Assessing Energy Efficiency in Small and Medium Sized Packaging Enterprises: Case Study of Egypt

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Abstract:
This study systematically examines the energy efficiency performance of three industrial factories operating under uniform electricity pricing conditions, revealing persistent inefficiencies in relation to established energy consumption targets. Although some months exhibited compliance with these targets—suggesting the feasibility of operational excellence, each factory demonstrated substantial annual deviations from their benchmarks: Factory B (23.95%), Factory A (20.36%), and Factory C (19.87%). Instances of peak inefficiency were particularly pronounced, with monthly deviations approaching 50% above target levels. Notably, Factory C consistently exhibited stronger adherence to energy management best practices, indicating its potential as a model for internal benchmarking. This research underscores the significance of strategic energy management in shaping industrial energy performance. By integrating operational data with assessments of management practices, the study identifies critical disparities between potential and actual efficiency outcomes. The findings

contribute to scholarly discourse on the behavioral, technological, and systemic factors influencing industrial energy performance, while also providing actionable insights for practitioners, particularly in emulating high-performance models and addressing periods of peak inefficiency. The study concludes with specific recommendations for future research, including the development of predictive energy management models, exploration of intra-organizational knowledge transfer mechanisms, and the incorporation of energy metrics into broader sustainability frameworks.

Keywords: Energy Management Practices, Energy Efficiency Awareness, Operational Factors, and Electricity Efficiency Measures.

الملخص :

تُحلل هذه الدراسة بشكل منهجي أداء كفاءة الطاقة لثلاثة مصانع صناعية تعمل في ظل شروط تسعير كهرباء موحدة، كاشفة عن وجود اختلالات مستمرة مقارنة بالأهداف المحددة لاستهلاك الطاقة. وعلى الرغم من أن بعض الأشهر أظهرت التزامًا بهذه الأهداف—مما يشير إلى إمكانية تحقيق التميز التشغيلي—فقد أظهر كل مصنع انحرافات سنوية كبيرة عن المعايير المرجعية: المصنع A (23.95%)، المصنع B (20.36%)، والمصنع C (19.87%). وكانت حالات الانخفاض الحاد في الكفاءة بارزة بشكل خاص، حيث اقتربت الانحرافات الشهرية من ٥٠% فوق المستويات المستهدفة. ومن الجدير بالذكر أن المصنع C أظهر التزامًا أقوى بشكل مستمر بأفضل ممارسات إدارة الطاقة، مما يشير إلى إمكانيته كنموذج للمقارنة الداخلية. وتُبرز هذه الدراسة أهمية الإدارة الاستراتيجية للطاقة في تشكيل أداء الطاقة في القطاع الصناعي. ومن خلال دمج البيانات التشغيلية مع تقييمات ممارسات الإدارة، تُحدد

الدراسة الفجوات الحرجة بين الأداء الكامن والفعلي في الكفاءة. وتُسهم النتائج في الخطاب الأكاديمي المتعلق بالعوامل السلوكية والتقنية والنظامية التي تؤثر على أداء الطاقة الصناعية، كما تقدم رؤى عملية قابلة للتنفيذ للممارسين، خصوصًا في ما يتعلق بمحاكاة النماذج عالية الأداء ومعالجة فترات الانخفاض الحاد في الكفاءة. وتختتم الدراسة بتوصيات محددة للبحوث المستقبلية، بما في ذلك تطوير نماذج تنبؤية لإدارة الطاقة، واستكشاف آليات نقل المعرفة داخل المؤسسات، ودمج مؤشرات الطاقة في **أطر الاستدامة الأشمل.**

الكلمات المفتاحية: ممارسات إدارة الطاقة، الوعي بكفاءة الطاقة، العوامل التشغيلية، وتدابير كفاءة الكهرباء.

Introduction :

Optimizing energy efficiency has become increasingly imperative for manufacturing firms due to rising energy costs and environmental concerns. The implementation of energy-saving measures presents a cost-effective, short-term solution to these challenges. According to Salah and Mustafa (2021), both corporations and governmental entities are actively engaged in identifying and adopting the most effective strategies to improve energy performance within production processes. A critical metric for evaluating this performance is Specific Energy Consumption (SEC), which quantifies the amount of energy utilized per unit of output. Reducing SEC can facilitate the decoupling of economic growth from corresponding increases in energy demand.

