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Impact of Revenue Generated from Waste Management on Gross Domestic Product: A Maximization Approach using Goal Programming

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ABSTRACTS

Solid waste management is increasingly important as the world transitions from the Millennium Development Goals to the Sustainable Development Goals (SDGs), which emphasize environmental sustainability. Economic growth often leads to higher waste generation, highlighting the need to understand the relationship between waste management and economic performance. While GDP reflects economic health, solid waste levels indicate environmental conditions. Improved waste management strategies not only benefit the environment but can also boost national GDP.
This study uses secondary data from the National Bureau of Statistics and applies goal programming to optimize the contribution of solid waste management to GDP. By focusing on integrated waste treatment methods such as recycling, composting, incineration, and waste-to-energy processes, the study demonstrates that these methods can enhance economic outcomes. Results show that effective resource allocation in waste collection and treatment can contribute up to 1.4% to the national GDP. Expanding waste treatment approaches, including sorting, RDF production, and composting, increases profit, creates jobs, reduces landfill use, lowers health risks, and boosts revenue through the sale of recycled materials and energy recovery.

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Introduction

Solid waste management study is highly essential on the ground that the World has moved away from the popular millennium development goals which ended in 2015 and the World is focusing on sustainable development goals which are relatively new concepts and catching the attention of World environmental agencies in their bid for the World to a better place for the humanity. Economic analysis of solid waste disposal methods are based on cost of disposing solid wastes and composition of solid waste.

The economic analysis of solid waste management is based on four element which are economic, technical, social and environment. Economic has to do with capital and operational cost; potential and maintenance cost; reducing cost associated with conventional waste process and disposal and labour cost.

Technical include potential and maintenance cost; degree of adaptation at all levels and compatibility with existing system and technology which social element are potential resettlement of people; potential for local job creation and relation with producers. Environment has to do with noise and visual pollution, transportation and greenhouse gas emission (Ugwu and Ahaneku, 2015).

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The typical structure, scale and scope of city economic development are creating uninvited impacts on the safety of the natural environment. Waste disposal in Nigeria is dominated by indiscriminate dumping of refuse, inefficient collection and sorting, poor documentation of waste composition and generation rate by household and industries, and incompetent management by informal sector.

It has been estimated that a range of 521.95 – 759.20 kg of waste is generated per person per year in the developed countries while waste generated per person per year in developing countries is put at 109.50 – 525.60 kg (Ugwu and Ahaneku, 2015).

Okumura et al. (2014) analyzed the relationship between economic growth and waste treatment methods in Asian countries such as Japan, Korea, and China. They observed that higher GDP per capita is associated with increased waste incineration rates but reduced composting rates in Japan and China, while Korea demonstrated a positive correlation between GDP and composting. These findings highlight how economic development influences waste management strategies, which vary across regions based on social, economic, and environmental considerations.

Shah et al. (2023) assessed the effects of economic growth, industrialization, and foreign direct investment on municipal waste in OECD countries from 2000 to 2020. Their research showed that economic growth and industrialization significantly increase waste generation, while the impact of foreign direct investment is less pronounced. However, technological advancements, particularly in research and development, play a critical role in mitigating waste generation. Despite these advances, late-stage economic growth remains challenging for waste reduction in OECD countries.

A lot of research has been carried out on food waste, wastewater, and agricultural waste in developed countries, referring to the challenges, environmental efects, cost, collection, treatment methods, conversion, recycling, and reuse. The relationship between municipal waste and GDP has been extensively studied by academics and organizations such as the World Bank, OECD, and the European Environment Agency. According to the OECD, many countries show a positive relationship between municipal waste generation and GDP, underscoring the need for sustainable waste management policies that align with economic development.

However, in Nigeria, there is lack of adequate information on the maximization of revenue generated from waste of food, water, and agriculture on the economy (Gross Domestic Product). This work intends to use goal programming methodology to maximize the contribution solid waste to National Gross Domestic

Literature Review

Numerous studies have explored solid waste management from various perspectives, employing different scopes, methods, theories, and variables, which often resulted in diverse findings. While some studies reached similar conclusions, others presented contrasting outcomes. For instance, Ajani (2008) examined the factors influencing the selection of waste service providers and the fees paid by residents in Ibadan metropolis. The findings indicated that the likelihood of using public waste collection services was positively associated with the age, location, and occupation of the recipients. Conversely, factors such as years of education, service fees, household size, and total monthly income were negatively correlated with the probability of using public waste collection services.

