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Prefeasibility Study for a Continuous-Production Carbon Nanotube Plant in Bogota and Suburban Areas.

Estudio de prefactibilidad de una planta, para la producción continúa de nanotubos de carbono en Bogotá y municipios aledaños.

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Abstract

Currently, it is evident the need to have materials with better specifications, which guarantee a long useful life of structures. In the last 10 years, nano-structured materials have been involved to improve the properties of asphalt mixtures and cementitious matrices, since the carbon nanotubes (NTC) allow to obtain an integral increase of the properties of pavements surpassing any type of modifier previously studied. Although the first world countries dominate the market, in Colombia the production of these nano-materials is emerging. Therefore, this paper studies the possible domestic production of large amounts of NTC needed to modify building materials and infrastructure. This work serves as input for a feasibility and construction of a future NTC production plant, That is, it determines whether it is possible to produce it lower costs than those proposed by the world market.

Resumen

En la actualidad, se evidencia la necesidad de contar con materiales con mejores especificaciones, los cuales garanticen una larga vida útil de las estructuras. En los últimos 10 años, se han involucrado materiales nanoestructurados con el fin de mejorar las propiedades de mezclas asfálticas y matrices cementantes, dado que los nanotubos de carbono (NTC) permiten obtener un aumento integral de las propiedades de los pavimentos superando cualquier tipo de modificante anteriormente estudiados. A pesar de que los países primermundistas dominan el mercado, en Colombia la producción de estos nano-materiales está surgiendo. Por lo tanto, este trabajo estudia la posible producción doméstica de las grandes cantidades de NTC necesarias para modificar materiales de construcción e infraestructura. Este trabajo sirve de entrada para una factibilidad y construcción de una futura planta de producción de NTC, es decir, determina si es posible producir a menores costos de los que propone el mercado mundial.

1. Introduction.

At present, there is a pressing need to develop materials with better specifications to enhance the service-life of structures. Therefore, existing materials, such as concrete and asphalt, have been tested with various additives to reinforce cementing matrices and thereby develop high-performance materials [10]. Over the last five years, nano-structured materials such as Carbon Nanotubes (CNT) have been used to achieve a comprehensive improvement in material properties [1][4][5][12][17][18][19][21]. In Colombia, the production of these nano-materials is relatively recent [7][15][16]. Most of nano-materials, internationally speaking, are sold by first-world nations. The limited production in Colombia is confined to the academic sphere, since the synthesis or production of these nano-structures is expensive and production yields are currently low [6].Take, for instance, the use of nano-materials in Colombia's academic field: 10 gr or less are produced daily. In this context, it is important to study the feasibility of industrial-level production given that, as explained in studies such as that of [7], CNT comprehensively improves pavement properties—and its improvements outstrip any modifier here to fore studied. A recent study underscores these results for CNT when added to cement paste [11]. Given such benefits, the present study is concerned with the production of large quantities of CNT, which are needed to modify construction and infrastructure materials and require industrializing the production of this nano-material.

Since the past decade, interest has been shown in improving construction materials by using nano-structured materials; of these materials, CNT stands out [9]. This research serves as a preliminary study of the feasibility of building a CNT production plant; it aims to determine if it is possible to produce CNT at costs lower cost than on the international market— especially since prices on the international market fluctuate (24 to 120 $/Gr) as a factor of CNT production and configuration. [14][20]

2. Data (Model Inputs).

2.1 Technical Diagnosis.

In this technical-economic diagnostic, the use of CNT was evaluated in asphalt mixes and mortars, as recommended by the existing scientific literature on the topic. For asphalt mixes, a cost comparison between different types of polymer additives was done. Results highlight the unsustainability of adding CNT at current production prices in Javeriana University - Colombia (3.6 $/Gr). The following in price increase (%) were relative to mixes without additives (**Table 1**). But, the fatigue strength, the dynamic module and the useful life are improved. [15]

Table 1: Unit Prices (m^3) of MDC-2 Mix with Different Additives

Price without addition	$	512,360	Rising %
Price with addition of CNT	$	13,224,257	2481%
Price with addition of SBS	$	570,101.00	11%
Price with addition of SBR	$	576,771.00	13%
Price with addition of EPDM	$	543,455.00	6%
Price with addition of EVA	$	554,561.00	8%
Price with addition of PE	$	541,234.00	6%
Price with addition of PP	$	537,902.00	5%

* Total unit price proximate to COP value.