The manufacturing sector constitutes a foundational component of Egypt's economy, accounting for approximately 16.1% of the national GDP in 2022 and employing a significant portion of the labor force (CAPMAS, 2023). Within this sector, the packaging industry is particularly essential, supporting crucial areas such as agriculture, food processing, pharmaceuticals, and exports. Small and medium-sized enterprises (SMEs) dominate this subsector, representing over 80% of businesses, thereby playing a central role in production capacity and job creation (Ministry of planning, Economic Development and International Cooperation, 2023).

Despite its economic significance, the manufacturing sector in Egypt continues to confront substantial challenges related to energy efficiency. The Egyptian Electricity Holding Company (EEHC) and the Ministry of Electricity and Renewable Energy (MOERE) report that the industrial sector consumes approximately 33–35% of the nation's total electricity supply, with a significant portion being utilized by outdated and inefficient systems (MOERE, 2021). The International Energy Agency (IEA, 2020) further indicates that Egypt's energy intensity—defined as energy consumption per unit of GDP—is approximately 2.5 times higher than the global average, highlighting the urgent necessity for efficiency improvements.

SMEs in the packaging sector are particularly susceptible to these challenges, as they frequently lack the capital and technical expertise required to implement energy-efficient technologies. Elevated energy consumption in areas such as motors, compressed air systems, thermal equipment, and lighting significantly increases operational costs. With the gradual removal of energy subsidies since 2014 and a consistent rise in electricity prices, these expenses have become an even more formidable challenge for SMEs (Egyptian Electricity Regulatory Authority, 2022).

As part of Egypt's Vision 2030 agenda—which encompasses the advancement of energy efficiency and the promotion of sustainable industrial growth—it is essential to investigate how packaging SMEs utilize energy and identify areas of inefficiency. This study aims to assess current energy consumption patterns, identify operational challenges, and explore opportunities for enhancement. Through a focused case study approach, the research endeavors to generate practical insights and policy recommendations to assist SMEs in reducing energy consumption, lowering costs, and aligning with national sustainability objectives.

Research Questions

This study entails the following research questions as follows:

1. To what extent are energy efficiency practices and policies being implemented by packaging SMEs in Egypt?
2. How do operational factors affect electricity consumption in packaging SMEs?

3. What is the level of awareness among employees and management regarding electricity efficiency?
4. Is there a significant relationship between energy management practices and electricity efficiency?
5. To what extent do awareness and operational practices influence electricity efficiency in packaging SMEs?

Research Objectives

This study aims at the following:

1. To evaluate the current energy consumption patterns in small and medium-sized packaging enterprises (SMEs) in Egypt.
2. To assess the level of implementation of energy efficiency measures among packaging SMEs.
3. To assess the extent of energy management practices adopted by packaging SMEs.
4. To examine the influence of operational practices on electricity consumption.
5. To evaluate the level of awareness initiatives toward electricity efficiency.

Literature review

Amjadi et al. (2022) characterized energy efficiency as the capacity to attain equivalent or superior levels of output while concurrently diminishing the requisite energy input. In a similar vein, Opoku et al. (2022) underscored the significance of energy efficiency in manufacturing, attributing it to the substantial share of energy costs within overall production expenditures. Implementing effective energy-saving strategies can yield numerous benefits, including reduced operational costs, optimized material utilization, resource conservation, enhanced sustainability and competitiveness, and diminished industrial emissions. Schulze et al. (2016) posited that the successful deployment of energy management systems within industrial contexts is contingent upon five foundational components: strategic planning, operational execution, control mechanisms, organizational structure, and corporate culture. Collectively, these elements are essential for realizing the full potential of energy efficiency in the industrial sector. Furthermore, methodologies such as systematic layout planning (SLP) and well-structured layout designs (LD) significantly contribute to facilitating energy optimization within manufacturing facilities.