Adebo and Ajewole (2012) analyzed the factors influencing willingness-to-pay for waste disposal in Ekiti State, Nigeria. Their findings indicated that gender, primary occupation, marital status, educational level, and average monthly income significantly affected willingness-to-pay. Conversely, family size, household headship, and proximity to dump sites were negatively associated with willingness-to-pay.

Ibiyemi (2008) analyzed the economics of solid waste management in Lagos State, revealing that less than 20% of the solid waste generated in the state was recovered, with no existing market for component separation. Similarly, Awosusi (2010) evaluated the environmental challenges and waste management practices in Ado-Ekiti, Nigeria. The study highlighted the significant contributions of waste management personnel to waste management in the area but noted that they face challenges. Addressing these challenges with adequate support could greatly enhance the effectiveness of the waste management system.

Aliu et al. (2014) assessed the performance of public-private partnerships (PPP) in household solid waste collection in Lagos, Nigeria. Regression analysis revealed that PPP performance is significantly influenced by factors such as economic status, affordability, flexibility, consistency, cleanliness, coverage, accessibility, number and maintenance of waste collection vehicles, trip rates, collection frequency, and the quality and number of personnel. The study found that Lagos residents have a strong positive perception of PPP as a waste collection policy framework.

Tan et al. (2015) evaluated the energy, economic, and environmental (3E) impacts of waste-to-energy (WTE) approaches for municipal solid waste management. The study compared various WTE scenarios and focused on waste incineration and anaerobic digestion (AD) as potential options in Malaysia. The 3E analysis identified incineration as the superior technology when both electricity and heat production were considered, while AD was more favorable when electricity production alone was prioritized.

Gillani et al. (2015) examined the economic burden of diseases linked to inappropriate waste disposal at the Hazar Khwani dumpsite in Peshawar, Pakistan. Results indicated an inverse and significant relationship between distance from the dumpsite and workdays lost or mitigation costs. The annual monetary benefit of adopting modern landfill management techniques for residents living within 4 km of the dumpsite ranged from 186,612,897.66 PKR to 192,559,787.24 PKR.

Ugwu and Ahaneku (2015) analyzed solid waste disposal in Nigeria to identify cost-effective methods. The study concluded that Mechanical Biological Treatment (MBT) is a favorable option, given the predominantly biodegradable composition of waste in Nigeria.

Yusuf and Adesola (2015) investigated the benefit incidence of government expenditure on solid waste management in Olorunda Local Government Area, Osun State, Nigeria. The study revealed that the average household expenditure on government-provided waste disposal services was ₦252.98, significantly higher than the government subsidy of ₦14.00 per unit. Approximately 63% of the total government expenditure benefited the poor, with a greater proportion favoring the moderately poor.

Miyata et al. (2016) conducted an economic analysis of municipal solid waste management in Toyohashi City, Japan, using evidence from the Environmental Kuznets Curve (EKC). The study demonstrated an inverse U-shaped EKC, indicating that the relationship between per capita economic levels, municipal waste management expenditures, and solid waste generation is influenced by national and local initiatives, economic development, and quality of life improvements. The findings suggest that Japan's national policies and legal frameworks significantly impact local governance, as evidenced by Toyohashi City's ability to enhance citizens' quality of life by addressing environmental pollution through higher income levels and advanced technologies. The EKC also highlighted the importance of adopting a sound-material-based society in waste management.

Igwe and Mgbasonwu (2017) analyzed household waste generation, disposal, and management in Umuahia metropolis, Abia State, Nigeria. The study found that income and educational level were positively significant at the 1% level, while household size had a negative significance at the same level. Additionally, the findings suggested that unit pricing for municipal waste charges would be a more effective alternative to the current flat-rate system.

Eleje et al. (2017) evaluated the financial and economic relevance of solid waste management in Nigeria. The study proposed two major hypotheses, both of which were supported by the findings. A significant proportion of respondents strongly agreed that solid waste management positively impacts internally generated revenue (IGR) and youth employment. The computed Z-values fell within the critical range of -1.96 to 1.96, validating the alternative hypotheses.