Additives dimensioned in **Table 1** are: carbon nanotubes (CNT), styrene-butadiene-styrene (SBS), Styrene-Butadiene Rubber (SBR), Ethylene Propylene Diene Type M ASTM (EPDM), ethylene vinyl acetate (EVA), polyethylene (PE), polypropylene (PP).

For an asphaltic mixture 5.5% of asphalt and polymer values of 1 to 5% [13][17]. Additionally, a comparison of the technical improvements (Fatigue, Dynamic Module and Rutting) offered by modified asphalt mixes were performed. In so doing, CNT was demonstrated to be the only additive that comprehensively improves material properties (compared to other polymer additives) [7][15]. Although CNT requires higher initial costs, savings can be seen in reduced maintenance programs in Bogota, Colombia: in an analysis of the city's Mobility Master Plan (Instituto de Desarrollo Urbano, IDU) lays out the significant investment required to meet the maintenance demands of the city's transportation network.

When adding CNT to mortar mixes, the low ratio of additive relative to cement weight (**Table 2**) meant that this process could be viable at market prices and could compete with products such as nano-silica, silica fumes and nano-alumina.

Table 2: Cost Estimates of Additives in 1m^3 of Mortar with 40 MPa of Compressive Strength

Addition	Compressive Strenght (Mpa)	Addition Cement Weight (%)	Cementant Weight (Kg/m^3)	Addition Weight (Kg)	Unit Price ($Cop/Kg)	Total Price ($Cop/m^3)
NANOSILICA	40	5	450	22,5	$ 2.639,00	$ 59.377,50
SILICA FUME	40	15	450	67,6	$ 324,80	$ 21.956,48
NANO ALUMINA	40	4	450	18	$ 852,60	$ 15.346,80
CARBON. NANOTUBES	40	0,01	450	0,05175	$ 1.015.000,00	$ 52.526,25

*Note: The prices used are the Colombian market in 2014.

2.2 Market Diagnosis.

In this second diagnostic, market diagnostics were investigated, both for CNT and its byproduct, Hydrogen. For the former, current production was examined in the form of the prototype from the Pontificia Universidad Javeriana (PUJ); this prototype was taken as which would be developed at industrial scale.

Currently, PUJ's production is 10 gr/day, which is far from the quantity needed for engineering purposes. An analysis of potential clients was carried out in line with market segmentation theory, which suggests that, hypothetically, cement producers and the country's only asphalt producer (Ecopetrol) would be possible potential clients for CNT. Likewise, an analysis of potential clients as possible clients for CNT was carried out. In the diagnostic of the possible demand for CNT, the survey tool was not considered: on one hand, in Colombia, the product has not been marketed, and on the other, international data on this material is of industrial supply because its novelty. The criteria used to define CNT demand was the method of attraction of demand meant for large-scale specific industrial and academic uses, for it is an input in the financial model. CNT percentages were defined as percentages of asphalt and cement production in the country according to percentages used in modifying materials (2% of asphalt weight and 0.0115% of cement weight) [7][11]. Based on this analysis, it was concluded that the possible daily demand for CNT would be 4,500 gr. From there, the suppliers for material production were evaluated and the SWOT matrix methodology was applied, because CNT is a new product on the Colombian market. Using this matrix, production strategies that stayed within reasonable budgets were generated (**Table 3**).

Table 3: Feasible Strategies as Determined by the SWOT Matrix

FEASIBLE STRATEGY	JUSTIFICATION
Show the project in private and gobernment business wheels.	It is necesary to disclose the product, in the productive sector and other sectors.
Seek oportunities to export the product for Latin America an the Caribbean.	Having such a case, demands that the country doesn't have any or have very low.
Increase production levels to reach breakeven.	To meet the demands that are taken at the time of the high consumption of the product.
Increase the production base to different plants, inside and outside of the city, to complite production at the time of an international constant demand.	Clambering in the market, incresing the product base with different production branches.
Reaching a competent gram price, proving the savings that it has in terms of maintaining modificate structures with CNT	It is necesary to find a competitive and sustainable price as this is an investment project.
. Encourage the academic research based on the early work developed in the topic CNT materials like asphalt and cement.	Only academic research can be obtain the real tecnics conclusions, of how work the product as an adition to other.
To introduce the product and its properties and benefits to different producing companies of aspfalt and cement in the country.	It is absolutely necessary introduce the product, because in general in the world, is a leading edge issue that is not understood in all its magnitude

