International Journal of Multiphysics
Volume 18, No. 3, 2024
ISSN: 1750-9548

A Framework for Economic Assessment of Construction and Demolition Waste Recycling Plant in Sharqia Governorate, Egypt

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Abstract

The construction sector boom in Egypt in the last 10 years has led to unprecedented accumulations of Construction and Demolition Waste (CDW) across Egyptian cities. CDW annual generation is estimated at 40 million tons; besides accumulations from previous years, around 200 million tons are scattered mostly in informal dump sites within Egyptian Cities posing significant environmental and economic challenges. The government has launched major programs for solid waste management and regulations to encourage the private sector to establish and operate CDW recycling stations across Egyptian governorates. This study evaluates the technical and economic feasibility of a 200-ton/hour stationary recycling plant in Belbeis, Sharqia, East of Egypt. The study evaluates different scenarios for CDW recycling plants' establishment, including direct government investment and Public-Private Partnership (PPP) models.

The results indicate that the project is financially viable under both frameworks, though the PPP model demonstrates superior efficiency through enhanced risk-sharing and contribution of private sector expertise. Sensitivity analysis identifies three critical drivers of financial performance: market prices for recycled aggregate, administrative expenses, and total operational costs.

Ultimately, establishing CDW recycling facilities provides a sustainable solution to Egypt’s waste challenges, supporting resource conservation and circular economy principles even without strict incentives. These findings offer a scalable framework for policymakers to enhance investment decision-making, while future research should address advanced technologies and alternative partnership structures to further optimize the CDW sector.

Keywords: Construction and Demolition Waste (CDW), Recycled Aggregates, Waste Management Sustainability, Public-Private Partnership (PPP), Sharqia Governorate, Circular Economy in Egypt.

1. Introduction

Construction and demolition waste (CDW) is a mixture of surplus materials generated from various construction, renovation, and demolition activities, including site clearance, land excavation, road works, and demolition (Shen et al., 2004).

In the United States, construction and demolition waste has been defined as a waste material "produced in the process of constructing, renovating, or demolishing buildings, including structures of buildings of all types (residential and non-residential) as well as roads and bridges, and components of C&D debris typically include concrete, asphalt, wood, metal, gypsum wall panels, and ceilings" (Franklin, 1998).

Globally, construction, demolition, and natural disasters generate vast quantities of waste, yet only a fraction of this material undergoes proper treatment before disposal.

Menegaki and Damigos (2018) estimated that 35% of CDW is directed to landfills without any additional treatment. CDW represents one of the largest waste streams worldwide, accounting for a substantial proportion of total solid waste.

For instance, statistics from 27 European Union countries indicate that CDW contributes to 49% of total solid waste generation (Villoria Saez et al., 2011), amounting to an estimated 700 million tons in 2017 (Iacoboaea et al., 2019; Gálvez-Martos et al., 2018).

In 2021, the Egyptian Ministry of Environment (MOE) and the Waste Management Regulatory Authority (WMRA) developed a national strategy and action plan for CDW Management. The studies conducted in relation to the Action Plan development estimated that the total annual generation of CDW waste in 2021 was approximately 40 million tons per year, in addition to 200 million tons accumulated from previous years and dumped across Egyptian cities in formal and informal dump sites (HBRC, 2021). This strategy encompasses six main strategic directions, including the active involvement of the private sector in constructing transport, collection, and recycling infrastructure (Attia, 2020).

Despite several attempts by private entities to establish CDW recycling plants, these initiatives have often failed due to insufficient awareness of the economics of CDW recycling and the lack of detailed studies on construction and operational costs necessary to ensure profitability for private investors.

In line with the state’s commitment to improving waste management, the Integrated Solid Waste Management Act (Act No. 202 of 2020) was promulgated, promoting partnerships between the private sector and municipalities to establish specialized companies for construction and demolition waste management (Attia, 2020).

These legal and strategic developments underscore the growing recognition of CDW recycling as a critical component of sustainable urban development and highlight the urgent need for comprehensive economic frameworks to guide the establishment of viable recycling facilities in Egypt.

Despite numerous studies on CDW recycling, several gaps remain in the Egyptian context. Existing research provides limited economic feasibility analyses at the governorate level, lacks localized cost data reflecting current market conditions and inflation, and rarely compares government-led models with Public Private Partnership (PPP) frameworks. Additionally, sensitivity analyses tailored to the Egyptian CDW market are scarce.

This study addresses these gaps by developing a region-specific financial model for a fixed CDW recycling plant in Sharqia Governorate, evaluating both total costs and economic feasibility under a PPP approach.

Research Objectives

This research aims to achieve the following objectives:

a) Estimate the total costs of collecting, processing, establishing, and operating a construction and demolition waste (CDW) recycling plant in Sharqia Governorate, based on expert-informed technical and economic data.
b) Assess the economic feasibility of the proposed plant using a financial model that integrates private sector participation within the governmental framework, considering all costs and projected revenues from recycled aggregate production.
c) Perform a sensitivity analysis to evaluate the impact of changes in key variables such as prices, operational costs, and production output on the project's profitability and economic viability.

2. Literature Review

Research on construction and demolition waste (CDW) management has expanded significantly in recent decades, particularly in relation to recycling technologies, economic feasibility assessment, and public–private partnership (PPP) models for waste management infrastructure. This section provides an overview of the most relevant studies that form the conceptual and methodological foundation of the present research.

2.1 CDW Generation and Recycling Practices

Several studies have examined the scale of CDW generation and the challenges associated with its management. Shen et al. (2004) defined CDW as a mixture of surplus materials resulting from construction, renovation, and demolition activities.

