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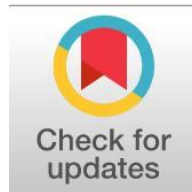
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Adopting Green Value Engineering to Enhance Cost Management Efficiency: An Applied Study

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Abstract

General Background Sustainability requires balancing economic and environmental demands. **Specific Background** Industries face intense pressure to reduce hazardous waste while remaining profitable. **Knowledge Gap** Existing literature lacks integrated models that bridge ecological compliance and budget control in developing nations. **Aims** This study evaluates how adopting this modern methodology optimizes industrial expenditures. **Results** Substituting hazardous materials at an Iraqi facility yielded 9.98% financial savings and a 60% reduction in carbon emissions. High-value resource allocation increased to 57.14%, with the computation stage driving 43% of operational optimization. **Novelty** The research translates abstract ecological goals directly into measurable budget optimizations. **Implications** These findings empower managers to eliminate waste, ensuring long-term economic resilience and regulatory compliance.

Highlights:

- ♦ Substituting toxic lead and plastic with eco-friendly alternatives directly saved 9.98 percent on unit production expenditures.
- ♦ Sustainable material adoption decreased smelting energy requirements by 75 percent and reduced overall carbon footprint by 60 percent.
- ♦ The quantitative computation stage proved to be the strongest statistical predictor of overall financial and ecological optimization.

Keywords: Green Value Engineering, Cost Management Efficiency, Sustainable Manufacturing, Budget Optimization, Ecological Compliance

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1. Introduction and Literature Review

Sustainability has become one of the key pillars of corporate strategy in the current business environment in terms of achieving growth and continuity by considering the economic, environmental, and social aspects (Hossain & Hasan, 2024). Competitive trends force industrial firms to use modern manufacturing technology to reduce the costs of green products and remove non-value-added activities that cause waste (Al-Shafeay, 2024). As a result, there are specific challenges and risks associated with the environmental legislation and costs of pollution control; therefore, the cost analysis becomes necessary to improve competitiveness (Rosengart et al., 2023). Nevertheless, traditional accounting system is unable to generate strategic information because of its narrow-minded short-term nature (Potnik Galic et al., 2021). In order to address this issue, modern management accounting system was developed to provide necessary support in control and achieve sustainable pricing and costing decisions (Hossain & Hasan, 2024). Therefore, Green Value Engineering (GVE) provides an innovative methodology to get rid of waste and offer eco-friendly solutions at reduced life-cycle costs (Gomaa, 2025). Also, the effective management of these variables requires moving from compliance-based management to the strategic one through benchmarking of undesirable outputs such as emissions and (Ubaid et al., 2026). Despite their importance, implementing modern cost management tools in developing countries faces regulatory and technological obstacles (Haron & Zafir, 2025). These challenges are evident in Iraq's battery manufacturing sector, which faces pressure to integrate sustainable production while controlling costs (Al-Shafeay, 2024). Accordingly, this applied study at the General Company for Battery Manufacturing in Iraq presents a practical model demonstrating how GVE stages improve cost management efficiency and convert environmental obligations into financial savings (Al-Shafeay, 2024). Regarding prior studies related to the research topics, they are as follows: Rosengart et al. (2023) evaluated the role of Green Value Engineering (GVE) in capital projects within process industries. Beyond economic indicators, the study incorporated sustainable parameters to mitigate environmental impacts. The findings confirmed that GVE successfully drives organizational transition toward sustainability, environmental preservation, and climate protection. Al-Shafeay (2024) examined the integration of GVE and Green Kaizen in reducing costs and promoting sustainable development. Using a theoretical-analytical approach, the study demonstrated that combining these techniques improves cost estimation accuracy, refines product pricing, and enhances production efficiency to build a sustainable competitive advantage. Lalevée et al. (2023) developed a Sustainable Value Analysis (SVA) framework based on the Doughnut Model to incorporate environmental and social dimensions into complex projects. Through interactive expert workshops, the results showed that this approach aligns stakeholder perspectives and enables balanced decisions that respect planetary boundaries.. Faza et al. (2025) applied Value Engineering to the Green Semesta housing project in Semarang to optimize project budgets under intense market competition. By evaluating creative design alternatives, the study successfully reduced unit production costs and enhanced developer profitability without sacrificing quality or functionality.

On the other hand, studies focusing on cost management are summarized independently as follows: Igwe et al. (2022) investigated the role of digital technologies (BIM, IoT, and AI) in enhancing cost control within construction projects. Utilizing a literature review and statistical analysis, the study revealed that real-time digital data collection streamlines traditional processes, minimizes waste, and optimizes resource efficiency in capital projects. Potnik Galic et al. (2023) proposed an integrated strategic cost management framework combining Target Costing, Activity Based Costing (ABC), and Value Engineering. Applying modeling and simulation to a metal manufacturing firm, the findings confirmed that merging these techniques significantly lowers lifecycle costs and improves product profitability assessment. Alani and Mahmoud (2023) identified key barriers to cost management efficiency in Iraqi construction companies. Analyzing 100 questionnaires via the Relative Importance Index (RII), the results highlighted material price volatility, resource availability, and technical staff expertise as critical factors requiring early control during planning and design. Zhou et al. (2024) conducted a bibliometric review using the PRISMA methodology on 63 Scopus articles (2000–2022) regarding prefabricated construction costs. The study concluded that modern research leans heavily toward integrating BIM and Big Data for precise estimation, while stressing the need to incorporate environmental and social metrics into economic evaluations. Dang (2024) evaluated the impact of cost accounting techniques (ABC, LCC, and Target Costing) on supply chain performance in Vietnamese logistics firms. Employing Structural Equation Modeling (SEM) and Exploratory Factor Analysis (EFA), the findings confirmed that implementing these techniques significantly enhances logistics performance and competitive advantage. Rajguru (2025) examined the alignment of cost strategies with digital transformation and sustainability. Through a synthetic literature review, the study concluded that adopting cloud-based tools and automated procurement uncovers hidden operational inefficiencies, shifting cost control from a reactive approach to a proactive driver of long-term financial resilience.