Hydrogen is regarded as a viable alternative in the energy field on account of its high calorific properties and low environmental impact (reduced CO2 emissions). The current market exhibits low demand for Hydrogen relative to oil and coal. Yet, over the last few years, a sales spike of 650% has been observed for products such as hydrogen cells, which are mainly used in portable batteries, fixed batteries and transportation (Fuel Cell Today), with the estimated scale-model production, it is crucial to look at the niche market at which the product is directed, as well as its region of influence. According to data published by a global energy Company "British Petroleum" in their report "Statistical Review of World Energy," the energy demand in North America and Latin America is 72 million tons of fuel per year, of which roughly 30% is demand for renewable energy.

Departing from this premise, the estimated production was analyzed for various options—due to the structure of each model—and linked to the production of CNT—because of that hydrogen is a byproduct of plant's continuous production of CNT.

2.3 Field Phase.

In this phase, the ideal location of the plant was determined to abide by parameters chosen in accordance with the plant's requirements and the economic impact of the investment required for the plant itself. Parameters included: Cheap Land Price, Availability and Continuity of Provision of Electricity, Availability and Continuity of Water and Sewage, Stable Topography, Minimal Land Use Issues. To this end, a geoprocessing tool (GVSIG) was employed, relying on data from different sources (Local Mayoral Offices, Bogota's Water and Sewage Authority, CODENSA S.A., E.S.P, IDECA – Unidad Administrativa Especial de Catastro Distrital, State's Governing Office, IGAC, SIGOT – Sistema de Información Geográfica para la Planeación y el Ordenamiento Territorial and INVIAS). The georeferenced model contained the following levels of data: Contour Lines for the state of Cundinamarca (Scale 1:100.000), National, Regional and Municipal Roads, Electricity Grids for Voltage Levels of 11.4KV – 34.5KV, Matrix Distribution Networks of Potable Water and Sewage, Land Valuation and Terrain Types. As a result of overlay data analysis and in addition to the consideration of topographical restrictions, land costs, proximity to public services and road access, four options were established. The first and second were located within 200m of the Bogotá – Sogamoso Highway (National Route 55), in the municipalities of Tocancipa and Sopó, respectively. The third option was located inside Bogota's city limits, in the industrial district near 13Th Street, near the Bogota River. The fourth and final option was within 200m of the Bogotá – Fusagasugá Highway (National Route 45ª) in the municipality of Sibaté. As decision-making parameters for these options, the cost of land and proximity to suppliers and clients were considered. Consequently, the third option was chosen (Fontibón, Bogotá D.C, 200m from Calle 13); see Figure 1 for more information.

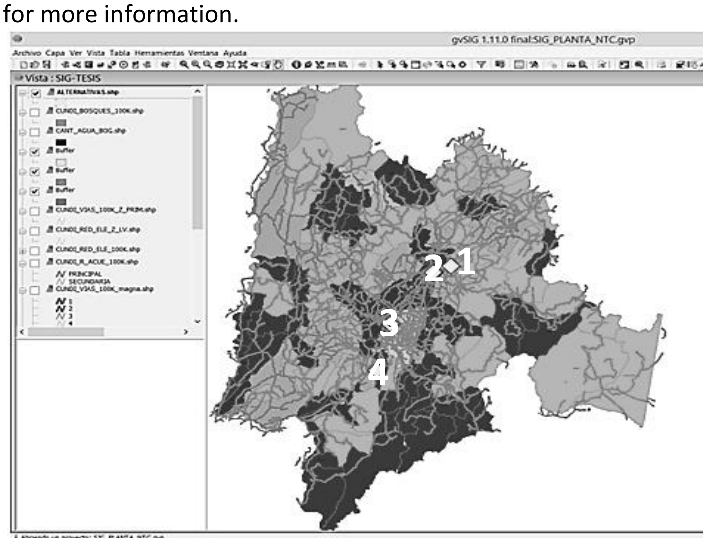

Figure 1: Final Options for Plant location.