Tam (2008) compared conventional aggregate production with recycled aggregate production, concluding that recycling can be both technically feasible and economically beneficial in urban areas with high waste generation rates. These findings highlight the environmental and economic potential of CDW recycling, especially in developing countries seeking sustainable construction solutions.

2.2 Technical Approaches for CDW Recycling

Boesman (1985) presented two widely referenced flowcharts describing processing systems for concrete waste, forming an early basis for subsequent technological studies.

More recent research, such as that by Coelho and de Brito (2013), analyzed different recycling plant configurations and their operational performance, emphasizing the impact of crushing and screening technologies on production efficiency and aggregate quality. These studies support the technical foundation for evaluating recycling plants in the Egyptian context.

2.3 Economic Feasibility Studies of Recycling Plants

Economic assessment has been central to several studies. El-Shaboury et al. (2018) conducted a comprehensive technical and financial model for concrete recycling in Egypt, demonstrating that recycled aggregates can be competitive with natural aggregates under specific economic conditions.

Coelho and de Brito (2013) similarly assessed capital and operational costs, highlighting the importance of scale, labor, energy consumption, and maintenance in determining feasibility. Such studies provide methodological guidance for financial modelling in the present research.

2.4 Public–Private Partnership (PPP) Models in Waste Management

PPP models have gained significant traction as strategic mechanisms to enhance investment efficiency and optimize risk distribution in waste infrastructure. International literature suggests that integrating private sector expertise not only improves operational performance and accelerates project delivery but also substantially alleviates fiscal burdens on municipal budgets (Dallas et al., 2024).

However, moving from theoretical benefits to long-term financial sustainability remains a complex challenge. The researchers stress that success depends on strong pricing policies, operating cost-sharing mechanisms, and decisive, precise distribution of risks in relation to market demand for recycled products.

In the Egyptian context, the feasibility of such partnerships is often tested by fluctuations in operational costs and economic fluctuations. Therefore, these ideas require rigorous financial evaluation, and the development of the PPP model in this research is guided by a sensitivity testing analysis of the most important critical variables that specifically consider labor costs, administrative expenses, and market-driven price changes.

3. Research Methodology

This study uses the descriptive analytical approach to evaluate the technical and financial feasibility of establishing a construction and demolition waste recycling plant (CDW) in Sharqia Governorate, Egypt. The methodology integrates data to estimate total costs, forecast revenues, and assess the potential for private sector participation.

3.1 Data Sources

The study relied primarily on data from an extensive review of previous research, technical reports, national and international regulations, and documented case studies on the construction and demolition of waste management and recycling practices. This review included published studies on recycling plant configurations, equipment performance, operational requirements, labor structures, capital and operating cost components, and economic assessments of similar facilities.

These sources provided the foundational technical and financial parameters used in developing the feasibility model and ensured that the assumptions adopted in the analysis reflect established industry practices and evidence-based benchmarks.

3.2 Economic analysis

The financial model estimates the total costs and expected revenues from the sale of recycled raw materials. Sensitivity analysis was performed to examine the effects of changes in key variables such as selling prices, operating costs, and production quantities on the project's profitability and its operation's sustainability.

3.3 Model Validation

Given that this study is based on a feasibility model rather than real operational data, the reliability of the estimations was ensured through rigorous internal consistency checks. The financial and technical assumptions were cross-verified with experts in the field to confirm that the cost components, production rates, and market-based parameters used in the model align with realistic industry conditions. This validation process strengthens the credibility of the model and supports the accuracy of the projected outcomes.

4. Technical and Financial Analysis of the Recycling Plant

4.1 Equipment Required for a Recycling Station

According to Trevorrow, Joynes, and Wainwright (1986), a typical recycling facility for processing concrete and producing crusher-operating materials in the United Kingdom should be equipped with the following machinery:

1. Wheel loader
2. Trucks
3. Vibratory feeder
4. Jaw crusher or impact crusher (primary crushing)
5. Cone crusher (secondary crushing)
6. Straight or swing conveyor with screening unit
7. Permanent magnetic separator
8. Sand washer

These components form the essential configuration required for efficient processing of construction and demolition of waste (CDW) and for producing high-quality recycled aggregates.

4.2 Types of Crushers Used

Crushers vary according to project requirements, desired aggregate specifications, production capacity, input material characteristics, and mobility needs. Common crusher types include jaw crushers, cone crushers, and impact crushers.

This study focuses on jaw crushers and cone crushers, as they are the most widely used in stationary recycling plants and are well-suited for treating concrete waste.

These selected crushers serve as the basis for the technical and financial modeling of the proposed recycling plant, ensuring alignment between equipment performance, production capacity, and economic feasibility.

4.3 Crushers and Their Technical Characteristics

4.3.1 Jaw Crusher

Jaw crushers are among the most used primary crushers in recycling facilities and quarries. The crushing process relies on cyclic compressive forces applied to the material until it is reduced and discharged from the chamber.

A jaw crusher consists of two inclined jaws in Figure (4-1), forming a converging V-shaped chamber. The typical angle between the jaws ranges from 19° to 22°, enabling the crusher to process extremely hard rock materials effectively.

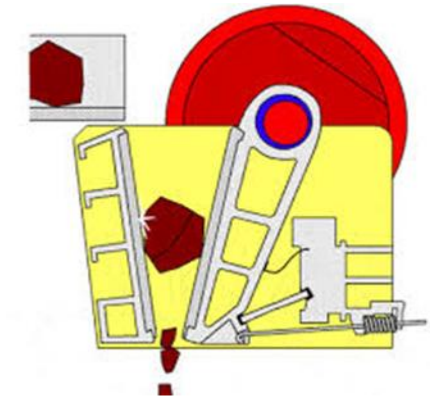

Fig. (4-1): Jaw Crusher side view diagram (Marmash & Elliott,2000)

The crushing process is defined by two key positions:

- Close Side Setting (CSS): minimum distance between the jaws
- Open Side Setting (OSS): maximum distance between the jaws

Jaw crushers are typically used as the primary crusher in concrete recycling plants (Marmash & Elliott, 2000).