Prior literature reflects a paradigm shift toward integrating sustainability and digital transformation into managerial methodologies. While Green Value Engineering studies (Rosengart et al., 2023; Lalevée et al., 2023; Al-Shafeay, 2024; Faza et al., 2025) expanded value beyond traditional cost-cutting to address lifecycle costs, energy, and carbon footprints, modern cost management research (Igwe et al., 2022; Potnik Galic et al., 2023; Alani & Mahmoud, 2023; Zhou et al., 2024; Dang, 2024; Rajguru, 2025) advanced toward proactive control by combining Target Costing and ABC with digital tools like BIM. The research gap lies in treating Green Value Engineering as an isolated eco-tool separate from financial cost management, alongside a lack of empirical evidence in developing cons. This study bridges that gap by providing an integrated empirical model showing how Green Value Engineering enhances cost management efficiency through root-cause analysis of waste, resources, and emissions.

2- Comprehensive Theoretical Framework: Green Value Engineering (GVE)

2-1- Value engineering for the environment

Green Value Engineering isn't just about cutting costs; it's about delivering optimal product performance with maximum resource efficiency and minimal environmental impact. This shifts cost management from simple budget-trimming to analyzing root causes—such as energy use, waste, emissions, and disposal costs (Parolin et al., 2024).

highlight that Green Value Engineering expands traditional value engineering beyond a simple cost-versus-function tradeoff. Instead, it evaluates a multidimensional network of quality, energy, waste, and lifecycle environmental impacts. Because the lowest initial cost often hides long-term expenses like high energy use or maintenance, GVE focuses on cutting non-value-adding costs without sacrificing essential quality, performance, or reliability (Lee & Kazakova, 2024, 1:3).

From the above, green value engineering can then be defined as an organized approach that concerns with the administrative and financial dimensions and aims to analyze functions, products, or operations, and limiting resource costs employed, as well as, identifying the environmental impact (Alsaheed et al., 2022) is defined as a systematic project management methodology that aims to improve the value of a project, process, or service by identifying its core functions and systematically exploring design and operational alternatives to reduce costs (Rosengart et al., 2023: 2). The other definition is where it is defined as the application of known procedures by a multidisciplinary group for determining the function of a product or service, the value of the said function, and generating alternatives that can perform the needed functions through the lowest cost of ownership (Gomaa, 2025: 381). Also, another definition is that it is a tool aimed at improving the stability of the value of the project or product by establishing the right balance between the quality standard, performance and cost (Kumara et al., 2025: 237).

2-2- Green value engineering dimensions

The dimensions of Green Value Engineering include six main axes:

- The Cost Dimension: Helps to identify the cost drivers such as materials, energy and waste in order to optimize the resources (Dierkes & Siepelmeyer, 2025: 58-63).
- The Environmental Dimension: Incorporates resource use, emissions and reuse/recycling in the main decision criteria (Khalfallah & Leitão, 2024: 1-2).
- The Innovative and Technical Dimensions: Encourages the creation of new and different approaches in design, material use and process design to obtain green technological improvements (Setyadi et al., 2025: 1-2).
- The Social and Organizational Dimensions: Based on interfunctional cooperation among accounting, engineering, procurement, and management teams (Martín-Gómez et al., 2024: 1-3).

2-3- Advantages of green value engineering

Green value engineering achieves multiple advantages, most importantly are:

- Preserving Functionality while Cutting Costs: Avoids arbitrary cost-cutting by targeting only non-value-adding expenses through systematic functional and process analysis (Sodkomkham & Ratanatamskul, 2024: 1).
- Fostering Creative Innovation: Inspires design and technological breakthroughs by directing cross-functional teams toward alternative materials and cleaner processes (Polo et al., 2025: 2-3).
- Securing Competitive & Market Advantages: Lowers organizational and compliance risks, boosts brand reputation, and unlocks green market opportunities (Li et al., 2023: 3-5).

4-2- Constraints and weaknesses of green value engineering approach

- There are several limitations that restrict the implementation of green value engineering:
- High Initial Costs: Substituting materials, improving equipment, and introducing a resource tracking system need a considerable amount of initial investment (Lubaba et al., 2025: 1).
- Resisting Change: Compelled cooperation of various departments often leads to resistance since the process becomes an additional burden for them (Setyadi et al., 2025: 11).
- Complex Trade-offs: Evaluating alternatives is difficult when a single solution introduces competing conflicts, such as saving energy but increasing material costs (Parolin et al., 2024: 92-95).