- Alternative 1 y 2: Tocancipá and Soup - 100 m from the Briceño, Tunja, Sogamoso Concession.
- Alternative 3: Fontibón (Bogota D.C) - 100m from Calle 13.
- Alternative 4: Sibaté - 100m from the Bogota - Girardot Highway Concession.

2.4 Propositive Phase.

In the last phase before financial evaluation, three essential parts of the engineering logistics were analyzed: i) distribution, ii) supply and iii) production. With these parts, it was possible to arrive at more accurate details on the potential commercialization of CNT in Colombia. As part of this analysis, transportation, packing, supply and distribution methods and policies, supplier location and product storage were all described. In the section of production (the last section), three options were evaluated, while accounting for production scales of the PUJ's actual prototype, capital expenditure (CAPEX) and operational expenditure (OPEX). These three options were divided as follows:

Option 1 (Independent Producers): Multiplication of the current process by which CNT is presently produced at the PUJ. The current model would be used and multiplied by 150 independent assemblies in order to meet the demand of 900 daily assemblies, each producing 5 gr, for a total of 4500 gr/day of gross production

Option 2 (Assembly Line): Like a production chain with different phases (Assembly, Heating, Cooling, Assembly and Cleaning). The current model's design was modified to meet demand—using less infrastructure and equipment—for 900 daily assemblies that produce 5 gr each, for a total of 4500 gr/day of gross production. CNT would be produced in the same tubes used in Option 1, though the number of tubes would be increased to 6 tubes in each of the 5 muffles, with 5 stations. Factoring in the 6 daily assemblies, gross production would be 4500 gr/day.

Option 3 (Large-scale): Established via an unreal large-scale schematic interpolation of the PUJ's CNT prototype. To achieve this, the current model was used and production areas equal to those found in a quartz tube were determined. This would match the gross production of 900 assemblies that produce 5 gr each (for a total of 4500 gr/day) with significantly less infrastructure and equipment. Pursuing Option 3, it would be possible to produce CNT in quartz sheets; for this option, 25 sheets to be exact. These sheets would be placed in a cubic oven covered with ceramic plates that would be heated by means of electrical resistors. The catalyzer would be introduced over the area of the quartz and through the CH_4 passage on the top of the oven in which CNT would be produced.

As a salable byproduct, 16,200 L of hydrogen would be produced daily: each assembly generates 18 L of hydrogen during CNT production. Sales were calculated based on these values.

An additional benefit of this study came in the form of analyzing buildings internal layout in 3D. Such analysis clearly demonstrated the different areas of each plant option with a great level of architectural detail. To this end, AUTODESK REVIT® was used, considering that these models were used to estimate quantities and costs for the initial investment (CAPEX).

Using cost analysis, the following ordering was obtained for each option (Figures 2 and 3):

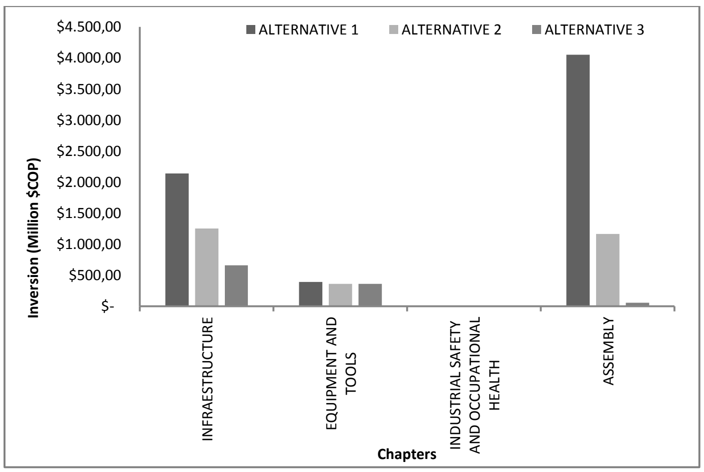

Figure 2: CAPEX Variation per Chapter.