4.3.2 Impact Crusher

Impact crushers operate by striking materials with high-speed rotating masses rather than applying compressive force. The kinetic energy imparted to the material causes fragmentation upon collision.

The crushed material is discharged by gravity and may pass through a screening grid to reduce oversize particles. Figure (4-2) shows the side view of the impact crusher.

Impact crushers are available in two major categories:

- Horizontal Shaft Impactors (HSI)
- Vertical Shaft Impactors (VSI)

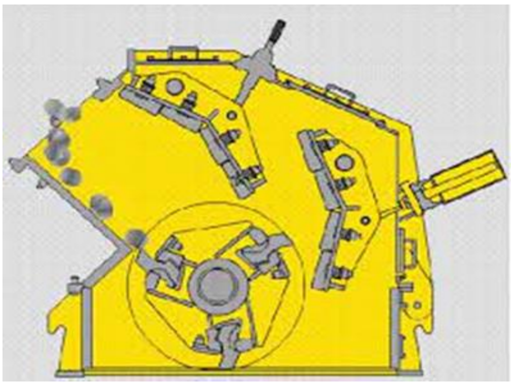

Fig. (4-2): Impact Crusher side view diagram (Marmash & Elliott,2000)

Impact crushers are especially effective in producing fine aggregates and reducing particle elongation, generating angular yet uniform grains (Marmash & Elliott, 2000).

4.3.3 Cone Crusher

Cone crushers serve as secondary crushers in concrete recycling plants. Crushing occurs through combined compressive and shear forces between a rotating cone and a fixed concave surface.

The material is progressively reduced as it moves down through the narrowing chamber. The crusher's performance is influenced by factors such as:

- Input size
- Material hardness
- Closed Side Setting (CSS)

Cone crushers offer consistent particle shape, high productivity, and reduced wear rates, making them particularly suitable for recycling applications.

5. The Government Model: Objective and Purpose

The government model is designed to serve as a reference scenario for the establishment and operation of a fixed construction and demolition waste (CDW) recycling plant in Sharqia Governorate. Its primary purpose is to evaluate the feasibility, technical requirements, and financial performance of a publicly managed facility that can efficiently process CDW into reusable construction materials.

By focusing on the public-sector approach, this model provides a baseline framework for assessing operational procedures, resource allocation, and cost structures, which will later serve as a benchmark for comparison with alternative investment and operational scenarios, such as the Public–Private Partnership (PPP) model.

5.1 Main Assumptions of the Government Model

The proposed government model is developed based on a set of technical, financial, and operational assumptions that reflect the characteristics of public-sector investment in the construction and demolition of waste recycling projects. These assumptions form the basis for all financial calculations and performance indicators adopted in the model.

In addition, human resource assumptions constitute a key component of the government model, as workforce size, skill composition, and wage levels directly influence operating costs and overall financial performance. The employment structure adopted in this study is based on the technical requirements of a fixed recycling plant with a production capacity of 200 tons per hour and is consistent with public-sector employment practices.

Table (5-1) presents the number of workers, skill categories, and corresponding salary levels incorporated into the model. This workforce classification is primarily based on the framework proposed by Hassanein (2014), with salary values adjusted to reflect current Egyptian market conditions, considering expert judgment and input from relevant stakeholders.

This approach ensures consistency and enables financial comparability between the government sector operation scenario and the private sector participation scenario.

Moreover, the observed differences in the government sector financial model scenario or participation model are primarily due to ownership, financing structure, and risk allocation mechanisms, rather than to differences in operational assumptions.

Table (5-1) Workers' Plan Showing All Employees' Salaries for 200 TPH fixed recycling plant

Labor Category	*Number of Workers*	*Salary/Month (EGP)*	*Total Salary/Year (EGP)*	*Operational Assignment*
Highly Skilled Labor	4	8,500	408,000	Haul input (2), Monitoring (1), Transportation (1)
Semi-Skilled Labor	4	7,500	360,000	Feeder (1), Primary Crushing (1), Secondary Crushing (1), Screening (1)
Normal Skilled Labor	8	5,000	480,000	Manual Filtering
Engineers	1	15,000	180,000	Overall Plant Monitoring
Foreman	1	10,000	120,000	Operations Supervision
Total	**18**	**46,000**	**1,548,000**	-

The main assumptions of the government model are summarized as follows:

- The recycling facility is assumed to be a single fixed plant with a production capacity of 200 tons per hour.
- The total number of plants considered in the model is one plant.
- **Working schedule:** 10 hours/day, 250 days/year.
- **Selling price:** EGP 100 per ton.
- **Annual production and sales:** 100% of total recycled output is assumed to be sold.
- **Total initial investment:** EGP 100 million, fully financed by the government.
- Government contribution: 100% public funding (no private sector participation).
- **Depreciation:** Annual depreciation is estimated at EGP 5 million.
- **Annual salary increases:** 12% per year.
- **Utility cost escalation:** Utility costs increase annually at a rate equivalent to the inflation rate of 12.8%.
- **Rent escalation:** Annual rent increase rate of 15%.
- **Salvage value:** At the end of the study period, the residual value of equipment is assumed to be 50% of the initial investment.
- **Study period:** 10 years.