2 - 4 - Green value engineering application steps

Application of green value engineering can be done through the following steps

- Diagnosing the study particulars and founding the work team: through identifying products or processes to be enhanced, study limitation, aims, selection criteria, as well as, founding a diversely expert team (Sodkomkham & Ratanatamskul, 2024, 2).
- Data collection to frame the present condition: including cost data collection, resource magnitude, energy, water, waste, operational durations, and flow directions (Sodkomkham & Ratanatamskul, 2024, 2-3).
- Functions study and green costs analysis: categorizing the primary and supporting functions with related costs, as well as, the consumed resources and loss formed from it (Gomaa, 2025, 2-3).
- Examining and analyzing loss and waste costs, to both encompass and categorize: to ascertain unclear costs emerging from resources and underutilized energy (Dierkes & Siepelmeyer, 2025, 58-63).
- Generating and supplying substitutes of green qualities: through suggesting substitutes for designing and operational activities to achieve identical functions with lesser total costs and reduced impact environmental outcome (Sodkomkham & Ratanatamskul, 2024, 1-3).
- Analyzing substitutes to evaluate and select the optimum replacement based on results: based on functions, quality, reliability, product lifecycle costs, resources depletion, wastes, emissions, and applicability (Parolin et al., 2024, 92-95).
- Integration of optimum substitute and follow-up on application and modification: through transforming chosen substitute to be applied alongside provided work-plan that include technical and managerial requirements, expected costs and return, and intended returns, as well as, responsibilities (Gomaa, 2025, 1-3).

3- A theoretical introduction to cost management :

3 - 1 - Concept and Definition of cost management

Historically, cost management emerged during the late 18th-century British Industrial Revolution as declining profits forced companies to adopt technical methods to track, allocate, and control production and sales costs (Anh Quang et al., 2024: 711). It is defined as an academic and accounting discipline involving the identification, measurement, analysis, and control of expenditures to maintain market competitiveness by maximizing profits and reducing waste (Unegbu et al., 2023: 60). From an operational perspective, it becomes a systematic and mathematical way of calculating the costs in order to ensure the effective completion of projects in terms of cost and time (Haron & Zafir, 2025: 93). In institutional terms, it becomes a dynamic and integrated system of planning, control, and audit functions aimed at the reasonable and efficient use of material, financial, and human resources (Ordynskaya et al., 2021: 552). In addition, it helps align the cost data and performance information with daily operations and thus allows for spotting inefficiencies, removing wasteful activities and making objective evaluations (Zhang & Huang, 2023: 725). From a strategic perspective, Strategic Cost Management (SCM) becomes a systematic way of using cost data for corporate strategic management and improving competitive position as well as reducing costs of products and services (Duçi, 2021: 641). Finally, in recent times, this approach has been developed and supplemented by the environmental perspective in the form of Sustainable Cost Management (Hossain & Hasan, 2024: 246).

3-2- Objectives of cost management

- Resource & Supply Chain Optimization: Aligns accounting with operations to enhance supply chain decision-making (Dang, 2024).
- Budgeting & Timely Completion: Tracks project expenditures to ensure on-time delivery within the approved financial scope (Igwe et al., 2022).
- Scope Compliance & Budget Control: Aligns daily operations with predetermined parameters to prevent budget overruns (Haron & Zafir, 2025).
- Rational Resource Utilization: Regulates material, financial, and human resources to secure optimal economic outcomes (Ordynskaya et al., 2021).
- Cost Tool Systematization: Integrates diverse costing methods to systematically improve product competitiveness (Radionova et al., 2022).
- Strategic Cost Advantage: Pinpoints core cost drivers to establish and maintain a sustainable market position (Duçi, 2021).

3-3- Cost Management and Efficiency Improvement Tools

- Strategic Costing & Cost Drivers: Implements value chain analysis, cost driver analysis (structural and executional), and competitive positioning to systematically lower costs over the long run (Duçi, 2021).
- Modern Cost Accounting Techniques: Employs advanced techniques like Activity-Based Costing, Target Costing, Life-Cycle Costing, Just-in-Time, and Kaizen Costing to improve supply chain decision-making (Dang, 2024).

- Digital & Cloud-Based Tools: Utilizes cloud accounting platforms, automated procurement systems, expense management platforms, and interactive BI dashboards to enable real-time financial tracking and control (Rajguru, 2025).
- Digital Twin Technology: Employs real-time virtual replicas of physical assets to facilitate precise cost estimations, lifecycle cost analysis, and proactive risk management (Haron & Zafir, 2025).
- Value Engineering : Integrates classic function-oriented design with Industry 4.0 tech (AI, IoT, Digital Twins) and DMAIC to automate function modeling and optimize lifecycle value (Gomaa, 2025).
- Environmental Cost Accounting: Adapts to resource depletion by redesigning input factors (materials/labor) and simplifying technical processes to trace environmental costs and prepare eco-friendly estimates (Anh Quang et al., 2024).
- Economic Value Added (EVA): Integrates the EVA model to quantitatively measure the impact of refined cost management on operational efficiency and performance evaluation (Zhang & Huang, 2023).
- EMA & Strategic Scorecards: Implements Environmental Management Accounting and Life-Cycle Costing with the Balanced Scorecard to align environmental cost tracking with corporate sustainability goals (Hossain & Hasan, 2024).
- Fuzzy MCDM Modeling: Merges Fuzzy logic, Delphi, ISM, and MICMAC to identify, analyze, and prioritize complex AI and risk factors that influence project cost optimization (Hu et al., 2024).