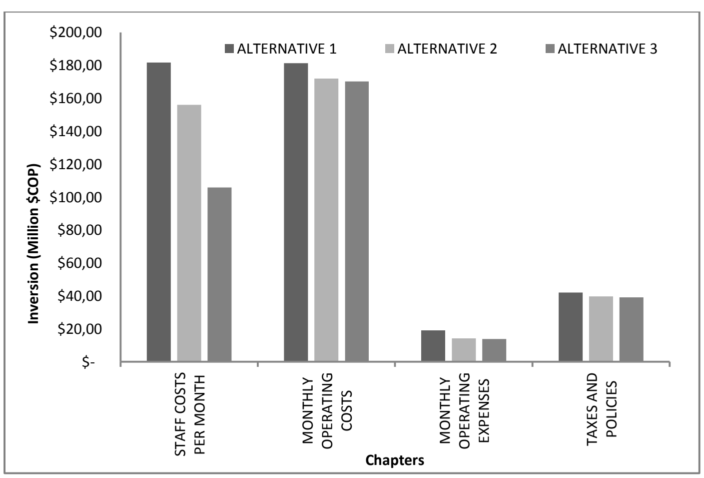

Figure 3: OPEX Variation per Chapter.

As can be seen in Figures 2 and 3, each option reduced costs relative to the immediately preceding option in each of the proposed and evaluated chapters.

3. Methodology.

To determine the project's feasibility, it is crucial to show stakeholders that the project offers an economic, financial and social opportunity within a reasonable time-span. For the options, time boundary was defined as 10 (ten) years (before reinvestment). Here, cost and financial evaluation were vital to demonstrating the feasibility of building a CNT plant.

The only objective of financial evaluation is profit or benefits for an actor (public or private entity). In financial evaluation, resources are allotted to different applications. Cornerstones of financial evaluation include: cash flow, conditions for money flow, Capital Expenditures (CAPEX), operational expenditure (OPEX), sales or income, risk, investment options, financial variables Consumer Price Index (IPC), Fixed-term deposit (DTF), Market Representative Rate (TRM), cash opportunity cost, time value of money, profit indicators Net Present Value (NPV) and Internal Rate of Return (IRR) and sensitivity analysis of the different hypotheses.

For the 3 options, the initial investment in infrastructure and inputs necessary for CNT production were determined; likewise, monthly expenses for CNT production were estimated. With these input parameters, many different cash flows were established for each option. For each of the three, the sale price ($/gr) or percentage sold monthly (%/g) was varied, which entailed observing the behavior of the investment's amortization over time. It is worth noting that for all cases, monthly debt amortization was set at 60% of the free cash flow.

Taking debt amortization into account for the free cash flow, the NPV and IRR were calculated for each option, along with concomitant variations in sales price ($/gr) and percentage sold monthly (%/gr).

4. Results and Analysis.

4.1 Break-Even Point.

The break-even point for debt repayment is an important index for establishing when the business will begin producing real profits. For this purpose, sensitivity analyses are performed; these analyses involve scenarios in which different models are created with varying sales price (per gram for the present case) and the percentage of actual sales. For Options 1 and 2, when the sales price/gram was varied, actual sales were kept constant at 70 %. Conversely, when actual sales were varied, price/gram was kept constant at $10,000COP/g. For Option 3, when the percentage of actual sales was varied, the sale price was kept constant at $5,000COP/g (in contrast to Options 1 and 2).

For Option 1, the price/gram was varied between $5,500 and $10,000 COP and the percentage of sales between 40% and 70%. For Option 2, the price/gram was varied between 4,400 and 10,000 COP and the percentage of actual sales between 31% and 70%. For Option 3, the price/gram was varied between 3,500 and 5,000 COP and the percentage of actual sales between 48% and 70%.

Higher prices/gram and higher percentages of actual sales meant real profits could be achieved within a shorter period. That is not to imply that this analysis only discovered one path to profits, but rather to offer a panorama of the business model and market to the investor.

4.2 Sensitivity Analysis (IRR and NPV).

IRR was compared to the average rate offered by a safe investment with 7.06% Effective Rate, thereby answering the question of at what price/gram and actual sales percentage would profit surpass the 7.06% Effective Rate. NPV was only studied to determine what price/gram and actual sales percentage were needed to ensure a positive NPV, and thus lead to profit.