5.2 Results and Discussion of the Government Model

The financial and operational performance of the proposed government-owned recycling plant was evaluated based on the assumptions described previously.

Table (5-2) presents the key financial indicators, including total annual costs, revenues from recycled materials, and net cash flows over the 10-year study period.

Table (5-2): Projected Income Statement for the Proposed Government Model with a Station Capacity of 200 TPD over 10 years

200 TPH Income Statement	1	2	3	4	5	6	7	8	9	10
Revenue	27,000,000	30,456,000	34,354,368	38,751,727	43,711,948	49,307,078	55,618,383	62,737,537	70,767,941	79,826,238
Cost of Goods Sold	6,750,000	7,614,000	8,588,592	9,687,932	10,927,987	12,326,769	13,904,596	15,684,384	17,691,985	19,956,559
Gross Profit	20,250,000	22,842,000	25,765,776	29,063,795	32,783,961	36,980,308	41,713,788	47,053,152	53,075,956	59,869,678
Total Salaries	1,548,000	1,733,760	1,941,811	2,174,829	2,435,808	2,728,105	3,055,478	3,422,135	3,832,791	4,292,726
Total Depreciation	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000
Rent	180,000	207,000	238,050	273,758	314,821	362,044	416,351	478,804	550,624	633,218
Utilities	2,700,000	3,045,600	3,435,437	3,875,173	4,371,195	4,930,708	5,561,838	6,273,754	7,076,794	7,982,624
Initial Investment	100,000,000	-	-	-	-	-	-	-	-	-
Administrative Expense	4,050,000	4,568,400	5,153,155	5,812,759	6,556,792	7,396,062	8,342,758	9,410,630	10,615,191	11,973,936
Total Expense	20,228,000	22,168,760	24,357,045	26,824,450	29,606,603	32,743,688	36,281,020	40,269,707	44,767,386	49,839,063
Net Profit	6,772,000	8,287,240	9,997,323	11,927,278	14,105,345	16,563,390	19,337,363	22,467,830	26,000,556	29,987,175
Profit Margin %	25.08	27.21	29.10	30.78	32.27	33.59	34.77	35.81	36.74	37.57

The results indicate that the proposed recycling plant can process 200 tons per hour while generating stable revenues under the assumed selling price of 100 Egyptian pounds per ton.

However, operating costs, including labor, utilities, and maintenance, are strongly affected by the assumed annual inflation rate (12.8%) and the annual salary increase rate (12%).

This highlights the sensitivity of the financial model to variations in key economic parameters, particularly cost-related assumptions.

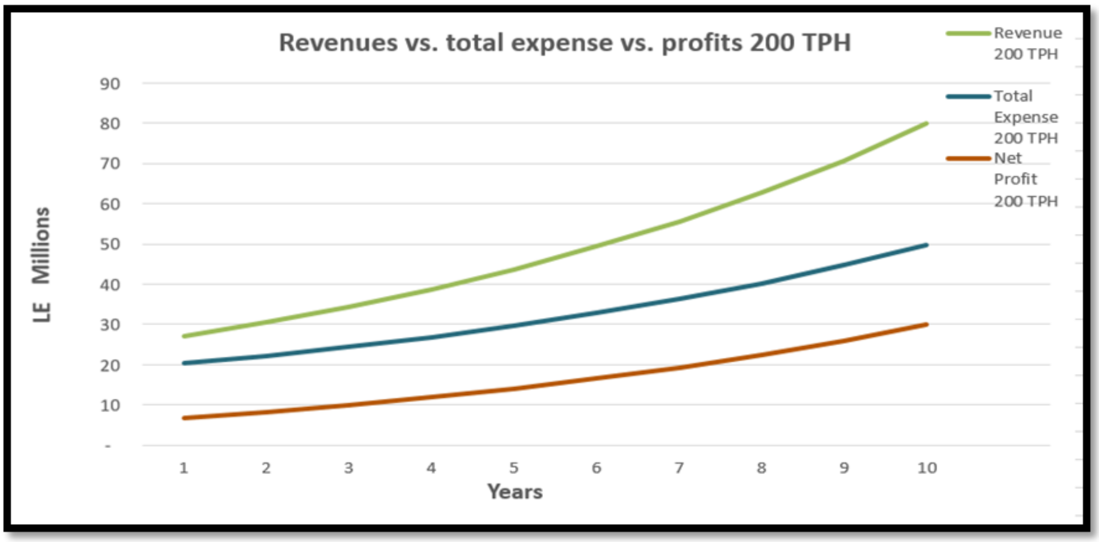

Fig. (5-1): Projected Revenues, Total Expenses, and Net Profit for the Proposed Government Model (200 TPH) over 10 years

Figure (5-1) shows that over ten years, revenues steadily increase while total expenses rise more moderately, resulting in a consistent upward trend in net profits and improved financial performance of the government-operated recycling plant.

5.2.1 Sensitivity Analysis

A sensitivity analysis was conducted to assess the impact of key expenditure variables on the financial performance of the proposed government recycling plant. The analysis focused on the main cost components contributing approximately 80% of total operating costs: Cost of Goods Sold (COGS), administrative expenses, and total salaries.

