of operation, had not been possible for legal reasons, for economic limitations, for expiration of the terms of the contract; or even for discouragement and lack of persistence of the responsible entity.

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The Expectations and Realities of a Landfill as A Unique Solution

With the poor experiences of the Moravia dump and of the failed waste recovery plant, the city decided to confront its urban solid waste problem, in a more rational way, at least within the existing information and available resources. For it (AMVA, 2006), between 1978 and 1980, the Federal School of Lausanne, Switzerland, advised the region to conduct a study on solid waste and its final disposition for the city of Medellín and its metropolitan area. With this base, the definitive designs of a new system, called the Curva de Rodassanitary landfill, were made by a local engineering firm, the "Compañía Colombia de Consultores", with the advice of "Greeley and Hansen" of Chicago, USA and the audit of the Centre for Environmental Research at the University of Antioquia. Three alternatives were reviewed in the studies: Incineration, composting and landfill.

Incineration was rejected given the high percentage of humidity of the urban waste and the topographical characteristics of the city of Medellin, which were considered too critical to handle the resulting atmospheric pollution. Also, because it did not allow for the recovery of the by-products, leaving at the end of the process a residue that will have to be disposed in a sanitary landfill. Composting was rejected due to the negative experiences of the failed plant and for the high costs associated with the treatment. It was concluded that the recommended choice was a sanitary landfill, as the more economical, the most adequate form the health and sanitary point of view and with the less risk of contamination.

After analyzing seven sites in the Aburrá Valley, the Curva de Rodas was selected as it offered greater advantages and was the least expensive alternative, counting with available materials for coverage, larger capacity and a longer useful life. In retrospect that decision led the region in different directions to those that have been chosen in many other places in the world, based in reasons considered valid at that time, but that were somewhat questionable when examined with a broader perspective.

In this sense, incineration can be adopted as part of a system of energy production, based on materials of higher calorific value or as part of a co-combustion plant, for which costs, observed from an integral point of view way and taking into account externalities, are competitive with those of a sanitary landfill. Incineration, in fact, should be considered as a system of energy production (WTE) equipped with the corresponding emission control systems that avoid polluting discharges and it does not have to be risky in this sense even in the valley of Aburrá. Landfills, on the other hand, generate greenhouse gases that need to be controlled, something that was not considered in the initial design of the Curva de Rodas landfill. The emissions of greenhouse gases equivalent in a landfill are greater than those existing in a comprehensive treatment system that includes WTE systems, selected recycling and composting. Although ash is generated when incinerating, which must be disposed of, this happens in proportion much lower than the ones to be disposed with the original waste in the landfill. WTE systems would contribute to the region energy basket and enable technological development and employment generation, giving rise to notable fuel savings in the transport of waste, and preventing large extensions of valuable land from being used to dispose of waste. Furthermore, WTE methods avoid the high generation of leachate contamination, and therefore the need for an expensive treatment plant, which was also not taken into account when conceiving the landfill project.

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Discarding composting systems based on the local failed experiences, does not consider the many other successful experiences that already existed in the world at that time and the possibilities of working culturally and educationally to improve the separation in the source, recycle and pre-separate the glass (as actually occurred) and treat the organic fraction properly separated. Additionally, there was an opportunity to deepen the experiences, making a diagnosis and an analysis of the real causes of the difficulties that were encountered.

This sanitary landfill, which was a pioneer of its kind in Colombia, become an important project that allowed to develop much technology, a site to be visited, an object of research, a source of valuable experiences. It generated different learned lessons, many resulting from its operational difficulties. In the operative practice several events and needs appeared which helped to perfect the capacity of responsible bodies for the management of landfills, such as ways to manage relationships with communities, including the design and implementation of contingency plans and risk management; establishment of programs and compensation plans with nearby communities, to allocate and manage resources for employment generation, organization of cooperatives and associated forms of work, educational, cultural, recreational, sporting and ecological programs. The need was recognized to have some kind of leachate treatment and to understand the complexities that this has. Also, the need of having specialized equipment, weighing systems and system to register and have statistics of trucks and operations. The need of having an ecological reserve zone in the vicinity of the landfill; of having ways of handling existing water currents in the landfill area; of having well-designed gas collection and treatment systems and a comprehensive plan for environmental management, continuously perfected as the project is developed, including monitoring and registering environmental variables; the need to manage pests and birds; the need to develop capabilities to prolong the life of the landfill and maximize operative capabilities and waste accumulation and the importance proper procedures and activities, for the closing and operation of the site after the end of its operation.