Abdelaziz et al. (2011) defined energy management as the strategic coordination of energy supply and demand to fulfill requirements in an efficient manner. This process involves the optimization of both systems and operational procedures to minimize energy consumption per unit of production while managing or reducing total production costs. Beyond merely delineating the concept, it is imperative to comprehend its implications for operational activities. Energy efficiency initiatives—whether technical, managerial, or organizational—typically originate from decisions made during the strategic planning phase. As noted by Peterson and Belt (2009), these decisions encompass the planning and management of resources, particularly financial investments, which necessitate the evaluation of payback periods for energy-related expenditures. They also advocate for continuous energy audits and management reviews to consistently identify new opportunities for efficiency enhancements.

Sivill et al. (2013) highlighted that key performance indicators (KPIs) play a vital role in assessing the outcomes of energy efficiency strategies, facilitating comparisons with internal and external benchmarks, and identifying necessary corrective actions. In addition, Shrouf et al. (2014) introduced electricity price volatility in spot markets as a significant parameter within energy-aware scheduling models. Wang and Li (2014) proposed an integrated methodology for calculating electricity costs by amalgamating energy consumption in kilowatt-hours (kWh) with peak demand in kilowatts (kW), thereby offering a more comprehensive perspective on electricity costs in manufacturing systems.

Periodic energy reporting and feedback mechanisms are crucial, as emphasized by Ates and Durakbasa (2012). They highlighted the necessity of providing management with regular updates on energy consumption data and associated costs. The organizational dimension of energy management, as they explained, entails the establishment of governance frameworks and the implementation of robust policies and procedures. Governance ensures clearly defined responsibility structures, while policies are formulated to address each phase of the energy value chain—from procurement and conversion to distribution and utilization.

Blass et al. (2014) asserted that the efficacy of energy efficiency initiatives is largely contingent upon the engagement of top management. Senior leadership must advocate for the cultivation of an energy-conscious organizational culture and promote open communication regarding energy-related issues. This culture is shaped by leadership's active involvement in energy decision-making, employee reward systems aligned with energy objectives, and ongoing education and training related to energy management.

Javied et al. (2015) investigated various electricity-centric energy efficiency indicators and emphasized the importance of identifying inefficiencies. Their research employed the Resource Efficiency and Cleaner Production (RECP) tool, as endorsed by the International Trade Centre, to assess levels of energy inefficiency.

Equations for Calculating Inefficiency

Let:

- **A** = Actual electricity used (kWh) per 10,000 units
- **C** = Total electricity consumption (kWh)
- **P** = Production output (in 10,000 units per month)
- **D** = Deviation from target (percentage)
- **T** = Target electricity usage per 10,000 units (kWh)
- **X** = Surplus energy used (kWh)
- **K** = Financial cost of inefficiency per month (in local currency)
- **U** = Electricity unit price (cost per kWh)
- **M** = Cost of inefficiency per kWh (in local currency)

The equations are as follows:

1. **Actual electricity used per 10,000 units (A):**
   $A = C / P$
2. **Percentage deviation from target (D):**
   $D = ((A - T) / T) \times 100$

3. **Cost of inefficient electricity usage per month (K):**

$$X = C - (T \times P)$$

$$K = X \times U$$

4. **Cost of inefficiency per kWh (M):**

$$M = K / C$$

Based on the previously discussed concept of energy efficiency and the identification of energy efficiency measures to be implemented in the practical component of this research, the following studies will be presented.

Researcher	Title	Year	Results of the study
1-Abadi et al.	Leveraging AI for energy-efficient manufacturing systems: Review and future prospectives	2025	This study proposes an energy-efficient digital twin concept and illustrates how a digital twin, enhanced with artificial intelligence techniques, can be utilized to address energy challenges in manufacturing systems.
2-Salah and Mustafa	Integration of energy saving with Lean production in a food processing company	2021	This study results that implementation of lean methodology significantly affects energy savings by eliminating specific energy consumption within the organization.
3-Hoffmann, and Menzel	A Guideline for the Implementation of an Energy Management System in Facility Management Organizations	2019	This study seeks to delineate the information requirements necessary for the establishment of energy management systems. These systems are designed to enable building owners, tenants, and operators to provide facility and energy management services in accordance with organizational policies and environmental standards.