Table (5-3): Sensitivity Analysis of Financial Results (Total Expenses, Net Profit, and Profit Margin)

0% (original)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Revenue	27,000,000	30,456,000	34,354,368	38,751,727	43,711,948	49,307,078	55,618,383	62,737,537	70,767,941	79,826,238
Total Expense (Original)	12,348,800	13,916,160	15,683,558	17,675,520	19,920,587	22,450,936	25,302,832	28,517,149	32,139,967	36,223,221
Net profit (Original)	14,651,200	16,539,840	18,670,810	21,076,207	23,791,361	26,856,142	30,315,551	34,220,388	38,627,974	43,603,017
Profit Margin % (Original)	54.26	54.31	54.35	54.39	54.43	54.47	54.51	54.55	54.58	54.62

− 20%	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Total Expense -20%	9,878,400	11,132,928	12,546,847	14,140,416	15,936,470	17,960,749	20,242,265	22,813,720	25,711,974	28,978,577
Net profit -20%	17,121,600	19,323,072	21,807,521	24,611,312	27,775,478	31,346,329	35,376,119	39,923,817	45,055,967	50,847,661
Profit Margin -20%	63.41	63.45	63.48	63.51	63.54	63.57	63.61	63.64	63.67	63.70
% variation from original (-20%)	16.86	16.83	16.80	16.77	16.75	16.72	16.69	16.67	16.64	16.62

− 10%	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Total Expense -10%	11,113,200	12,524,544	14,115,203	15,907,967	17,928,529	20,205,842	22,772,548	25,665,434	28,925,971	32,600,899
Net profit -10%	15,886,800	17,931,456	20,239,165	22,843,760	25,783,420	29,101,235	32,845,836	37,072,102	41,841,970	47,225,339
Profit Margin -10%	58.84	58.88	58.91	58.95	58.98	59.02	59.06	59.09	59.13	59.16
% variation from original (-10%)	8.43	8.41	8.40	8.39	8.37	8.36	8.35	8.33	8.32	8.31

+20%	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Total Expense +20%	14,817,600	16,699,392	18,820,270	21,210,623	23,904,705	26,941,123	30,363,397	34,220,579	38,567,961	43,467,865
Net profit +20%	12,182,400	13,756,608	15,534,098	17,541,104	19,807,243	22,365,954	25,254,986	28,516,957	32,199,980	36,358,373
Profit Margin +20%	45.12	45.17	45.22	45.27	45.31	45.36	45.41	45.45	45.50	45.55
% variation from original (+20%)	(16.85)	(16.83)	(16.80)	(16.77)	(16.75)	(16.72)	(16.69)	(16.67)	(16.64)	(16.62)

+10%	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Total Expense +10%	13,582,800	15,307,776	17,251,914	19,443,071	21,912,646	24,696,030	27,833,114	31,368,864	35,353,964	39,845,543
Net profit +10%	13,417,200	15,148,224	17,102,454	19,308,656	21,799,302	24,611,048	27,785,269	31,368,672	35,413,977	39,980,695
Profit Margin +10%	49.69	49.74	49.78	49.83	49.87	49.91	49.96	50.00	50.04	50.08
% variation from original (+10%)	(8.42)	(8.41)	(8.40)	(8.39)	(8.37)	(8.36)	(8.35)	(8.33)	(8.32)	(8.31)

Percentage variations of −20%, −10%, 0% (baseline), +10%, and +20% were applied to these variables, and their effects on total expenses, net profit, and profit margin were evaluated.

The Table (5-3) illustrates the sensitivity of total expenses, net profit, and profit margin to ±10% and ±20% variations in key inputs. They highlight the responsiveness of financial outcomes to changes in operational and cost factors, providing insights for risk assessment and supporting confidence in the model's projections, which are further analyzed in the model validation section.

5.2.2 Model Validation Based on Sensitivity Analysis Results

The government model has been validated through sensitivity analysis to ensure reliable financial results. Adjusting key expense criteria by ±10% and ±20% over the ten years showed a consistent and expected behavior: lower costs increase the profit margin, while higher costs reduce it.

For instance, a 20% reduction in expenses raised the profit margin by approximately +16.8% in the first year, stabilizing at about +16.6% by the tenth year, whereas a 20% increase reduced it by a similar magnitude.

Sensitivity Analysis results (Table 5-3) further illustrate a linear and symmetric relationship:

a 10% and 20% increase in total expenses reduced net profit by 8.3% and 16.6% and decreased the profit margin to 49.7% and 45.1%, respectively, while equivalent decreases in expenses increased net profit by 8.3% and 16.8% and raised the profit margin to 58.8% and 63.4%.

These results confirm the robustness and reliability of the governmental model, highlighting the critical role of cost management and providing a solid foundation for subsequent analysis of the public-private partnership (PPP) model.

6. Public–Private Partnership (PPP) Model: Objective and Purpose

The Public–Private Partnership (PPP) model is developed to assess the feasibility, financial performance, and operational efficiency of establishing and operating a fixed construction and demolition waste (CDW) recycling plant in Sharqia Governorate with private sector participation.

This model's main goal is to leverage the strengths of the public and private sectors. In this framework, the private sector contributes capital, managerial expertise, and operational efficiency, while the public sector ensures regulatory oversight, environmental protection, and alignment with national waste management policies.

This collaborative approach creates a profit-oriented and efficiency-driven investment environment, providing a robust foundation for encouraging private sector involvement in sustainable infrastructure projects in developing countries.

6.1 Main assumptions of the Private Sector Participation Model (PPP)

- **Plant capacity:** 200 tons/hour with an average operational efficiency of 80%.
- **Working schedule:** 10 hours/day, 250 days/year.
- **Selling price:** EGP 100 per ton.
- **Annual production and sales:** 100% of total recycled output is assumed to be sold.
- **Total initial investment:** EGP 100 million, covering equipment, installation, and operational setup.
- **Government contribution:** Land provided as an in-kind share equivalent to 30% of the total investment.
- **Private sector contribution:** 70% cash contribution covering equipment, operation, and working capital.
- **Depreciation:** Annual depreciation is estimated at EGP 5 million.
- **Annual salary increases:** 10% per year, reflecting private sector wage adjustments.
- **Utility cost escalation:** Utility costs increase annually at the inflation rate of 12.8%.
- **Rent escalation:** Annual rent increase rate of 15%, where applicable.
- **Profit distribution:** 30% government, 70% private sector.