Economic growth does not necessarily hinder environmental protection; in fact, it can contribute positively to solving environmental challenges. By fostering economic development, resources become available for investments in cleaner technologies, institutional improvements, and enhanced environmental education and awareness. Economic growth also promotes innovation, facilitates the spread of sustainable technologies, and increases society's capacity to adapt to environmental issues.

Grossman and Krueger (1995) explored the link between economic growth and environmental impact, focusing on waste. Their study revealed that during early stages of economic growth, municipal waste generation rises due to increased consumption of goods and services. However, as economies advance, technological progress and innovation enable more efficient consumption and reduced waste generation. They conclude that economic growth can align with environmental preservation if effective waste management policies are implemented. Incorporating environmental protection costs into national GDP calculations can provide a more accurate representation of economic progress, reflecting the investments needed for sustainable growth.

Kinnaman (2006) examined the relationship between GDP and municipal waste generation, finding an elasticity coefficient between 0.8 and 0.9. This means that for every 1% increase in GDP, municipal waste generation grows by 0.8–0.9%. As a result, household waste generation rises in tandem with economic growth.

Asif Razzaq et al. (2021) analyzed data from 1990 to 2017 in the USA to investigate the long-term relationship between GDP and municipal solid waste generation. Their findings highlight a unidirectional causal relationship between recycling municipal waste and economic growth, carbon emissions, and energy efficiency. This indicates that policies promoting waste recycling can significantly influence economic growth and environmental outcomes.

Inglezakis et al. (2021) studied the economic and waste management dynamics in Romania, Bulgaria, Slovenia, and Greece from 2000 to 2013, emphasizing the EU's "decoupling principle," which seeks to separate economic growth from resource use. Using indicators like population growth, GDP, and municipal waste, they developed the Municipal Waste Indicator (MWI) to facilitate comparisons between countries. Their findings suggest that decoupling occurs when waste generation grows at a slower pace than the economy.

Scholars agree on a positive correlation between GDP and household waste generation, though its magnitude and specifics vary by methodology and context. Additionally, economic growth influences waste treatment and management choices, emphasizing the need for tailored strategies to balance economic and environmental goals.

Methodology

Research Design

This research design focuses on identifying the main features of Multi-objective Optimization Model implemented in SWM problems world-wide. As most relevant models in SWM have multiple objectives and therefore require the use of Multi objective Optimization Models to learn the best practices and identify the possible gaps concerning the Federal Capital City situation, such as the optimization criteria that drive the problem solution (parameters). Such features include the different limitations that need to be considered in each type of problem (constraints), the algorithms used to solve the optimization models (methods/techniques) and the results obtained. There has been extensive research into the application of goal programming to solid waste management system difficulties. Several authors have proposed linear and non-linear models to handle waste management concerns in the past. Goal programming is an optimization technique for solving problems having many, frequently competing objectives. Instead of attempting to discover a single solution that optimizes all objectives at the same time, goal programming aims to strike a balance among several objectives while taking their relative importance and limits into account (Barbosa *et al.*, 2019). The technique separates objectives into priority levels, with each level representing a unique set of goals that must be met to differing degrees. Goal programming enables decision-makers to make informed decisions, even when certain objectives cannot be completely realized owing to resource restrictions or other factors (Ryńca and Ziaeian, 2021).

As a result, there is an urgent need for an innovative and integrated approach that optimizes resource allocation to satisfy the numerous objectives associated with solid waste management. This research aims to address managerial decision making, goal conflict, resource allocation, sustainability, implementation, promoting recycling, waste to wealth, job creation, technology and infrastructural challenges posed by solid waste.

The research design is directed towards the development and testing of a multi-objective planning model based on the goal programming approach for proper solid waste management in the Federal Capital City Abuja. The mixed integer linear programming mathematical model was formulated to determine the establishment of collection, transfer station with sorting line, material recovery center, recycling, composting, combusting, and hazardous centers at a minimum cost. Due to the realization that measuring transportation costs per trip is more relevant to most cities of developing countries, the current situation of Abuja metropolitan, where the technology to measure waste as it is carried away from the waste sources is not available, we may want to measure transportation costs in terms of costs per trip of a truck from waste collection center, j to any of the centers or from one center to another. The planning horizon is a day, i.e., decisions are to be taken on a day-to-day basis.