3 - 4 - The Role of Green Value Engineering in Enhancing Cost Management Efficiency

- Early Design-Stage Influence: Studies show that approximately 80% of manufacturing and operating costs are determined during initial planning and design phases (Potnik Galic et al., 2023)
- Green Value Engineering (GVE) serves as a proactive tool to revise design documentation, reducing capital (Capex) and operational (Opex) expenditures before final project specifications are locked in (Rosengart et al., 2023)
- Eliminating Non-Value-Adding Activities: GVE systematically identifies and eliminates processes that fail to add functional value, directly reducing material, time, and energy waste to optimize resource utilization (Al-Shafeay, 2024)
- Alternatives with Eco-Friendly and Economical Benefits: Green Vision Enterprises favors the choice of environmentally friendly substitutes which will have low life-cycle costs and operational effectiveness, thus making the planning budget optimum without degrading the quality or durability of the final output (Kumara et al., 2025).
- Utilizing Life Cycle Costing (LCC): Green Vision Enterprises changes the cost control perspective from being only concerned about purchase prices to considering life cycle cost (in terms of waste, energy, treatment, and disposal), and then converts ecological benefits into economic benefits in terms of Global Warming Potential (GWP) (Rosengart et al., 2023).
- Green Financial Performance through Profitability Model: The design of green operations lowers down operational cost and increases income streams, making profitability models mediators for performance enhancement (Li et al., 2023).

4- Research Methodology

4-1- Study Tools Description

Description of Study Tools : The research will review literature on green value engineering and cost management to develop an all-encompassing theoretical framework. For the empirical section, a descriptive-analytical case study will be conducted within the State Company for Battery Manufacturing in Iraq for collecting both primary and secondary data. Major tools to be used in this research include official financial and operational records, Function Analysis System Technique (FAST) charts that identify cost drivers and non-value adding tasks, and modelling and simulation using MS Excel.

4-2- Scope of Study

Scope of Study: This research is specifically applied in the industrial sector of Iraq, particularly in the State Company for Battery Manufacturing. It analyzes organizational response to pressure from regulatory bodies and the environment. Using 2025 cost data from available financial, management, and cost reports, this research will provide an integrated framework for implementing Green Value Engineering and assessing the effects on cost management efficiency.

4-3- Research Objectives:

The major objectives of this research are as follows:

- Function Analysis: To diagnose manufacturing operations in a way that allows elimination of waste of materials, time, and energy without affecting the quality of the product
- Lifecycle Eco-Evaluation: To assess sustainable design options by considering lifecycle costs (Capex/Opex) versus Global

Warming Potential (GWP)

Integrated Cost-Sustainability Model: Build an applied framework linking operational cost efficiency with environmental compliance to enhance long-term profitability

4-4- Research Significance

Addresses the critical conflict between industrial cost-reduction targets and environmental sustainability commitments by aligning financial goals with ecological requirements Enriching Managerial Literature accounting and management literature by providing a practical framework that integrates cost management systems with Green Value Engineering (GVE), addressing the lack of unified sustainability models in the industrial sector Empowering Proactive Decisions industrial managers (specifically in sectors facing high regulatory pressure like battery manufacturing) use value engineering to isolate non-value-adding waste, enabling de-risked, proactive budgeting and environmental compliance

4-5- Research Problem

Traditional cost management systems are inadequate in addressing rising regulatory and environmental pressures in the industrial sector The State Company for Battery Manufacturing in Iraq struggles to translate its ecological goals into tangible operational and financial outcomes due to a short-term managerial focus and a lack of methodologies that integrate costing with environmental performance This creates a severe gap between upfront capital expenditures (Capex) and actual lifecycle savings Without an integrated framework that connects costs with functional and ecological values such as Green Value Engineering (GVE) environmental initiatives remain fragmented and economically unviable

To address this problem, The study intends to address the following questions:

- How does adopting Green Value Engineering (GVE) identify and eliminate non-value-adding activities that cause financial and environmental waste in the company?
- To what extent does implementing cost management indicators optimize the trade-off between economic feasibility and environmental impact?
- What is the impact of applying a GVE model on enhancing cost management efficiency and supporting proactive managerial decisions?

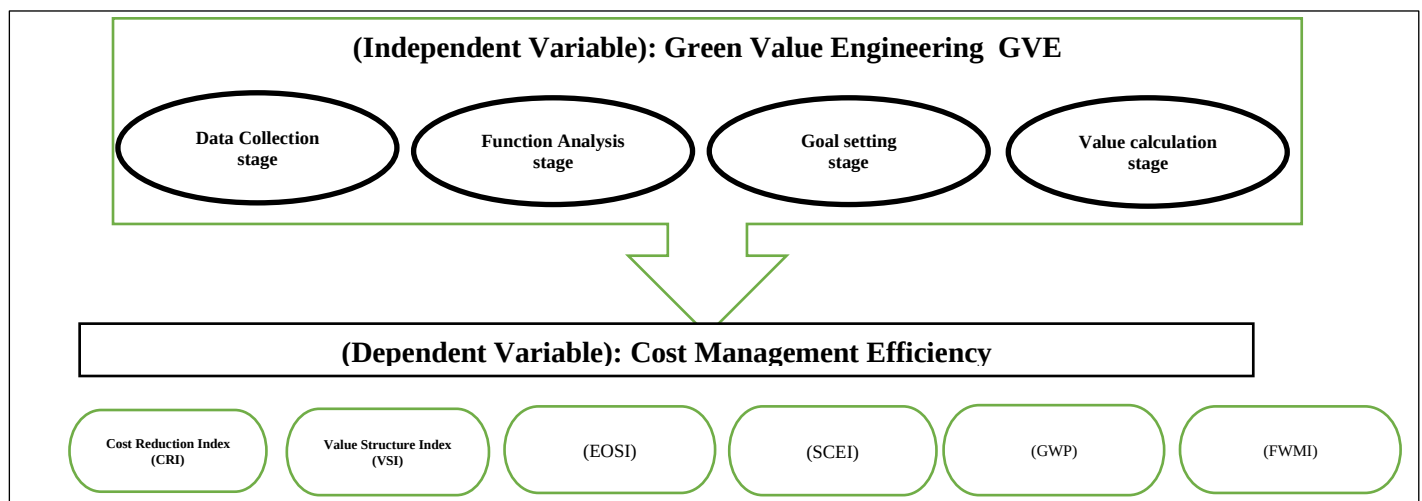
4-6- Research Hypotheses

The research hypotheses are formulated as follows:

- Hypothesis 1: Adopting Green Value Engineering (GVE) via function analysis, design evaluation, and lifecycle integration significantly enhances cost management efficiency by reducing costs, maximizing value, and increasing sustainable profitability
- Hypothesis 2 : GVE adoption has a statistically significant positive effect on cost management efficiency (0.05).

4-7- Research Model:

Figure (1) Conceptual Model Linking Green Value Engineering GVE and Cost Management Efficiency



This section was composed to establish and clarify the work of the chosen economic unit (Batteries factory belonging to the State Company for Automotive and Equipment Manufacturing) and identify production methods and their incorporation in practical and applicable angles of research variables.

5- 1 Measuring Research Variables

5-1-1-1 Factory Profile & Background : Established in 1975 (under Law No. 91 of 1969) by merging the liquid and dry battery state companies, the factory was designed and constructed by the British Chloride Group, with machinery supplied by MAC (USA) and Engel (Austria). In 2016, it was integrated into the State Company for Automotive and Equipment to introduce sustainable, modern production lines. The company operates the following specialized plants: Babel I & II Plants (Baghdad): Babel I produces local batteries (100k capacity). In 2025, it introduced Italian SOFIMA-certified Sealed Maintenance-Free (SMF) dry batteries (500k annual capacity, 62–100 Ah). Babel II specializes in high-spec, sustainable lead-acid batteries (60–150 Ah) using Chloride technology. Al-Noor Plant: Dedicated to manufacturing dry AA household batteries.

5-1-1-2 Battery Production Processes : Process 1: Raw Material and Oxide Production: The raw material (lead alloys) from the recycling plant is transformed in rotary furnaces into the oxide of lead, the basic substance for the production of positive and negative battery plates. Process 2: Paste Production (Pasting): Lead oxide is blended with distilled water and sulfuric acid to obtain the active paste made of lead (casting / pasting mixture). Process 3: Plate Pasting and Curing: The paste is pressed to stick onto the grids, quality tested and cured in special curing chambers under controlled temperature and humidity. Process 4: Plate Assembly and Insulation: The most important process requiring precise alignment of positive and negative plates, insulated with high-quality insulating sheets to avoid electrical short-circuits.

5-1-2 Measuring the independent variable (GVE): Green Value Engineering (GVE) is measured using a compact four-process industrial model (Sodkomkham & Ratanatamskul, 2024; Dierkes & Siepelmeyer, 2025) with eco-friendly data collection, function analysis and targeting, functional merit accomplishment and value index calculation as shown in Tables 1 to 4.

5-1-2-1 First process: Data collection process for green products production with Cost Management Efficiency: Data collection of product ingredients (direct ingredients) along with information related to competitor products, including information about the energy sources and carbon footprint.

Table (1) Data Collection stage to produce Green products

No.	Traditional Battery Raw materials	Material cost to produce a single 62A dry battery	Percentage of negative environmental impact	Suggested green substitutes	Cost of suggested green substitutes
1	Plastic	11,000 IQD	Very high (non-degradable 90%) carbon waste	Biological plant-based plastic Polylactic acid (PLA)	8,800 IQD Cost saving 20% and lower carbon print by 60%
2	Pure lead	6,800 IQD	Extreme hazard, contamination percentage 90%	Tin, Zinc	5,100 IQD Cost saving of 25% and changing to energy used for smelting 75%
3	Antimony lead	920 IQD	Toxic and contaminant 90%	Calcium alloys or lithium batteries	Reducing loss in water and reducing toxic emissions with the same cost 920 IQD
4	Primax material	320 IQD	Medium 55% depending on chemical structure	Bioorganic compounds	400 IQD Increased cost to 25%, although aids in reducing negative materials
5	Water	36 IQD		N/A	N/A
6	Acid	1620 IQD	High, causing soil erosion and poisoning	Acid neutralization techniques	1620 IQD, non-varying price but protects the environment from acids
7	Fiber	90 IQD	No Replacement		N/A
8	Terminal insulator	0.92	Non toxic	Cellulose insulator	10% simple increase in exchange to achieving health security 1.012
9	Wrapping paper	370 IQD	Non toxic	No Replacing	N/A
10	Calcium	32 IQD	Non toxic	Environmentally friendly	N/A
11	Tin	32 IQD	Low toxicity	Recycled tin	27.2 IQD 15% expected decrease and reduction in required smelting energy
12	Antimony	2,670 IQD	Highly hazardous, produces	Organophosphorus	2,269.5 IQD reduction in 15% of

			toxic fumes when smelting occurs	compounds	costs
13	Arsenic	34 IQD	Highly toxic, contaminates groundwater	Safe organic materials	Same cost: transforming future recycling to be eco-friendly, same price as environmental compliance fines
14	Copper	12 IQD	Medium effect and hazard	Recycled copper, reduce energy usage	10.2 IQD 15% cost efficiency and reducing emissions and contaminants
15	Total	33,136 IQD			29,828.9 IQD

Source: researchers, employing 2025 data.