International Journal of Multiphysics
Volume 18, No. 3, 2024
ISSN: 1750-9548

- **Salvage value:** At the end of the study period, the residual value of equipment is assumed to be 50% of the initial investment.
- **Study period:** 10 years.
- **Labor structure:** The same number of employees, job categories, and basic salary levels are employed as shown in Table (5-1). In the government model, to be able to make a fair comparison between the two models.

6.2 Results and Discussion of the PPP Model

The financial performance of the proposed Public-Private Partnership (PPP) model is evaluated based on the technical, operational, and economic assumptions of a 200-ton-per-hour fixed construction and demolition waste (CDW) recycling plant.

The results indicate that the public-private partnership framework provides an efficient and balanced operational structure, with the government contributing 30% of total investment primarily through the provision of in-kind land, while the private sector finances and manages the remaining 70%. This arrangement supports stable financial performance and sustainable profitability throughout the study period.

Table (6-1): Income statement projections for the public-private partnership model with a capacity of 200 tons/hour for a period of 10 years

The results contained in the expected income statement shown in Table (6-1) also indicate that the gross profit margin rises from 42.5% in the first year to 48.1% by the tenth year, with the government's share increasing from 12.7% to 14.4% and the private sector's share from 29.8% to 33.7%, reflecting its greater financial and administrative participation.

Overall, these results confirm that the PPP model effectively integrates public sector oversight with private sector efficiency, enhancing operational efficiency, profitability, and long-term sustainability while being aligned with the Sustainable Development Goal (SDG 17).

These results further highlight that the PPP structure not only enhances profitability but also promotes risk-sharing and operational efficiency, providing valuable insights for future investments in sustainable waste management projects.

6.3 Sensitivity Analysis of the PPP Model

200 TPH Income Statement	1	2	3	4	5	6	7	8	9	10
Revenue	36,000,000	40,608,000	45,805,824	51,668,969	58,282,598	65,742,770	74,157,845	83,650,049	94,357,255	106,434,984
Cost of Goods Sold	6,750,000	7,614,000	8,588,592	9,687,932	10,927,987	12,326,769	13,904,596	15,684,384	17,691,985	19,956,559
Gross Profit	29,250,000	32,994,000	37,217,232	41,981,038	47,354,611	53,416,001	60,253,249	67,965,665	76,665,270	86,478,424
Total Salaries	1,548,000	1,702,800	1,873,080	2,060,388	2,266,427	2,493,069	2,742,376	3,016,614	3,318,275	3,650,103
Total Depreciation	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000
Utilities	2,000,000	2,256,000	4,580,582	5,166,897	5,828,260	6,574,277	7,415,784	8,365,005	9,435,725	10,643,498
Initial Investment	100,000,000	-	-	-	-	-	-	-	-	-
Administrative Expense	5,400,000	6,091,200	6,870,874	7,750,345	8,742,390	9,861,416	11,123,677	12,547,507	14,153,588	15,965,248
Total Expense	20,698,000	22,664,000	26,913,128	29,665,562	32,765,063	36,255,531	40,186,433	44,613,510	49,599,575	55,215,408
Net Profit	15,302,000	17,944,000	18,892,696	22,003,407	25,517,534	29,487,239	33,971,411	39,036,538	44,757,680	51,219,575
Net Profit for Gov.	4,590,600	5,383,200	5,667,809	6,601,022	7,655,260	8,846,172	10,191,423	11,710,962	13,427,304	15,365,873
Net Profit for Private	10,711,400	12,560,800	13,224,887	15,402,385	17,862,274	20,641,067	23,779,988	27,325,577	31,330,376	35,853,703
Profit Margin %	42.51	44.19	41.25	42.59	43.78	44.85	45.81	46.67	47.43	48.12
Profit Margin % for Gov.	12.75	13.26	12.37	12.78	13.13	13.46	13.74	14.00	14.23	14.44
Profit Margin %for Private	29.75	30.93	28.87	29.81	30.65	31.40	32.07	32.67	33.20	33.69

Sensitivity Analysis 20%	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cost of Goods Sold	8,100,000	9,136,800	10,306,310	11,625,518	13,113,584	14,792,123	16,685,515	18,821,261	21,230,382	23,947,871
Administrative Expense	6,480,000	7,309,440	8,245,048	9,300,415	10,490,868	11,833,699	13,348,412	15,057,009	16,984,306	19,158,297
Total Salaries	1,857,600	2,043,360	2,247,696	2,472,466	2,719,712	2,991,683	3,290,852	3,619,937	3,981,931	4,380,124

Sensitivity Analysis 10%	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cost of Goods Sold	7,425,000	8,375,400	9,447,451	10,656,725	12,020,786	13,559,446	15,295,055	17,252,823	19,461,184	21,952,215
Administrative Expense	5,940,000	6,700,320	7,557,961	8,525,380	9,616,629	10,847,557	12,236,044	13,802,258	15,568,947	17,561,772
Total Salaries	1,702,800	1,873,080	2,060,388	2,266,427	2,493,069	2,742,376	3,016,614	3,318,275	3,650,103	4,015,113

Sensitivity Analysis 0% (original)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cost of Goods Sold	6,750,000	7,614,000	8,588,592	9,687,932	10,927,987	12,326,769	13,904,596	15,684,384	17,691,985	19,956,559
Administrative Expense	5,400,000	6,091,200	6,870,874	7,750,345	8,742,390	9,861,416	11,123,677	12,547,507	14,153,588	15,965,248
Total Salaries	1,548,000	1,702,800	1,873,080	2,060,388	2,266,427	2,493,069	2,742,376	3,016,614	3,318,275	3,650,103

A sensitivity analysis was conducted to evaluate the robustness of the PPP financial model under varying economic and operational conditions. Consistent with the governmental model, key variables, cost of goods sold, total salaries, and administrative expenses were tested using ±10% and ±20% deviations from the baseline over the ten-year operating period, as presented in Table (6-2).