Assumptions of the Proposed Model

i. All wastes from the sources are to be moved to the collection center at the expense of the generators.
ii. All generated wastes are assumed to be collected and transported every day.
iii. Sorting and separation of significant types of waste are assumed to start from the transfer stations with sorting line center TSs.
iv. All categories of wastes are assumed to be correctly sorted at the transfer station with sorting line TSs and sent to material recovery facility center s.
v. All categories of wastes are assumed to be sent to the various treatment centers from the material recovery facility.

Sets and Indices of the Model

l = 1,2,..., L: location of final disposal center (landfill).
$i = 1, 2, \ldots, I$: location of waste sources.
$j = 1, 2, \ldots, J$: location of collection points.

tss = 1, 2,….,TS: location of transfer station with sorting line.

mrf = 1, 2,….,MRF: location of material recovery facility
$k = 1, 2, \ldots, K$: location of combusting center (incinerators).
$r = 1, 2, \ldots, R$: location of recycling/reuse centers.
$c = 1, 2, \ldots, C$: location of composting center.
$h = 1, 2, \ldots, H$: location of hazardous center.
$q = 1, 2, \ldots, Q$: location of other factories/ markets.
$s = 1, 2, \ldots, S$: capacity of a center.
$g = 1, 2, \ldots, G$: waste type

Decision Variables

x_{gjtss},x_{gjmrf},x_{gjr}, x_{gjc}, x_{gjk}, x_{gjh}, and x_{gjl} = unit amount of various types of waste in tons per day from collection center j to transfer station with sorting line , to material recovery facility (MF),and to the various category of waste ce$nter$.
X_j, X_{tss},X_{mrf}, X_r, X_c, X_h, X_k, X_l, = total amount of waste in tons transported per day to collection j, transfer with sorting, material recovery facility, and all the centers respectively.

Data/Parameters

The sum of daily generated waste from different collection centers within the metropolitan is given as:
$w_1 + w_2 + \ldots + w_N = W$
W_j = all generated wastes in tons per unit per day at collection j.
TC_{mrf}, TC_{tss}, TC_r, TCc, TC_k, TC_h, TC_L, = cost (in Naira) per day of transporting significant categories of waste from material recovery facility to various centers respectively.
S_{tss}, S_{mrf}, S_r, S_c, S_h, S_k, S_l, = maximum available size/capacity of the various centers.
FC_r, FC_c, FC_k, FC_h, = fixed cost (in Naira) of establishing and maintaining the various centers.
MC_j, MC_l, = cost of managing collection center j and final disposal center l, respectively.
Fr = fraction (in kilogram) of recoverable waste of various categories at material recovery facility (mrf).
P_c, = percentage of recoverable waste materials at various facilities/ centers.
HC_r, HC_c,HC_h,HC_k,HC_l = waste handling cost to manage the unit amount of various waste categories at material recovery facility (mf).

Methods of Data Collection

The data for this study is collected from National Bureau of Statistics (NBS) and Abuja Environmental Protection Board (AEPB). In addition, data were also collected from interviews, to get the cost of transporting and managing the waste, scavengers, and vendors of solid waste to get the prices of recoverable and reusable wastes.

According to AEPB Abuja metropolitan generates more than 1,200 tons of solid waste per day. Out of this figure (1,200tonnes per day), average of 750-800 tons per day can be collected by AEPB, leaving 500-700 uncollected every day due to diversion to open dumping and recycling processes. As a result, a heaping amount of waste is seen almost everywhere in metropolitan areas.

Recovery processes in Abuja (as stated above) mainly include; plastic waste recycling centers, metallic waste recycling centers, aluminum waste recycling centers, and decomposed substances as fertilizer. In most cases, generation/collection centers serve as processing centers where waste treatment/separation and indiscriminate open burning occur. Also, recyclable waste, whether hazardous or non-hazardous, are mostly locally separated by scavengers (Bola boys) and then taken to vendors then to recycling/reuse centers within and outside Abuja. Thus, most of the waste residue produced after selecting the recyclable/reusable wastes is burnt, buried or transferred to final disposal sites (dumpsites) by trucks and individually if the collection centers are accessible.

Technique for Data Analysis

The technique used for data analysis in this research is a formulated mixed-integer linear programming mathematical model. It optimizes the objective of minimizing the total cost of SWM, which includes the cost of transporting different types of waste between other locations plus the fixed cost of establishing and maintaining/operating some facilities.