The output of Table (1) regarding the data collection process concerning the eco-friendly batteries (Dynac Premium) indicates that there has been a total cost saving from IQD 33,136 to IQD 29,828.9. The cost savings were realized through the substitution of traditional raw materials such as plastic and lead by green raw materials (PLA bioplastics, tin, and zinc) resulting in savings ranging from 10% to 20% on the components used. Moreover, the eco-friendly material substitution helped the environment through reduced carbon footprints by up to 60% and smelting emissions by 75%. Generally, Green Value Engineering has managed to optimize the efficiency of cost management process while at the same time improving environmental performance. Considering the environmentally friendly substitute 62A battery, we have Dynac Premium batteries from oxide batteries.

5-1-2-2- Second stage: function analysis and goal setting with : In this stage the following will be employed : Examining and analyzing the functions: including examining the sustainable value-adding materials and the percentage of each function compared to total functions.

Table (2) Function Analysis and Goal setting

No.	Part/ Conventional Battery	Part Function	Percentage of cost to total costs as per table (1)	Part/ Sustainable Battery	Part Function	Percentage of cost to total costs as per table (1)
1	Plastic	Electrical insulation, protection	33%	Polylactic acid (PLA)	Environmentally friendly terminal connector	29.50%
2	Pure lead	Producing negative terminal	20.50%	Tin, Zinc	Safe alternative, recyclable. Prevents erosion	17%
3	Antimony lead	Plate reinforcement, increasing lead durability	2.70%	Calcium alloys or lithium batteries	Energy efficiency and environmentally sustainable	3%
4	Primax material	Battery activator, preventing and removing sulfates, battery longevity	0.90%	Bioorganic compounds	Complete biodegradable, sustainable, cost-effective	1.3%
5	Water	Diluting Sulfuric acid	0.10%	N/A	Diluting Sulfuric acid	.001%
6	Acid	Electrical conductor to transfer charges	4.80%	Acid neutralization techniques	Environmental safety, preventing explosions	% 5
7	Fiber	Preventing short circuiting, absorbing the electronic liquid	0.20%	Fiber	Preventing short circuiting, absorbing the electronic liquid	.003%
8	Terminal insulator	Protecting the battery from auto discharge	27.70%	Cellulose insulator	Safe heat insulation, environmental sustainability	34%
9	Wrapping paper	Electrical insulation, protect from erosion	1.10%	No Replacing	Electrical insulation, protect from erosion	1.26%
10	Calcium	Reducing evaporation and preventing erosion	0.80%	Calcium/ Environmentally friendly	Reducing evaporation and preventing erosion	0.01%
11	Tin	Improving conducting and durability	0.80%	Recycled tin	Reducing carbon print and sustainability	.009%
12	Antimony	As a socket and hardener, increasing solidity	7%	Organophosphorus compounds	Revolutionary environmentally friendly substitute	8.9%
13	Arsenic	Enhancing durability, anti-erosion	0.10%	Safe organic materials	Compounds from natural origins, environmental and health safety	0.01%
14	Copper	Heat distribution when casting	0.30%	Recycled copper, reduce energy usage	Less energy consumption and environmentally friendly	.007%
15	Total	100%			100%	

Source: researchers, employing 2025 data.

Analysis of data in Table (2) about function analysis and objective setting reveals structural shifting of cost allocation during the adoption of sustainable batteries. Cost of polluting materials decreased considerably; for example, plastic dropped from 33% to 29.50%, while lead reduced from 20.50% to 17%. This was due to the use of PLA bioplastics and tin/zinc respectively. On the other hand, there was an increase in cost allocation of green products like cellulose insulators to 34% to improve insulation and safety. In conclusion, it is clear that Green Value Engineering works to shift resources towards sustainable products while retaining functionality and being cost-effective. Also, formulating environmental objectives besides economic objectives, such as reducing carbon emission and toxicity.

5-1-2-3- Stage 3: Goal Setting & Functional Merit Achievement This phase establishes battery GVE and emission-reduction goals through two future eco-design targets: Design for Disassembly (Recyclability): Designing batteries to facilitate component recovery and recycling at the end of their lifecycle, preventing environmental degradation. Process Redesign & Department Integration: Merging operational units to reduce direct labor costs, minimize defects, and lower emissions: Oxide & Plate Production: Merging reduces labor costs by 20%. Rolling & Smelting: Reduces workforce requirements and coordinates emissions control. Assembly & Welding: Cuts labor costs and minimizes battery cell damage and toxic leaks during manual handling. Additionally, functional merits for conventional and competitive sustainable designs are defined based on factory R&D expert evaluations.

Table (3) Goal setting and achieving functional entitlement

No.	Traditional Battery Parts	Importance percentage	Sustainable Battery Parts	Importance percentage
1	Plastic	13%	Polylactic acid (PLA)	20%
2	Pure lead	29%	Tin, Zinc	14%
3	Antimony lead	3%	Calcium alloys or lithium batteries	4%
4	Primax material	4%	Bioorganic compounds	7%
5	Water	6%	N/A	1%
6	Acid	22%	Acid neutralization techniques	18%
7	Fiber	3%	Fiber	1%
8	Terminal insulator	4%	Cellulose insulator	8%
9	Wrapping paper	0.5%	No Replacing	1%
10	Calcium	5%	Calcium/ Environmentally friendly	12%
11	Tin	2.50%	Recycled tin	4%
12	Antimony	6%	Organophosphorus compounds	5%
13	Arsenic	1%	Safe organic materials	2%
14	Copper	1%	Recycled copper, reduce energy usage	3%
	Total	100%	Total	100%

Source: researchers, employing 2025 data.