4-Mawson and Hughes	**The development of modelling tools to improve energy efficiency in manufacturing processes and systems**	**2019**	**This paper examines methodologies for energy analysis at the machine level utilizing discrete event simulation, with a particular emphasis on energy consumption within manufacturing processes in the transition towards Industry 4.0.**
5-Gahm et al.	**Energy efficient scheduling in manufacturing companies: a review and research framework.**	**2015**	**This study delineates three dimensions: energetic coverage, energy supply, and energy demand. Furthermore, it specifies that each of these dimensions encompasses categories and attributes that define energy-related characteristics pertinent to energy efficiency systems.**
6- Bunse et al.	**Integrating energy efficiency performance in production management e gap analysis between industrial needs and scientific literature**	**2011**	**This study illustrates the existence of a disparity between the solutions that are available for energy efficiency and their actual implementation within industrial enterprises.**

Table 1: previous studies

Research Gap

The increasing global emphasis on sustainable industrial development has elevated energy efficiency to a prominent position within policy and operational agendas, particularly in energy-intensive sectors such as manufacturing. In the context of Egypt's manufacturing industry, existing literature provides a thorough understanding of energy efficiency concepts, management frameworks, and technical measures. For example, Amjadi et al. (2022) and Opoku et al. (2022) have investigated the strategic significance of energy efficiency in production processes, while Schulze et al. (2016) and Abdelaziz et al. (2011) have elucidated the organizational, operational, and technical enablers of energy performance improvements. Additionally, studies by Ates and Durakbasa (2012) and Blass et al. (2014) have examined the influence of governance structures and leadership in cultivating energy-aware organizational cultures. However, these investigations frequently concentrate on large enterprises or offer generalized frameworks, lacking sufficient empirical exploration of small and medium-sized enterprises (SMEs) operating within developing economies.

In the Egyptian context, there is a notable scarcity of empirical studies that examine energy efficiency at the enterprise level, particularly among SMEs in the packaging industry. This represents a significant oversight, given the sector’s considerable contribution to employment and its inherent vulnerabilities, such as limited capital, outdated equipment, and insufficient access to technical expertise. Furthermore, while methodologies such as the Resource Efficient and Cleaner Production (RECP) tool and key performance indicator (KPI)-based assessments have been advocated (Javied et al., 2015; Sivill et al., 2013), their application in conducting comparative evaluations of real-world energy efficiency performance across similarly sized firms in a developing country context remains rare.

Moreover, current research inadequately addresses the behavioral, managerial, and operational factors that influence energy efficiency in SMEs, nor does it evaluate how awareness, monitoring practices, and strategic investments affect performance. The dearth of sector-specific, data-driven studies that incorporate both qualitative and quantitative assessments—such as surveys on energy management practices and actual consumption data—impedes the capacity of policymakers and business leaders to formulate targeted and effective interventions.

Consequently, a significant research gap persists in empirically assessing the electricity efficiency of packaging SMEs in Egypt through a structured, comparative framework. This study seeks to bridge this gap by integrating technical performance metrics with survey-based evaluations of managerial practices. The findings will provide actionable insights into the determinants of inefficiency and propose practical recommendations for enhancing energy use, reducing costs, and supporting national sustainability objectives.

Based on the preceding discussion, a research model has been developed and is presented as follows.

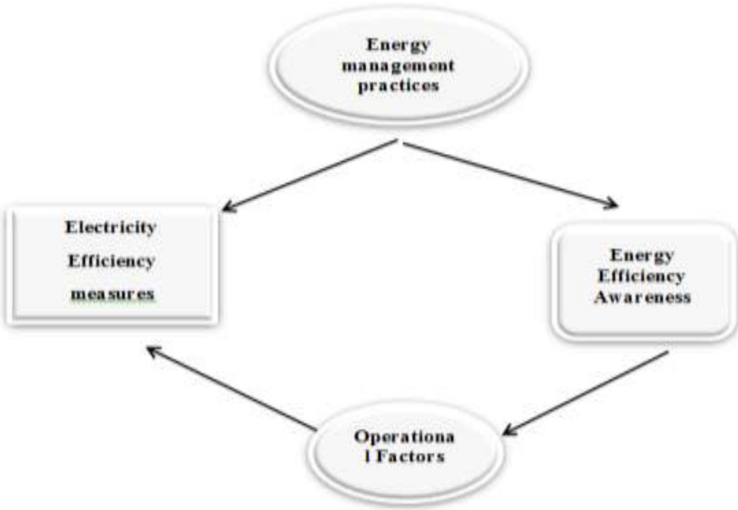


Figure 1: Conceptual framework

Therefore, it is concluded that:

a-Independent Variables: are classified as: Energy Management Practices, Operational Factors and Awareness for energy efficiency.

b-Dependent Variable: is classified as: Measured Electricity Efficiency.