In this research, an Integrated Solid Waste Management System (ISMS) configuration is proposed for the deployment in Nigeria where it depends on the adoption of commonly used solid waste management technologies worldwide. The model is under several reasonable constraints. In general, the constraints Include, flow balance (mass balance) constraints, capacity constraints, facility Establishment constraint, goal constraints, non-negative variable constraints.

Flow Balance (Mass Balance) Constraints

The incoming number of wastes at any facility in the SWM system must be equal to the outgoing number of wastes at that facility after processing.
The sum of daily generated waste ($w_1 + w_2 + \ldots + w_N$) from N different collection centers within the metropolitan must be equal to the total daily generated waste (W_j)

$$w_1 + w_2 + \ldots + w_N = \sum_{j=1}^{N} W_r \quad (1)$$

The unit amount of recyclable waste (x_{gmr}) that will be moved from material recovery facility to recycling/reuse center r constitutes the fractions of recoverable plastic, recoverable aluminum, recoverable metal, and recoverable other wastes found in the total daily generated waste

$$W_j = \sum_{m=M} \sum_{r=R} x_{gmr} + \sum_{m=M} F_p W_j + \sum_{m=M} F_a W_j + \sum_{m=M} F_m W_j + \sum_{m=M} F_o W_j \quad (2)$$

The unit amount of compostable waste (x_{gmc}) found in the total daily generated waste (W_j) that will be moved from material recovery center (mrf) to composting center c is given as:

$$\sum_{m=M} \sum_{c=C} x_{gmc} = \sum_{m=M} F_c W_j \quad (3)$$

The unit amount of combustible waste (x_{gmk}) found in the total daily generated waste (W_j) that will be moved from material recovery facility (mrf) to combusting center k is given as:

$$\sum_{m=M} \sum_{k=K} x_{gmk} = \sum_{m=M} F_k W_j \quad (4)$$

The unit amount of hazardous waste (x_{gmh}) found in the total daily generated waste (W_j) that will be moved from material recovery facility (mrf) to hazardous center h is given as:

$$\sum_{m=M} \sum_{h=H} x_{gmh} = \sum_{m=M} F_k W_j \quad (5)$$

The unit amount of incombustible waste residue (x_{gmd}) found in the total daily generated waste (Wj), that will be moved material recovery facility (mrf) to final disposal center l is given as:

$$\sum_{m=M}\sum_{l=L} x_{gml} = \sum_{k=K} F_l W_j \qquad (6)$$

The sum of recyclable waste (x_{gmr}) moved from material recovery facility (mrf) to recycling/reuse center r and recyclable hazardous waste (x_{ghr}) moved from hazardous center h to recycling/reuse center r must be equal to the total unit amount of recyclable waste (Xr) transported to recycling/reuse center r.

$$\sum_{m=M}\sum_{r=R} x_{gmr} + \sum_{h=H}\sum_{r=R} x_{gmr} = \sum_{k=K} X_r \qquad (7)$$

The sum of all fractions of combustible waste residues from material recovery facility (x_{gmk}), from composting center c (x_{gck}), from recycling/reuse center r (x_{grk}), and from hazardous center h (x_{ghk}), Moved to combusting center k must be equal to the total unit amount of waste (Xk) transported to combusting center k

$$\sum_{m=M}\sum_{k=K} x_{gmk} + \sum_{c=C}\sum_{k=K} x_{gck} + \sum_{r=R}\sum_{k=K} x_{grk} + \sum_{h=H}\sum_{k=K} x_{ghk} = \sum_{k=K} Xk, \qquad (8)$$

The sum of all fractions of incombustible waste residues from material recovery facility (x_{gmd}), from recycling/reuse center r (x_{grd}), from composting center c (x_{gcd}), from combusting center r (x_{gkd}), and from hazardous center h (x_{ghd}) moved to final disposal center l must be equal to the total unit amount of waste (Xl) transported to final disposal center

$$\sum_{m=M}\sum_{k=K} x_{gmd} + \sum_{c=C}\sum_{k=K} x_{gcd} + \sum_{r=R}\sum_{k=K} x_{grd} + \sum_{h=H}\sum_{k=K} x_{ghd} + \sum_{m=M}\sum_{k=K} x_{gld} = \sum_{l=L} X_L , \qquad (9)$$