Figure 5: Curva de Rodas landfill in its final stages of use and after closure (taken from a report from EMVARIAS)

Many of these things had not been taken into account when approving the project, and they were certainly given and still give rise to significant costs and investments that had not been considered. It is clear that in every sanitary landfill program there are a lot of externalities that should be considered in the analysis of alternatives and at the time of comparing with systems like those of WTE. As the Sanitary responsible authority points out (Loaiza, 2012), eventually the 40 hectares

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of the site could become, partly, a great natural park. This implies important resources to be allocated, that apparently have not yet been established.

Insistence on Landfills. La Pradera Site: From Environmental Park to A High Specification Landfill

Once again, the responsible entity was subjected to emergencies and short deadlines when the useful life for the Curva de Rodas site was reached and the waste flows and the municipalities attended were increased. The need for a new site was considered. This was no easy task: there was opposition from communities and reactions coming from several concerned organizations. After the corresponding environmental assessments, submitted to CORANTIOQUIA, the environmental authority assigned to the chosen site, a batch landfill system was selected on La Pradera, in the municipality of Donmatías, about 60 km away from Medellín. The project was awarded its environmental license in July 2003. At the time, EMPRESAS VARIAS of Medellín E.S.P. the state body in charge of waste, undertook actions aimed at the incorporation of new alternatives of solution in addition to the simple landfilling, supported on a study called SIAM5 (Geographic information system of the integrated waste handling and treatment service for Medellin and other five townships), (AMVA, 2006).

The sanitary landfill in La Praderacame into operation in June 2003. There the solid wastes of Medellín and the metropolitan area of the Valley of Aburrá and some other neighboring towns, with a total of about 1,800 tons/day (augmented with the 700 that attended the filling of the Guacal) are received. This project contemplates the possibility of solutions for the future in the integral management of solid waste, since it has a large land area, 354 hectares, with several natural ravines that can be converted in final disposal sites. It should be noted that this project, despite the foregoing, began and was approved as a contingency environmental measure in 2002, for a period of up to 30 months, as an urgent response to the need for an immediately closure of the Curva de Rodaa site. Eventually a petition to change this was approved and the environmental license was conceded for a time related to the filling up of its capacity. It is necessary to point out that this was achieved because the project was presented under the concept of Environmental Park. This concept involved a treatment of waste once discharged in the area, taking it through a conveyor belt, where it was expected to manually separate the useful materials (plastics, glass, metals, paper, cardboard) and a system of compost piles and homogenization of composting material to generate a product for agriculture. This system began to be operated with great optimism and expectations, but after a certain time, it was entirely eliminated, probably because of operation cost problems, the generation of uncontrolled leaching in compost piles (augmented by the difficulties with the very rainy climate of the region) and problems with the marketing of the recovered products. The project was then converted into a traditional sanitary landfill, in which design and operation the various lessons learned in Curva de Rodas were surely taken advantage of. However, there were great difficulties with the leachates, since La Pradera is a very rainy zone, something that should always be avoided when conceiving a sanitary landfill, because the rainwater will contribute to increase the leaching flows and the entrainment of pollutants. For this a very simple treatment was conceived, by means of simple retention lagoons. Eventually the environmental authority asked for a true leachate treatment. After many years, in 2015, a sophisticated system for this was installed, which includes a microfiltration process. The investment in the plant was 24 000million pesos. It has a capacity of 12 liters per second in the primary stage and four liters per second in

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advanced treatment based in ultrafiltration membrane systems. This second stage was recently augmented to 8 l/s (Álvarez, 2015).

Another issue that has been the subject of complications is the treatment of the gases generated in the landfill. For several years the site was able to sell carbon credits based on a system that collected the gases and burned them, with its operation in charge of a third party, and was profitable. But in 2015 such system was suspended because of the fall in international prices of carbon credits. In view of the foregoing, the EPM (EmpresasPúblicas de Medellín) group that absorbed the Emvarias entity that operated the landfill, initiated a process to evaluate how the operation of the capture and burn system can be restarted in a sustainable manner. It will continue with the evaluation of the viability of the use of the biogas, either for the generation of electrical energy, heat or improvement of biogas to take it to the natural gas network (EPM, 2015).