For Option 1, at 5,900 COP/gram and an actual sales percentage greater than 41%, the venture became profitable. For Option 2, at sales 4,550 COP/gram and an actual sales percentage of 31.5%, the venture became profitable. For Option 3, at 3,550 COP/gram and an actual sales percentage of 49.5%, the venture became profitable. Across all analyses, higher sales volumes and higher sales price per gram improved the likelihood of profits and feasibility. See Figures 4-7 for more information.

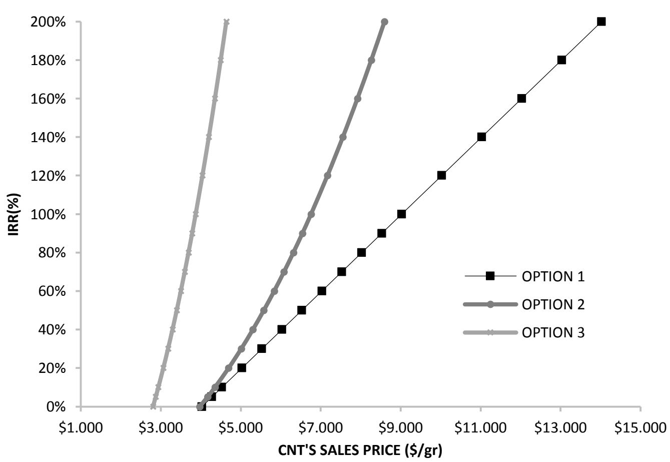

Figure 4: IRR Variation (%) vs Sales Price ($/gr). The value is displayed at each equilibrium point.

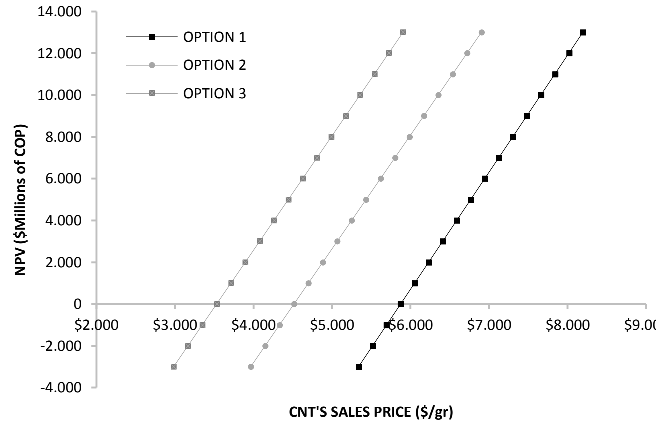

Figure 5: NPV Variation ($) vs Sales Price ($/gr).

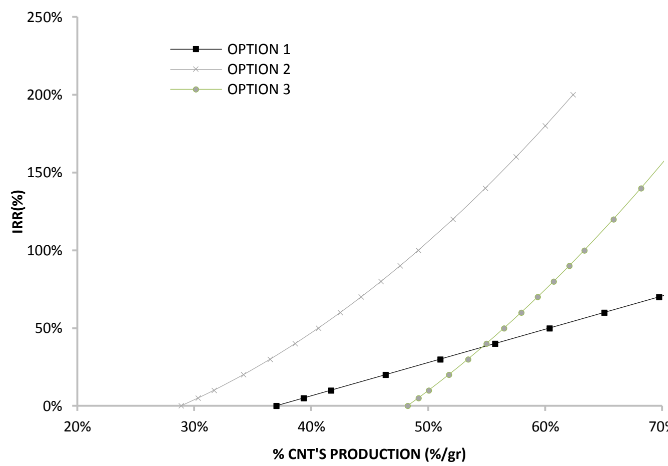

Figure 6: IRR Variation (%) vs % Actual Sales (%/gr). % Of minimum sales of the product to find the equilibrium point with 7.06%, from their profits are obtained.