The sum of all fractions of compostable waste (x_{gmc}) moved from material recovery facility (mrf) to composting center c must be equal to the total unit amount of waste (Xc) moved from material recovery facility (mrf) to composting center c

$$\sum_{m=M}\sum_{c=C} x_{gmc} = \sum_{l=L} X_c , \qquad (10)$$

The sum of all fractions of hazardous waste (x_{gmh}) moved from material recovery facility (mrf) to hazardous center h must be equal to the total unit amount of hazardous waste (Xh) transported to hazardous center h.

$$\sum_{m=M}\sum_{h=H} x_{gmh} = \sum_{h=H} X_h \qquad (11)$$

Justification of the model

Application of goal programming to solid waste management system is justifiable as it address a critical research gap in the existing literature. It help the researcher to discover the problem of solid waste and create awareness about the danger associated with improper solid waste management. It is also relevant to the municipal administration and municipal environmental health department as to how to properly manage solid waste .The research assist policy makers to draw concrete plans that will tackle the problems of solid waste management to utilize the limited resources efficiently, incorporates waste recovery process efficient, economic, environmental waste disposal system for the citizens and stimulate further research.
Hence reduces cost and generates revenue when implemented.

Data Analysis

Linear Programming to Maximize the Contribution of Solid Waste to National Gross Domestic Product (NGDP).

Table 4.1 Contribution of Solid Waste to National Gross Domestic Product

Sector	Decision Variable (Xi)	Contribution to NGDP (%)	Average Waste Collection Capacity (tons)
Waste Collection	x1	0.36%	32,000,000
Recycling	x2	0.34%	3,840,000

Table 4.11 depicts the contribution of solid waste to National Gross Domestic Product. The waste collection (X_1) has 0.36% contribution to the National Gross Domestic Product (NGDP) with average collection capacity of 32,000,000. The recycling (X_2) has 0.34% contribution to National Gross Domestic Product (NGDP) with average collection capacity of 3,840,000.

Minimum Waste Collection Capacity Requirement for Waste Collection (W1) = 64,000,000 tons

Minimum Waste Collection Capacity Requirement for Recycling (W2) = 7,680,000 tons

Total Budget = #500,000,000

Objective Function
The goal is to **maximize the total NGDP contribution**:
Maximize $Z = 0.36x_1 + 0.34x_2$

Constraints
1. **Waste Collection Capacity Constraint**:
   Ensure each sector meets a minimum waste processing capacity:
   For Waste Collection (x_1):

$$32{,}000{,}000x_1 \geq W_1$$

For Recycling (x_2):

$$3{,}840{,}000x_2 \geq W_2$$

Total Budget Constraint:
- Let's assume the total budget (hypothetical value) is set to ensure the cost does not exceed the available budget.

$$30{,}000{,}000x_1 + 35{,}000{,}000x_2 \leq Total\ Budget$$

Step 1: Set Up the Constraints with Assumed Values
1. **Waste Collection Capacity Constraints**:
   - For Waste Collection (x1):

$$32{,}000{,}000x_1 \geq 64{,}000{,}000$$

Solving for x_1:

$$x_1 \geq \frac{64{,}000{,}000}{32{,}000{,}000} = 2$$

For Recycling (x_2):

$$3{,}840{,}000x_2 \geq 7{,}680{,}000$$

Solving for x_2:

$$x_2 \geq \frac{7{,}680{,}000}{3{,}840{,}000} = 2$$

vSo, $x_1 \geq 2$, $x_2 \geq 2$ $to\ meet\ the\ capacity\ constraints.$

2. **Budget Constraint**:

The total cost of implementing $x_1 and\ x_2$ should not exceed #500,000,000.

$$30{,}000{,}000x_1 + 35{,}000{,}000x_2 \leq 500{,}000{,}000$$

Let's check the cost when both x_1=2 and x_2=2:
Total Cost=30,000,000 x 2+35,000,000 x 2=60,000,000+70,000,000=#130,000,000
This value (130,000,000) is within the budget constraint of #500,000,000, so both values satisfy the budget.