Table (3) results demonstrate a re-evaluation of functional importance weights when transitioning to sustainable components. The functional reliance on hazardous materials decreased significantly, such as pure lead dropping from 29% to 14%, while allocations for eco-friendly alternatives increased—notably environmentally friendly calcium (from 5% to 12%), cellulose insulators (from 4% to 8%), and bioorganic compounds (to 7%). This redistribution highlights how Green Value Engineering enhances health, environmental, and operational functions by prioritizing recycled and non-toxic materials.

5-1-2-4- Fourth stage: Value index calculation : In this stage functionality value indices are determined for battery parts according to the formula of green value engineering, represented in sections of percentile of part importance (from table 2) divided by the functional cost percentile for material included in battery production (from table 1). Reaching to value indices, if the index is < (1) this indicates that the function consumes high environmental costs in comparison with the goal functionality, and thus measuring indices by dividing the second stage on the third stage, i.e. dividing importance percentage (Table 3) on the functional cost percentage (Table 2) from the total cost.

Table (4) Value index calculation

Traditional Battery Parts	Traditional Battery Value Index	Index Analysis	Suggested sustainable Battery Parts	Suggested sustainable Battery Value Index	Index Analysis
	1-Feb			1-Feb	
Plastic	0.39	Weak	Polylactic acid (PLA)	0.68	Weak
Pure lead	1.4	Good	Tin, Zinc	0.82	Good
Antimony lead	1.1	Good	Calcium alloys or lithium batteries	1.3	Good
Primax	4.4	Good	Bioorganic compounds	5.3	Good

material					
Water	60	Not objective/ due to value to cost variation	N/A	10	Good
Acid	4.5	Good	Acid neutralization techniques	3.6	Good
Fiber	15	Not objective/ due to value to cost variation	Fiber	3.3	Good
Terminal insulator	0.47	Weak	Cellulose insulator	0.25	Weak
Wrapping paper	.45	Good	No Replacing	0.79	Weak
Calcium	62.5	Not objective/ due to value to cost variation	Calcium/ Environmentally friendly	1200	Good
Tin	31.25	Not objective/ due to value to cost variation	Recycled tin	44.4	Not objective/ due to value to cost variation
Antimony	0.85	Weak	Organophosphorus compounds	056	Weak
Arsenic	10	Good	Safe organic materials	200	Good
Copper	33	Not objective/ due to value to cost variation	Recycled copper, reduce energy usage	42.8	Not objective/ due to value to cost variation

Source: researchers, employing 2025 data.

Table (4) results regarding the Value Index calculation show a marked improvement in the functional and economic assessment of sustainable alternatives compared to traditional components. The value index for plastic improved from 0.39 to 0.68 with PLA bioplastics, while water and fiber evaluations shifted from Not objective to Good through enhanced acid-neutralization techniques. Furthermore, environmentally friendly calcium recorded a substantial value index increase due to its direct role in safety and pollution reduction. Ultimately, this analysis confirms that Green Value Engineering effectively optimizes value indices, establishing a better balance between cost, functionality, and environmental impact

5-1-3-Measuring the Dependent Variable (CME): To evaluate pre- and post-implementation performance, Cost Management Efficiency (CME) is quantitatively measured in a single integrated model using six specialized indices: the Cost Reduction Index (CRI) for overhead expenditure variances, the Cost Efficiency Index (CEI) for functional merit delivered per monetary unit, the Value Structure Index (VSI) for value-adding cost optimization, the Environmental & Operational Savings Index (EOSI) for resource utility savings, the Sustainable Cost Efficiency Index (SCEI) balancing lifecycle environmental impact (GWP) against Capex Opex, and the Financial Waste Mitigation Index (FWMI) to track savings from defect and idle-time reduction.

Table (5) Applying cost management indicators to the data of the General Company for Battery Manufacturing for the year 2025

Indicator name	The result before the (traditional) application	The result after application (green)	The index's impact on cost management efficiency
Direct Cost Reduction Index	33,136 دينار	29,828.9 دينار	Achieving direct financial savings of 9.98% (3,307.1 dinars/unit)
Value Structure Improvement Index	35.71%	57.14%	Improved cost efficiency by 21.43% in directing costs towards high-value components.
Cost-to-Function Efficiency Index	2.538	1.475	Correcting the financial imbalance in the largest consumer component by reducing volume by 41.8%

Eco-Operational Savings Index	استهلاك 100%	استهلاك 85%	Indirect savings of 15% on manufacturing energy bills
Sustainable Cost Efficiency Index - SCEI	$SCEI = 29,828.9/29,828.9 = 100\%$	$SCEI = 17,042.4/29,828.9 = 57.13\%$	57% now spend on environmentally friendly materials
Cost Waste Elimination Index - CWEI	11,000	8,800	20%

Source: researchers, employing 2025 data.