Table (6-2): Impact of Expenditure Variations on Financial Indicators under the PPP Framework

Sensitivity Analysis -20%	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cost of Goods Sold	5,400,000	6,091,200	6,870,874	7,750,345	8,742,390	9,861,416	11,123,677	12,547,507	14,153,588	15,965,248
Administrative Expense	4,320,000	4,872,960	5,496,699	6,200,276	6,993,912	7,889,132	8,898,941	10,038,006	11,322,871	12,772,198
Total Salaries	1,238,400	1,362,240	1,498,464	1,648,310	1,813,141	1,994,456	2,193,901	2,413,291	2,654,620	2,920,082

Sensitivity Analysis -10%	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cost of Goods Sold	6,075,000	6,852,600	7,729,733	8,719,139	9,835,188	11,094,092	12,514,136	14,115,946	15,922,787	17,960,903
Administrative Expense	4,860,000	5,482,080	6,183,786	6,975,311	7,868,151	8,875,274	10,011,309	11,292,757	12,738,229	14,368,723
Total Salaries	1,393,200	1,532,520	1,685,772	1,854,349	2,039,784	2,243,763	2,468,139	2,714,953	2,986,448	3,285,093

The results show that a 20% increase in costs negatively affects the net profit margin and may delay capital recovery, while cost reductions of 10–20% lead to noticeable improvements in profitability indicators.

Overall, the PPP model demonstrates strong financial resilience, maintaining acceptable economic performance under moderate cost fluctuations due to effective risk and return sharing between the public and private partners.

6.4 Comparative Analysis between the Governmental Model and the PPP Model

Table (6-3) presents a comparative assessment of the PPP and governmental model over the ten-year operating period, highlighting differences in revenues, total expenses, net profit, and profit margin.

Table (6-3): Variations of the PPP Model Relative to the Governmental Model (Revenue, Expenses, Net Profit, and Profit Margin)

Variations PPP Relative to the Governmental Model	1	2	3	4	5	6	7	8	9	10
Revenue %	33.33	33.33	33.33	33.33	33.33	33.33	33.33	33.33	33.33	33.33
Total Expense %	2.32	2.23	10.49	10.59	10.67	10.73	10.76	10.79	10.79	10.79
Net Profit %	125.96	116.53	88.98	84.48	80.91	78.03	75.68	73.74	72.14	70.80
Profit Margin %	69.47	62.39	41.73	38.36	35.68	33.52	31.76	30.31	29.11	28.10

The results show that the PPP model consistently generates higher revenues than the governmental model, with a constant increase of 33.33% across all operating years, reflecting enhanced operational efficiency and performance-driven management under private-sector participation.

Total expenses under the PPP model increase modestly, rising by 2.32–2.23% in the first two years and stabilizing at 10.5–10.8% thereafter, indicating controlled cost growth relative to revenue gains.

Net profitability under the PPP model is higher, exceeding the governmental model by 125.96% in the first year and remaining about 70.80% higher by the tenth year. Similarly, the profit margin shows a significant improvement, increasing by 69.47% initially and remaining 28.10% higher at the end of the study period.

Overall, the findings confirm that the PPP model outperforms the governmental model in terms of revenue generation, net profit, and profit margin, while maintaining a moderate increase in total expenses. This demonstrates the economic efficiency and financial sustainability of the PPP framework as a viable alternative for developing and operating construction and demolition of waste recycling plants in Sharqia Governorate.

By comparing the results obtained from the two previous proposed models (the government sector model and the public-private partnership model) with the results of previous studies to evaluate their validity and consistency.

The results indicated that the financial feasibility of the fixed construction and demolition waste recycling plant identified in this study is consistent with the conclusions of El-Shaboury et al. (2018), who asserted that recycling construction waste in Egypt can be economically viable under stable market conditions and controlled operating costs.

In addition, the superior financial performance and operational efficiency observed in the PPP model are consistent with the findings of Coelho and de Brito (2013), who highlighted the advantages of private sector participation in improving efficiency and risk allocation in recycling projects.

Moreover, the sustainability results of the proposed model are consistent with studies such as Tam et al. (2018), which emphasized the role of construction waste recycling in supporting the principles of resource conservation and the circular economy.

While earlier research by Tam (2008) focused on the technical and economic viability of such initiatives, this study demonstrates that these financial gains are inextricably linked to long-term environmental sustainability.

Overall, the agreement between current findings and previous literature spanning from initial feasibility to modern circularity enhances the strength of the proposed models and confirms their applicability to the local conditions of Sharqia Governorate.

7. Conclusion and Future Research

This study evaluated the financial and economic feasibility of establishing a fixed construction and demolition waste (CDW) recycling plant with a capacity of 200 tons per hour in Sharqia Governorate under two alternative institutional frameworks:

a purely governmental model and a Public–Private Partnership (PPP) model. A comprehensive financial analysis, supported by sensitivity and comparative assessments, was conducted to examine the performance, robustness, and sustainability of each model over a ten-year operating period.