It is observed that despite the previous experiences, considerable difficulties, unexpected costs and additional investments were experienced in the new La Pradera Project. These can be considered as new externalities, which must be part of any analysis of alternatives. Additional lessons are to be learned, such as the following.

Sanitary landfills should not be placed in such rainy areas as La Praderasite, as these circumstances complicate the design, difficult the operation, increase the required investments, and give rise to greater size, greater complexity and higher operating costs of the leachate treatment plant. Leachate treatments are complex and costly and involve high-level technologies and sophistication in their operation. Biogas utilization technologies must be included within the project's investments and costs. Any design and operation of systems of conditioning, recovery, separation, classification and composting that is placed in a landfill, trying to take advantage of the waste that arrives mixed, involves very sophisticated systems, previous experience, pilot tests, investments and additional costs that could not be recovered, in general, with the sales of the resulting products.

Figure 6: La Pradera landfill site showing a vase being filled and another vase after closure (up) and the lixiviate treatment plant (down) (photos taken by the author)

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It is worth supplementing the operation of the landfill with many actions of prevention, separation at the source, recycling, education. There is a risk of conceiving the landfill as a guaranteed receiving place that disguises the cultural and waste problems of a society and makes it to avoid taking the far-reaching actions, the complementary and alternative systems, and the integral vision this requires, giving the relative comfort the landfill offers as a waste treatment method as long as the operation lasts.

New Insistence on Landfills. El Guacal: From Environmental Park to Closed Sanitary Landfill

Despite the experiences already accumulated, the region insisted on establishing another large sanitary landfill, proposing again a project under the concept of Environmental Park that had already been put into place without success in La Pradera, with a recycling system installed to treat wastes that reached the landfill. This was done in the El Guacal site, located on the crest of the mountains of the south west of the Aburrá Valley. Although these were modern facilities, equipped with important pieces of equipment, which included systems to stow and compact the treated waste after entering the landfill; Sadly, after several intents and essays and operating this separating and treating systems for several years, success was not achieved and on the site treatment tasks were suspended, whereupon El Guacal became a traditional sanitary landfill. This had a leachate treatment plant that operated irregularly at least in its beginnings, which was finally improved and stabilized after several studies and working experiments. This sanitary landfill was launched on the initiative of the Municipality of Envigado since 2005 and during its best years of operation came to handle 700 tons per day of waste generated by 26different municipalities, some of them quite fat from the site. However, it never managed to achieve the desirable levels of profitability that could ensure its sustainability, so that this business of disposal of solid waste has not meant profitability or economic attractiveness for the owners of the project. Contributed to this situation the complexity of the chosen site and different operation troubles, with many contingencies and difficulties; The management of environmental permits was especially complex, as the environmental authority was very demanding in the depth and extent of the studies required to renew the license, once the initial permit was suspended as the commitments to operate the site as an environmental park were not fulfilled And there were also difficulties related to the treatment of leachates.

A major problem with landfills, which was particularly serious in this case, is the transport of waste over long distances, including its passage through urban areas. This happened here, because the vehicles had to cross the urban area of an important town, passing through narrow streets, generating a lot of social rejection. At first it was anticipated to build an alternate road that did not cross the town, but this was never done

Finally, after 10 years of operation, the environmental authority denied the permission to extend the capacity. The landfill is not receiving waste, although, naturally, it requires management, surveillance and environmental conservation, which will imply significant costs and responsibilities for a significant number of years (Álvarez, 2016).

As lessons learned, it could be highlighted that every company, to be sustainable must generate surplus as a result of its activity. If that is not the case, a sponsor will be required to sustain the operations and cover the deficits that are generated. If this is not the case, there is a risk that there

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will be no capacity to respond to contingencies and to accumulate reserves for future operations, when the site does not generate revenue, but continue to require attention. A landfill must be operated for years, and closed adequately and have enough resources for improvements, innovations and new developments. It is important to operate normally without being overwhelmed by budgetary constraints. This was not the case here.

When commitments are made with the environmental authorities, they must be assumed with full responsibility, knowledge and capacity to meet the requirements. Often the authorities impose very severe conditions, and even, of impossible fulfillment, which result from the recommendations that are made in the studies of environmental impact by those who prepare them the studies or from the response that the authorities give to such studies and recommendations. It could be that the responsible site owner or operator that receives the permission just believe they are easy to comply, with no major thinking given on capacities and limitations to follow them, feeling relief and satisfaction once the permissions are conceded. When operations begin, it may turn out that the site is unable to meet all the requirements, which may result in fines, closures of operations, surcharges and disputes. In addition, it is essential to consider everything that has to do with the affected communities.