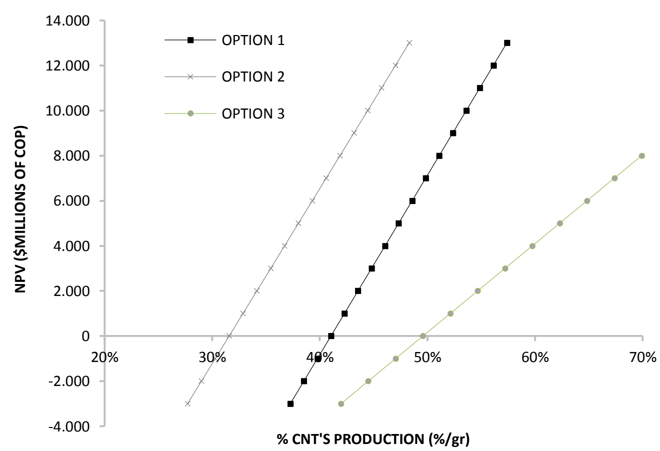

Figure 7: NPV Variation ($) vs % Actual Sales (%/gr). Variation of the profit in millions (COP), with reference to the percentage of sales of the production.

5. Conclusions and Recommendations.

This article established the feasibility of industrial-scale CNT production in Bogota and its suburban areas. CNT modified asphalt improves the response to fatigue by 22% over conventional and a 34% increase in dynamic modules. Which in a mechanic design of pavement doubles the useful life of the structure of pavement. The product would be used as an additive for special cases, i.e. materials such as cement and asphalt mixes in specific building projects for which large quantities of nano-material is not required (but which would benefit from the use of CNT additives). In the case of rutting in stop areas, testing the efficiency and effectiveness of CNT as an additive in asphalt mixes would be useful for determining if CNT represents a long-term profitable investment, especially relative to maintenance and repair costs.

The economic impact of using CNT at 2% of asphalt weight in a m3 of MDC-2 mixture proved expensive when comparted to other additives on the market. However, CNT strengthens many properties and thus ensures a comprehensive improvement of material quality. Therefore, CNT is rightly framed as an attractive solution to service life issues when compared to conventional additives, notably because the latter do not provide a comprehensive solution to the problem of improving material characteristics.

The economic impact of using CNT at 0.0115% of cement weight in mortars was not as high as asphalt. CNT affords possible reductions in material quantities when constructing buildings because of their enhancement of a material's mechanical properties. This implies that CNT is an attractive additive for cement producers. CNT might even prove more attractive to cement producers than to Ecopetrol. In this case, CNT could occupy an important niche in the market.

Using the GVSIG tool to overlay a few parameters (geographic, financial and strategic), a favorable location for the CNT was ascertained. Of the possible options, the location identified as most favorable was in Fontibón (Bogotá D.C), as can be seen in the proposed plans included in this document. Building here would minimize investment in transportation of monthly inputs, industrial property taxes, and public utilities costs; moreover, it would obviate the construction of access roads to the plant or any other type of infrastructure.

For each of the three options, the buildings internal layout in 3D were designed with AUTODESK REVIT® software, thus achieving a high-level of detail for possible feasibility and plant construction. Furthermore, this software was used to calculate the amount of material later evaluated in CAPEX for each option. Such distribution-related details will save time for any future feasibility and construction studies.

The CAPEX and OPEX cost analysis for the three options determined the third option to be best, given that it would require less investment than the other two options, thereby entailing less risk for business rollout. Regardless, all three options could be feasible.

In the break-even point analysis for debt repayment, there was no single best answer, for all three options were feasible. The selection criteria were based on variations of the interest rate on the loan, the debt's amortization period and the unit sale price of the CNT. This analysis allows investors to see a breakdown of when they will recoup their investment given certain parameter variations.

Similarly, sensitivity analysis did not provide a single "definitive" option. All options proved feasible. Selection criteria included IRR and NPV. For each option, IRR varied in relation to the amount invested, operating costs and monthly cash flow. Under these budgets, the limit values at which profitability would be achieved for the options were as follows. For Option 1, at 5,900 COP/gram and an actual sales percentage greater than 41%, the venture became profitable. For Option 2, at sales 4,550 COP/gram and an actual sales percentage of 31.5%, the venture became profitable. For Option 3, at 3,550 COP/gr and an actual sales percentage of 49.5%, the venture became profitable. Based on this analysis, it is possible to determine the sales price per gram and quantity that must be sold for each option in accordance with the objectives of the investors.

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