The results demonstrate that while the governmental model provides a stable and conservative financial structure, the PPP model significantly outperforms it in terms of revenue generation, net profitability, and profit margin. The improved performance of the PPP framework is attributed to private sector operational efficiency, performance-driven management, and effective risk-sharing mechanisms. Sensitivity analysis further confirms the resilience of both models; however, the PPP model maintains stronger financial viability under varying cost scenarios, reinforcing its suitability for long-term investment.

Overall, the findings suggest that the PPP model offers a more economically efficient and financially sustainable approach for developing and operating CDW recycling plants in Sharqia Governorate. In addition to enhancing profitability, the PPP framework supports public-sector objectives related to environmental protection and resource efficiency while aligning with Sustainable Development Goal 17, which emphasizes partnerships for sustainable development.

Future Research Directions

1. Environmental and Life-Cycle Analysis:

Future studies could expand upon this framework by integrating Environmental Impact Assessments (EIA) and Life-Cycle Cost Analysis (LCCA). Quantifying the carbon emission reduction benefits associated with CDW recycling would further align localized projects with global circular economy benchmarks.

2. Optimization of PPP and Financing Frameworks:

There is a significant opportunity to explore alternative Public-Private Partnership (PPP) structures and innovative financing mechanisms tailored to market volatility. Refining risk allocation schemes remains essential to enhance investment attractiveness and financial resilience for private sector participants.

3. Geographical Scalability and Advanced Modeling:

Finally, expanding this analysis to other governorates or incorporating uncertainty-based modeling approaches would strengthen national waste management strategies. Such advancements would provide policymakers with more robust, data-driven frameworks for navigating the complexities of the construction waste sector.

References

1. Attia, T. (2020); “Towards a National Strategy for C&D Waste Management in Egypt Construction and Demolition Waste Management,
2. . https://www.researchgate.net/publication/348326626
3. Boesman, W. C. (1985). Public-private partnerships in science and technology. Congressional Research Service, Library of Congress.
4. Coelho, A., and Brito, J.D., 2013, "Economic viability analysis of a construction and demolition waste recycling plant in Portugal - part I: Location, materials, technology and economic analysis", Journal of Cleaner Production, Vol. 39, pp. 338-352.
5. Coelho, A., and Brito, J.D., 2013, "Economic viability analysis of a construction and demolition waste recycling plant in Portugal Part II: Economic sensitivity analysis ", Journal of Cleaner Production, Vol. 39, pp. 329-337.

6. Dallas, B., Andrewson, S., & Dave, A. (2024). Public–Private Partnership (PPP) Models and Hybrid Decision Frameworks for Recycling Infrastructure. Advances in Recycling & Waste Management, 9(5), 211. https://doi.org/10.35248/2475-7675.24.9.211
7. El-Shaboury, N., Abdelhamid, M., & Marzouk, M. (2019). Framework for economic assessment of concrete waste management strategies. *Waste Management and Research*, *37*(3), 268–277. https://doi.org/10.1177/0734242X18815962
8. Franklin, W. E. (1998). Characterization of building-related construction and demolition debris in the United States. US Environmental Protection Agency.
9. Gálvez-Martos, J. L., Styles, D., Schoenberger, H., & Zeschmar-Lahl, B. (2018). Construction and demolition waste best management practice in Europe. Resources, conservation, and recycling, 136, 166-178. https://doi.org/10.1016/j.resconrec.2018.04.016
10. Hassanein, O. F. (2014). Recycling concrete construction and demolition wastes: A financial feasibility model [Master's Thesis, the American University in Cairo]. AUC Knowledge Fountain. https://fount.aucegypt.edu/etds/1226
11. HBRC (2021). Action Plan for the National CDW Management Strategy for Egypt, Ministry of environment, Housing and Building National Research Center, Egypt; Sept. 2021.
12. Hussin, J. M., Rahman, I. A., & Memon, A. H. (2013). The way forward in sustainable construction: issues and challenges. International Journal of Advances in Applied Sciences, 2(1), 15-24.
13. Iacoboaea, C., Aldea, M., & Petrescu, F. (2019). Construction and demolition waste-a challenge for the European Union? *Theoretical and empirical research in urban management*, *14*(1), 30-52.
14. Marmash, N., & Elliott, T. (2000). Feasibility of construction and demolition of waste recycling. (Technical Report).
15. Menegaki, M., & Damigos, D. (2018). A review of current situations and challenges of construction and demolition of waste management. Current Opinion in Green and Sustainable Chemistry, 13, 8-15.
16. Shen, L. Y., Tam, V. W., Tam, C. M., & Drew, D. (2004). Mapping approach for examining waste management on construction sites. *Journal of construction engineering and management*, *130*(4), 472-481.
17. Tam, V. W. Y. (2008). Economic comparison of concrete recycling: A case study approach. Resources, Conservation and Recycling, 52(5), 821-828. https://doi.org/10.1016/j.resconrec.2007.12.001
18. Tam, V. W. Y., Soomro, M., & Evangelista, A. C. J. (2018). A review of recycled aggregate in concrete applications, 2000–2017. Construction and Building Materials, 172, 272-292. https://doi.org/10.1016/j.conbuildmat.2018.03.136
19. Trevorrow, A., Joynes, B., & Wainwright, P. (1986). Construction and demolition waste: Disposal and recycling.
20. Villoria Saez, P., Río Merino, M. D., Porras Amores, C., & San Antonio González, A. D. (2011). European legislation and implementation measures in the management of construction and demolition waste. Open Construction & Building Technology Journal, 5(Suplem), 156-161.