A Waste Valorization Project That Came Close to Be a Reality but Did Not Happen

It cannot be said that the region has not tried, in a variety of ways, to approach the issue of solid waste. As it has been described, various circumstances have occurred, and projects have been developed that did not have all the desirable success. The municipality of Medellín executed between 2008 and 2009 the design of a well-conceived project to dignify the recycling tasks of the communities of recyclers in the Moravia area, through the start-up of a set of small plants, placed in parallel, in a beautiful facility which were conceived to be profitable, The idea was to give added value to various waste (selected plastics, glass, metals and paper). This project, called the Moravia Transformation and Recycling Industrial Park, was presented in 2009 in its conceptual design phases (very much based on architectural designs) and on basic engineering concepts. This initial pre-feasibility study indicated estimated required investments of 20,000 million colombian pesos and with this base the project was approved; but after this, a deeper conceptual engineering found necessary investments between col 36000 and col 55,000 million pesos, according to the alternatives to be selected. All of this, for a projected production of 1,500 tons per month. It was found that the project was sustainable in terms of its operating costs. Unfortunately, a budget was earmarked for the very optimistic project, based on the initial conceptual estimates, of around 20,000 million col. $. So, when the project was refined, in greater detail, in the conceptual engineering and it was found that the necessary investments were rather larger, the project was suspended, due to lack of resources and it has not been proposed again (Rentería, 2010).

As lessons learned, it is concluded that it is important to approve the projects and allocate assignments only when you have a clear picture, at least, at the conceptual engineering stage, Taking care to consider additional reserves sufficient for contingencies; And, hopefully, define the actual budget when you have the basic engineering, leaving still a margin of 10% for the changes that appear in detail engineering.

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It is important to have a long or at least medium-term vision with these projects, so that they are carried out, without depending on both the administrations of shift and the immediate budgetary validity. Here a notable effort was made to communicate with the communities that were going to benefit, and in that case, it must be ensured by the real start-up of the projects.

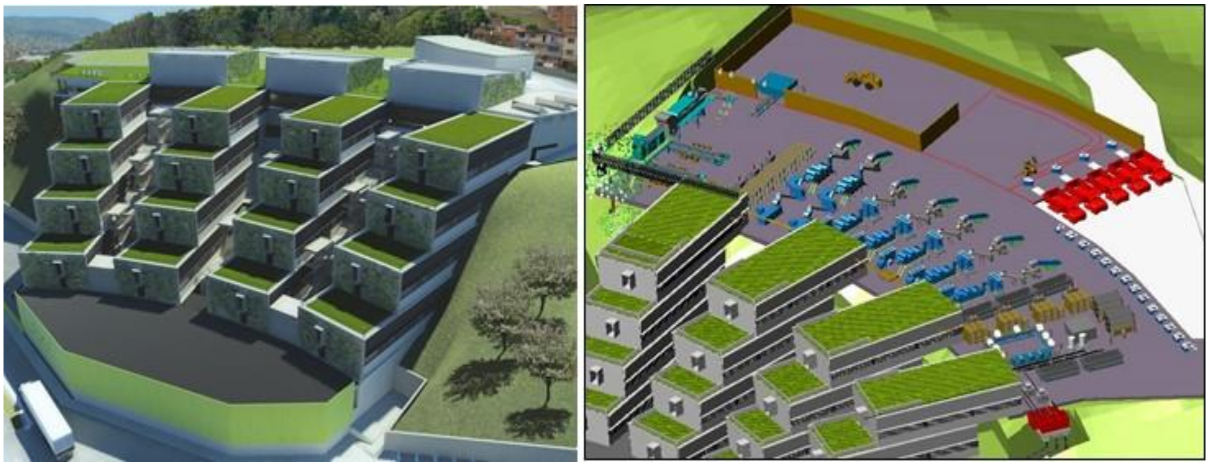

Figure 7: Planned recycling plant. Initial and proposed draft after more refined conceptual engineering

3. The Need for High Quality and Complete Engineering

One of the reasons that have led the region to focus on the solutions that have been detailed in the presented historical review, is that, apparently some of the proposed solution did not require complete engineering designs, or could be put into place as turnkey projects or as projects that were based in initial studies or for which engineering could be developed once the project stars as it goes on. However, the most advanced projects, such as continuous recycling schemes, the treatment of domestic organic compounds and WTE systems, require deeper approximations, more design, more knowledge. It should be considered that the country and the region have sufficient maturity, knowledge and methodological processes to begin to take on the challenges that lead to more sustainable systems than sanitary landfills.