Building upon the previously discussed research conceptual framework, the research hypotheses have been formulated to clarify the relationships among these variables.

H1: There is a significant positive relationship between energy management practices and electricity efficiency measures in packaging SMEs.
H2: Operational efficiency factors are significantly related with lower electricity consumption in packaging SMEs.
H3: Awareness initiatives for energy efficiency are positively related to electricity efficiency measures in packaging SMEs.
H4: Packaging SMEs that implement energy efficiency measures have significantly lower energy consumption per unit of output.

Research methodology

This study employs a mixed-methods approach, integrating both quantitative and qualitative methodologies to facilitate a comprehensive understanding of energy efficiency practices within Egyptian packaging small and medium-sized enterprises (SMEs). The rationale for this methodological design is to triangulate data pertaining to managerial energy efficiency practices, operational factors, and employee awareness, thereby enabling a holistic assessment in conjunction with energy efficiency measures. The research specifically targets small and medium-sized carton packaging enterprises in Egypt. This approach permits an in-depth exploration of real-world practices, contextual factors, and operational environments, rendering it particularly effective for investigating complex phenomena such as energy efficiency in the manufacturing sector.

Sample of the study

The target population for this study comprises small and medium-sized enterprises (SMEs) operating within the carton packaging industry in Egypt and they provide product for customer B and C classes according to the productivity (as the maximum capacity for units produced for each company is 50000 units/month) for those companies. A purposive sampling technique was employed to select three companies based on their relative market share within the SME segment. The selected companies represent leading performers in the industry, holding estimated market shares of 15%, 12%, and 10%, respectively. These firms were chosen to ensure the inclusion of diverse operational scales while maintaining relevance to the study's objectives (*https://www.egypt-business.com/company/katalog/industry/paper-packaging*).

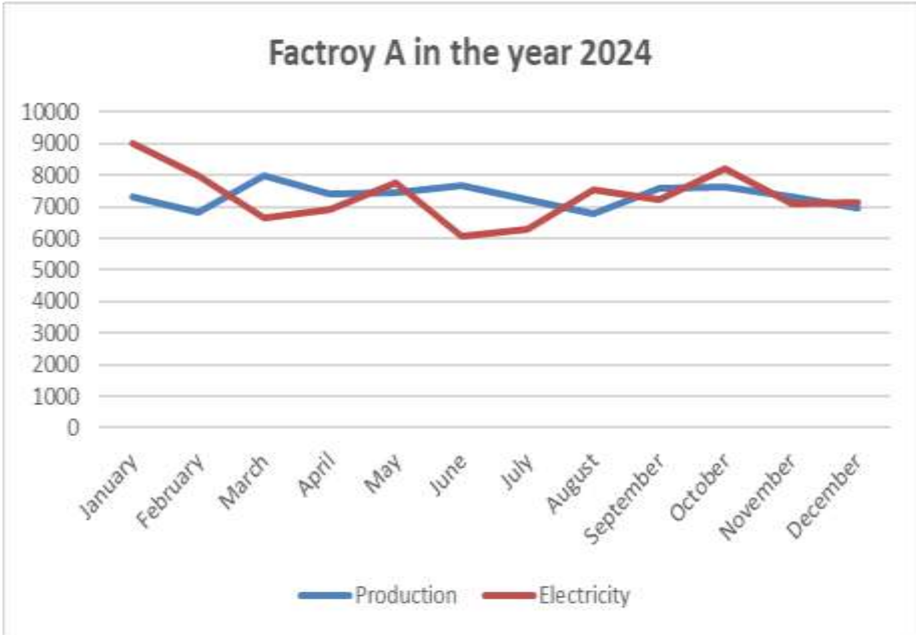
Primary operational data were obtained from each company, covering the period from January to December 2024. This dataset includes monthly electricity consumption (measured in kilowatt-hours, kWh) and corresponding production output (in number of units produced). These records serve as the basis for calculating energy efficiency indicators and performing comparative analyses across the selected enterprises.