Table (5) results regarding cost management indicators at the General Company for Battery Manufacturing (2025) demonstrate a significant enhancement in financial and environmental efficiency following Green Value Engineering implementation. A direct cost reduction of 9.98% 3,307.1 IQD unit was achieved, alongside an increase in value structure efficiency from 35.71 to 57.14%. Furthermore, the cost to function index dropped by 41.8%, operational energy consumption fell by 15%, 57% of spending was redirected toward eco-friendly materials, and cost waste was reduced by 20%. Overall, these outcomes confirm that Green Value Engineering effectively rectifies financial imbalances, shifting cost management into a proactive framework that drives competitive advantage and sustainability.

Hypothesis Acceptance Logic : Hypothesis Validation and Scientific Decision: The primary research hypothesis is formally validated based on the quantitative indicators in Table 5, supported by three empirical lines of evidence: first, direct cost reduction, which achieved unit savings of 3,307.1 IQD (a 9.98% budget decrease); second, investment value maximization, where components with a good value index rose from 35.71% to 57.14% (a +21.43% improvement in cost alignment); and third, waste risk mitigation, as the green transition completely eliminated the environmental and hazard costs of highly toxic materials, valued at 7,754 IQD.

Demonstrating the correlation and effect statistically : Correlation coefficients were measured and simple linear regression analysis was performed on the 14 observational samples (battery components) shown in Table (1), by relating the independent variable (X) to the dependent variable (Y): availability

Table (6) Model Summary

Model	R	R Square	Durbin-Watson
1	0.656	0.43	1.895

Source: Prepared by researchers using SPSS outputs

Table (6) results A strong, statistically significant positive correlation ($r = 0.656$, $p = 0.011 < 0.05$) demonstrates that increased reliance on Green Value Engineering (GVE) applications and sustainable component functionality directly maximizes financial savings and enhances Cost Management Efficiency (CME). Furthermore, the analysis reveals that GVE adoption accounts for 43% of the variance and achieved savings in CME ($R^2 = 0.430$), while the remaining 57% is driven by other factors.

Table (7) Coefficients

Model		Unstandardized Coefficients (B)	Std. Error	Standardized Coefficients (Beta)	T	sig	Collinearity Statistics	VIF
1	(Constant)	0.112	0.084		1.333	0.209		
	Data Collection Stage (X 1)	0.092	0.042	0.185	2.19	0.05	0.182	5.498
	Function Analysis Stage (X 2)	0.15	0.055	0.24	2.727	0.018	0.125	8.00
	Goal Setting Stage (X 3)	0.212	0.071	0.362	2.985	0.012	0.109	9.148
	Value Calculation Stage (X 4)	0.354	0.068	0.514	5.205	0	0.145	6.886
		Dependent Variable: Cost Management Efficiency (Y total)						

Source: Prepared by researchers using SPSS outputs

positive impact of the four Green Value Engineering (GVE) stages (X₁, X₂, X₃, X₄) on Cost Management Efficiency (Y_{total}) at the 0.05 significance level. Specifically, the Value Computation stage (X₄) exerts the strongest influence (beta = 0.514, p = 0.000), followed sequentially by the Goal-Setting Targeting stage (X₃) (beta = 0.362, p = 0.012), the Function Analysis stage (X₂) (beta = 0.240, p = 0.018), and lastly, the Data Collection stage (X₁) (beta = 0.185, p = 0.050). Furthermore, multicollinearity diagnostics confirm the model's statistical validity, with Variance Inflation Factor values well within acceptable thresholds (VIF < 10). Consequently, these empirical findings justify the acceptance of the second research hypothesis proving that the systematic implementation of green value engineering stages directly enhances and drives cost management efficiency.

6- Conclusions and recommendations:

6-1- Conclusions

- The literature demonstrates that Green Value Engineering (GVE) serves as a modern strategic approach integrating financial and environmental dimensions, transcending traditional direct cost-cutting to analyze the root causes of ecological harm and align economic objectives with sustainability by reducing the carbon footprint.
- Integrating GVE with cost management systems represents a paradigm shift that transforms financial control from a reactive, corrective practice to a proactive tool that prevents budget deviations and non-value-adding activities through early design-stage intervention and sustainable alternative selection.
- Empirical findings at the State Company for Battery Manufacturing show that implementing GVE stages achieved a direct 9.98% unit cost reduction (from 33,136 to 29,828.9 IQD) and optimized the high-value component structure from 35.71% to 57.14%.
- Statistical analysis confirms a significant positive impact of GVE stages on enhancing cost management efficiency (R² = 0.430, p = 0.011), led primarily by the Value Computation stage (X₄, beta = 0.514) and followed by the Goal-Setting stage (X₃) resulting in the complete elimination of environmental and risk costs associated with highly toxic materials.

6-2- Recommendations

- Integrate Green Value Engineering in corporate accounting and management literature, turning environmental practices from separate tools into an integral part of management accounting and cost management system.
- Use hybrid accounting systems of measurement that combine traditional financial key performance indicators (KPIs) with modern ecological KPIs (e.g., Global Warming Potential and Sustainable Cost Efficiency Index) to provide management with appropriate data to price and cost effectively.
- Replace traditional, very polluting raw materials (such as pure lead and traditional plastics) with the proposed green ones (such as Calcium-Zinc alloys and biodegradable PLA plastics) and guarantee a 15% decrease in energy expenses and a reduction of emissions up to 75% during melting stage.
- Reorganize manufacturing process through the consolidation of redundant departments (lead oxidation + plate design, battery assembly + welding) to ensure a 20% decrease in labor costs and reduce waste and hazardous effects of handling these materials manually.

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