Of course, technology has to do with all this. The country does not have a portfolio of companies that can manufacture equipment for thermal treatment systems capable of handling hundreds or thousand tons per day of mixed waste, burning them in a controlled way, generating electricity and controlling the air pollution problems related to this. So, there are no local suppliers pushing for projects or offering alternatives as EPC (Engineering Procurement Construction) installations. This mean that local responsible waste-handling entities will tend to look for solutions with external providers, unless some kind of industrial and manufacturing development could be put into place locally. This, foreseeing the important market that could surge if the 65 cities with more than 100,000 people would decide that WTE is a real option and start planning and developing these projects in the coming 20 years. It is important that concerned authorities and planners see the opportunities for job and technology creation if a strong commitment is assumed in WTE solutions. An important example is what has happened in China and India, which have developed competitive sectors in the WTE technology, able to confront their own situations and to export technology and equipment.(Annepu, 208), (Fernandez, 2018), (Mi, 2017), (Sharma, 2018).

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Engineering and design are very important components of the technology necessary to impulse WTE in a country. These systems require detailed studies and planning activities and it is advisable to do the projects taking into account all the engineering stages. There is always the temptation and the idea that the projects can be accelerated and put into place based on the experience and support of suppliers and makers, by means of EPC developments, in such a way that engineering stages can be simplified or even avoided. This normally is a much costlier and rigid solution and does not contribute to developing local technology and prosperity. In the solution of the problems, there is ample space to develop a region, as compared to relying only on external provided solutions.

The authors consider that this chapter provides a good opportunity for them to present what are the complete engineering stages that should be part of a WTE project or of any possible alternative to waste management (Posada 2010), (Posada 2012), (Posada 2017) and they will be discussed here.

The sustainable future implies facing important challenges, leading society to forms of work that ensure the balance between nature (the environment), man (society) and economics (prosperity and the ability to generate and exchange goods and wealth). Many new things will have to be designed and created, many schemes will have to be broken, since currently the desirable equilibria are not occurring, all types of threats exist (global warming, depletion of resources, misery, inequity and social injustice, wars, extinction of and impoverishment of species). Engineering, with its capacity for project development, can convert any promising idea or concept into a reality through well-known and experienced methodologies, which involve planning based on the establishment of clear objectives of the project and each of the tasks to achieve a desired goal; execution, where the development of project activities will be carried out to achieve the objective; control, with which, the project is monitored, as it progresses, within the budgeted costs and with the required quality; feedback and recurrent work, based on discipline, interdisciplinary team work, motivation and leadership, to achieve constant perfection.

It is important to point out the stages of well-done engineering. Often, companies, the state and the different entities that demand project-engineering services, pretend to save processes and stages, with the aim of lowering costs and time. However, they generate with it serious risks for the sustainability of the projects, such as excessive costs and investments and loss of profitability; severe impacts to the environment; excessive consumption of energy; excessive tensions and demands on the people involved; low generation of good quality employment and social prosperity and few opportunities to use the resources of the regions. These stages are Conceptual, Basic, Detailed, Execution, Starting-up, Auditing and Closing-up, and will be next described.

The stage of **Conceptual Engineering** is always necessary and should not be ignored. With it, the objective of the project is clarified by proposing viable solution alternatives for each of the aspects involved. The first part of conceptual engineering is the **definition of the concept**. The second part is the **analysis of alternatives**. The third part is the **selection of the alternatives** that make up the project. Then the conceptual design is developed, based on flow diagrams, mass and energy balances, essential determination of sizes and dimensions and preparation of a plant layout for the desired productive size. Calculations and estimates of energy consumption, material requirements, personnel requirements and other production costs are prepared. Polluting emissions are estimated,

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and forms of control and mitigation are established for them. Finally, budget estimates of the necessary investments are made (with approximations that are estimated at 30%) and a cost-benefit and economic feasibility analysis is presented.