Step 2: Evaluate the Objective Function with x_1=2 and x_2=2
Now, plug x_1=2 and x_2 =2 into the objective function to maximize the NGDP contribution:
Total NGDP Contribution $0.36x_1 + 0.34x_2$

$$0.36 \times 2 + 0.34 \times 2$$

$$0.72 + 0.68 = 1.4\%$$

Therefore, the final result shows that the optimal solution to **maximize the contribution of solid waste management to the NGDP**, while satisfying all constraints, is:

$$x_1 = 2, \quad x_2 = 2$$

with a total **NGDP** contribution of **1.4%**.
Linear Programming for minimizing the Land use

Table 4.12 Land Data for the LP

Sector	**Decision Variable (xi)**	**Cost per Hectare (ci)**	**Land Use per Hectare (li)**	**Capacity Requirements:**	**Capacity per Hectare (capi)**
Waste Collection	x_1	#30,000,000	100 m²	150,000 tons	79,725.20 tons
Recycling	x_2	#35,000,000	200 m²	1,000,000 tons	513,378.65 tons

Table 4.12 represent the land data used for the minimization of the Linear Programming
The waste collection (X_1) has #30,000,000 cost per hectares, 100 m² land use per Hectares, capacity required is 150,000 tone with capacity per Hectare (($capi_1$) of 79,725.20 tons. The recycling (X_2) has #35,000,000 cost per hectares, 200 m² land use per Hectares, capacity required is 1,000,000 tons with capacity per Hectare (($capi_1$) of 513,378.65 tons.

Constraints

1. **Capacity Requirements**:

Waste Collection: R_1= 150,000 tons
Recycling: R_2= 1,000,000 tons
Total available land: L_{max} =1,000,000 m²

Total Budget:
Budget: #500,000,000

Objective Function
Minimize the total cost of land:

$$Min\ Z = 30{,}000{,}000x_1 + 35{,}000{,}000x_2$$

Step 1: Satisfy the Capacity Requirements

Each hectare provides a specific capacity, so let's start by calculating the minimum number of hectares required for each sector to meet the capacity:

For Waste Collection (x_1)
The capacity requirement for Waste Collection is:

$$79{,}725.20x_1 \geq 150{,}000x_2$$

Solving for x_1:

$$x_1 \geq \frac{150{,}000}{79{,}725.20} \approx 1.88$$

Since x_1 must be an integer, rounded up to x_1 =2.
For Recycling x_2
The capacity requirement for Recycling is:

$$513{,}378.65x_2 \geq 1{,}000{,}000$$

Solving for x_2:

$$x_2 \geq \frac{513{,}378.65}{1{,}000{,}000} \approx 1.95$$

Rounding up, x_2=2
So, the minimum values that meet the capacity requirements are:

$$x_1 = 2, \qquad x_2 = 2$$

Step 2: Check the Land Use Constraint
With $x_1 = 2$ and $x_2 = 2$, let's see if the land use is within the maximum area allowed.

$$100x_1 + 200x_2 = 100 \times 2 + 200 \times 2 = 200 + 400 = 600m^2$$

This is within the $L_{max} = 1{,}000{,}000m^2$
Limit, so the land use constraint is satisfied.
Step 3: Check the Budget Constraint

Now, calculate the total cost for $x_1 = 2$, $x_2 = 2$

$$30{,}000{,}000x_1 + 35{,}000{,}000x_2 = 30{,}000{,}000 \times 2 + 35{,}000{,}000 \times 2$$
$$= 60{,}000{,}000 + 70{,}000{,}000 = 130{,}000{,}000$$

This is well within the total budget of #500,000,000, so the budget constraint is also satisfied.
Step 4: Evaluate the Objective Function
The total cost with x_1=2 and x_2 =2 is
Total Cost=30,000,000·2+35,000,000·2=130,000,000
The optimal solution to minimize the total land cost, while meeting all constraints, is:

$$x_1 = 2, \; x_2 = 2$$

with a total cost of #130,000,000.

Conclusion

After solving the optimization model which resulted in a total National Gross Domestic Product (NGDP) contribution of 1.4%. This indicates that the solid waste management sector can significantly contribute to the NGDP by effectively allocating resources to both waste collection and recycling within the specified constraints. The results align with previous studies that demonstrated the potential of waste management systems to contribute to national economies when optimized efficiently, as highlighted by Zhang et al. (2018).

An optimal solution is obtained based on economically feasible, environmentally sound option, ensure operation efficiency and serve as a decision support tools. Increasing the type and treatment of waste leads to an increased net profit, therefore incorporating sorting, recycling, compost, refuse derived fuel (RDF) production leads to more profit, job creation, high reduction of waste to the landfill, reducing health hazards and increasing revenue generated from the sales of different recycled product, compost and incineration

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