The conceptual engineering permits developing a good idea of the future possibilities of the project, through the cost-benefit analysis that is reflected in the time returns of the investment and in the estimated rates of return. If a situation of negative or poor profitability appears, in principle the owners of the project should not proceed with the following stages of project engineering. Rather, it will be necessary to rethink the idea, taking into account the critical aspects that have been detected in the conceptual engineering. If this happens, the engineering company can be part of feedback processes to achieve the renewed enthusiasm of those who support the idea, since in general there will always be innovative ways to break existing limitations and find alternatives, based on new tests and explorations. The engineering work already developed allows the new alternatives to be studied more easily and it is convenient that the contacts already established between the stockholders of this process are not lost.

When the nature of the project warrants it, especially if it is noticed that there are possibilities of profitable and feasible development, it is convenient to include in the conceptual engineering a conceptual design of a pilot plant, to give stronger bases for the work developed and demonstrate various issues. One very important is to have enough production to carry out application tests and analysis of stability and reliability of the developed processes. Another is to be able to demonstrate the technology to third parties and facilitate the process of obtaining financing for future stages. When the project has been shown to be feasible, it may be submitted to the following stages of engineering. These should also apply to any possible pilot plant approved for execution.

In the stage of **basic engineering**, the goal is to obtain a very clear idea of how the project will look for the best alternative selected in conceptual engineering. To do this, descriptions, plans, diagrams, models, sketches are used. Lists of equipment, routes of networks and supplies are elaborated, and the technical and economic feasibility is refined through a greater definition of project components and closer contacts with equipment suppliers, which allows to approach investments and costs of operation with greater certainty (at this stage the approximations to investments and costs can be estimated at 15 to 20%). The most important consequence of developing this stage is the determination of technical and economic feasibility. The idea is that the next stage, detail engineering, is not to be executed for projects that are not feasible. The conceptual engineering should have a good probability of feasibility, but it is the basic engineering that should really define the project.

In the **detailed engineering stage**, the documents that allow the realization of the project with the minimum of setbacks are produced, ensuring the operational success, in accordance with the goals; this stage defines the capital assets that make up the project and everything related to detail plans for services, equipment and components, facilities and electric, instrumentation, controls and civil works. It includes aspects of industrial safety, the various human factors, the preservation of the environment and work comfort. The budget and the execution plan are refined, and the financial and temporal parameters are adjusted to high levels of precision (within 5 to 10%) that facilitate the allocation of execution resources and the control thereof.

The **execution engineering** stage has a different character. In the previous stages, everything done is of a virtual or documental nature, therefore the mistakes and the modifications made represent a small additional cost compared to what would be in this execution stage, where the correction of an error represents generally very high cost overruns (Figures8,9). Management, administration and control are vital here.

The **starting-up engineering** stage aims to prepare for the operation, verifying the agreement between the budgeted and the executed. The **auditing engineering** stage is presented as a transversal element that has to do with the various stages, especially with the detailed engineering, where the different implementations of quality control, budget, and logistics are important to ensure quality and transparency. The **closing-up-engineering** of the project, has the purpose of gathering all the documents and evidences that are necessary for the delivery of the project and finishing and commissioning it in an appropriate way.

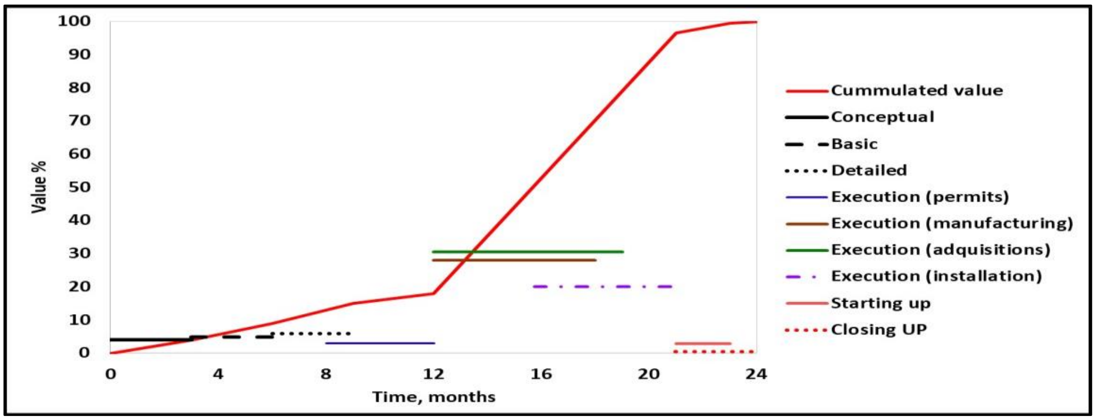

Figure 8: How potential costs behave in the different stages of project engineering (prepared by author)

In Colombia there is a good availability of engineering and consulting firms with enough capability to undertake these stages. However, frequently they are subjected to do incomplete engineering work, under very short time limits and restricted budgets. This way of working means clear risks for WTE projects.

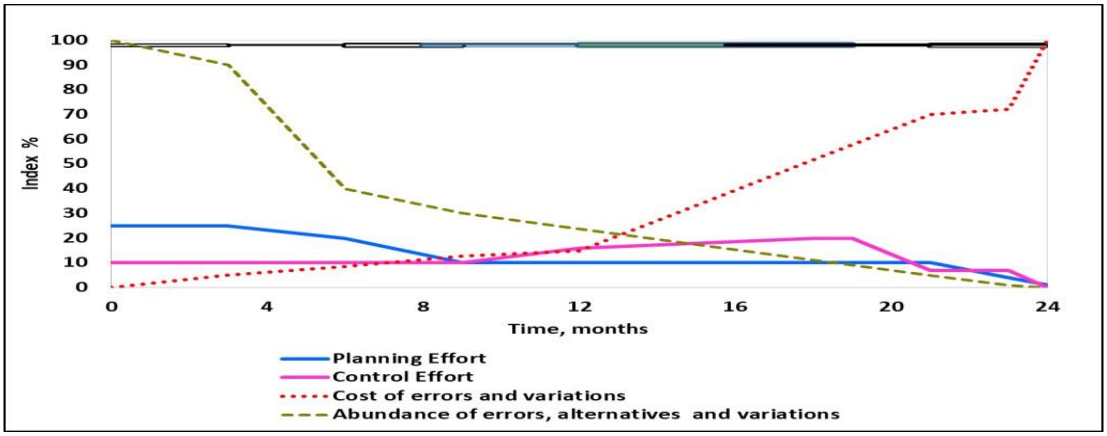

Figure 9: Planning and control efforts and impact of variations in the different stages of project engineering (prepared by author)

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4. Cost Benefit Aspects in A WTE Project

In (Themelis et al, 2016) an excellent analysis is made of the implications of all kinds, economic, environmental, social, strategic, which has a WTE project in the Latin American and Caribbean environment. The reader is referred to this work.

After developing a comparative matrix (tables 1, 2 and 3) among the preferred alternative in Colombia to dispose of waste after recycling, what, so far, is that of sanitary landfills, with two other possible WTE alternatives, which are those of a digestion process with compost making and use of the biogas generated, to produce electric energy; and that of massive combustion in a burning system to generate electrical energy, it can be concluded that it is necessary to add to the economic considerations the obvious and hidden, social and environmental benefits, which should be monetized and included in the cash flow to evaluate a given project. These include the following:

- Employment generation. This is especially important if the decision is made to integrate, as possible, local engineering, installation and manufacturing in the project. This also applies to the work associated with coal production in the case of coal co-combustion
- Contribution to the elimination of greenhouse gases.
- Contribution to eliminating water and air pollution.
- The value and scarcity of the land needed for future landfills and expansion of existing ones.
- Early recovery of valuable land from existing landfills for public use
- Cost of leaching and biogas treatment for any landfill expansion that is required.
- Valued added by the necessary research and development associated with WTE systems and their technology. Intellectual property can be generated and negotiated.
- Cost of transportation to distant landfills.
- Electric power available to balance supply when hydroelectric plants suffer from lack of rainfall.
- Availability of electrical energy to develop industrial and high-tech agriculture in sites near WTE plants.
- Possibility of uses for ashes from WTE plants.

Table 1: Comparing cost and benefits for solid waste management projects for landfills and for two WTE systems – Technical aspects

Aspect	**Landfill**	**WTE cogeneration**	**Composting and WTE**
Nature of the land used	Very large; Scarce Far away sites; Preferred to be placed in relatively dry zones	Compact size Industrial type land Close to the cities	Medium sized. Industrial type or close to rural areas or to cities
Power generation	Low (applicable when they have systems for use of the biogas generated) Costly to put into place	High It is a central objective The power can be high when using normal fuel co combustion	Medium to low It is one of the objectives, as an additional use for the biogas

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Aspect	Landfill	WTE cogeneration	Composting and WTE
Problems with communities	High. Related to the vehicle circulation, potential presence of vectors, spills in the roads, fires, discomfort for the neighbors.	Medium. Related to the need to explain how the risks of emissions, smells and impact of vehicle traffic in the area are avoided.	Medium. Related to the need to explain how the risks of emissions, smells and impact of vehicle traffic in the area are avoided.
Technical complexity in the design	High (if the project is done with very good design, as it should be).	Medium to High. Typical of an industrial thermal project. There are many experimented suppliers.	Medium to High (there is a relative variety of design options, which have varying degree of complexity)
Operational complexity	High. Intense in machinery to waste handling. It is necessary to plan carefully the operations. Medium-high in leachate and gas handling	Low-middle. In general, operations can be automated	Medium-High. It depends on the design, it can be high in the handling of composting.

Table 2: Comparing cost and benefits for solid waste management projects for landfills and for two WTE systems – Environmental aspects

Aspect	Landfill	WTE cogeneration	Composting and WTE
Environmental liabilities	High and long term. Related to the large quantities of buried materials, many of them of slow degradation	Low. Related to the ashes that come out, which must be disposed of or used	Low
Greenhouse Gases	High, related to CH4 escaping in biogas. Medium if this biogas is burned or used to generate electricity	Medium, associated with additional fuel from cogeneration and any non-renewable products being burn	Low if biogas is burned to generate electricity
Generated employment	Low-Medium	Medium	Medium-high
Necessary investments	High and long-term	High, short-term	Medium-high, short-term
Environmental monitoring needs	High and continuous	Medium and continuous	Medium and occasional
Need for additional resources	High (covering, membranes, leachate treatment supplies, civil machinery, civil works, ecological works and protection zones	Medium (co-combustion fuel)	Low

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Operational complexity	High. Intense in machinery to waste handling. It is necessary to plan carefully the operations. Medium-high in leachate and gas handling	Low-middle. In general, operations can be automated	Medium-High. It depends on the design, it can be high in the handling of composting.
Transportation costs	High	Low	Medium

Table 3: Comparing cost and benefits for solid waste management projects for landfills and for two WTE systems – Risks and Economic aspects

Aspect	**Landfill**	**WTE cogeneration**	**Composting and WTE**
Risks	Landslides. Fires and explosions. Risks associated to transporting waste to distant sites, passing through populated areas. Risks from excessive rains leading to large leaching flows.	Typical of a combustion-based electrical generation process plant. These are generally well demarcated and properly covered with operating systems and industrial maintenance.	Biological risks. Typical of a plant where processes and combustible gases are handled, which are generally well demarcated and well covered.
Production of useful by-products	Low or non-existent with current technology	Average, if uses are developed for the ashes generated.	High: Agri-products. They are regulated and could require additives
Adaptability to innovations, changes and improvements	It tends to be low, so it is necessary to maintain a culture of innovation deliberately.	There are ways, as in any industrial process, to innovate and optimize processes.	Medium.
Generation of useful heat or electricity	Non-existent. Low if electricity or useful heat are generated by the produced biogas	High. It is an important objective of the project.	Average, generated by biogas
Cultural Awareness and Recycling	Incentives are reduced to separate material at the source and to recycle.	There is an interest in ensuring availability of materials with good calorific power and low humidity. This can facilitate previous separation and classification.	Contributes to the establishment of waste separation practices and hence recycling,

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Profitability and sustainability	Sustainability is guaranteed by gate fees. In the long run It tends to generate deficits and might require capital injections with time.	Once financed the initial investment, sustainability can be achieved with energy sales, also contributing the gate fees.	Gate fees and low-priced compost sales. Electricity sales can be marginal.

5. Conclusions

It is important to ensure that in projects for solid waste management in the cities and regions of Colombia, designs and plans with long-term vision are made, considering, in an integral way, all the stages of the engineering project management and design.

The historical review of municipal solid waste management projects in the Aburrá Valley region allows to appreciate many lessons learned, which must be taken into account in future developments.

There are important advantages in the application of WTE systems (waste energy utilization) to the region. It is advisable to stimulate the development of various activities to begin to change the philosophy of bringing waste to landfills by one of integral use, naturally accompanied by a rationalization of the use of materials and improving on good practices.

It is very important to create a culture of valuation, use and sustainable waste management.

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