Construction of questionnaire

In addition to the primary operational data collected from selected carton packaging SMEs in Egypt, a structured questionnaire was developed based on the study's conceptual framework and an extensive review of relevant literature, including works by Schulze et al. (2016), Abdelaziz et al. (2011), and Hoffmann and Menzel (2019). The questionnaire was designed to capture key constructs identified in the framework, specifically: Energy Management Practices, Energy Efficiency Awareness, Operational Factors, and Electricity Efficiency Measures. All items were measured using a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree), enabling standardized data collection and facilitating quantitative analysis. To ensure content validity and contextual relevance, the draft questionnaire was reviewed by an expert panel comprising academics in operations management and senior managers from the participating packaging firms. Based on their feedback, minor revisions were made to improve clarity, linguistic accuracy, and contextual appropriateness. The finalized questionnaire was distributed across multiple functional departments, including operations, logistics, quality control, and procurement. A total of 140 questionnaires were distributed to top and middle management personnel between February10 and April 27, 2025. A total of 75 completed questionnaires were returned, resulting in a response rate of approximately 53.57%.

Discussion of results

a- Electricity Efficiency measures



1- Factory A analysis:

Figure 2: Graph

Figure 2 illustrates the monthly electricity consumption and production levels for Factory A during the year 2024.

Throughout the year, production levels remained relatively stable, fluctuating moderately between approximately 6,500 and 8,000 units. In contrast, electricity consumption showed more significant variation, starting high in January (around 9,000 kWh), then decreasing sharply until June, where it reached its lowest point (around 6,000 kWh), and rising again through October before stabilizing. Notably, in October, electricity usage peaked above production levels, suggesting a period of lower energy efficiency. Conversely, June and July exhibited more favorable efficiency as electricity use was lower relative to production. This variability implies potential inefficiencies in electricity usage and suggests that operational optimization could enhance energy performance.

Based on figure 2 analysis, the following calculations for electricity inefficiency will be taken place.

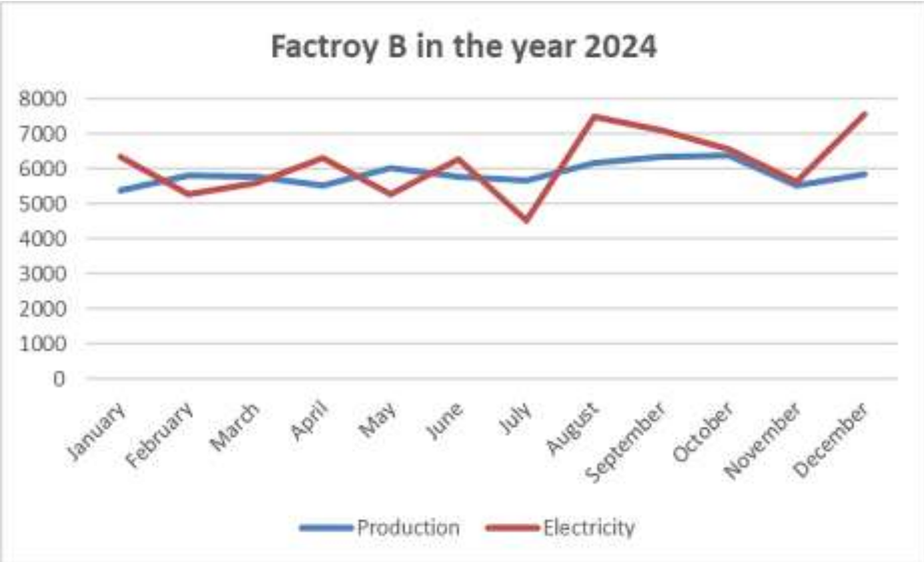
Electricity consumption per month (in 2024)	*% difference between company values and target (D)*	*Cost (in local currency) of inefficient electricity consumption per kWh consumed in given month (U)*	*Total costs (in local currency) of inefficient electricity consumption per month (M)*
January	49.05%	0.49	4456.85
February	41.15%	0.44	3496.48
March	0.00%	0.00	0.00
April	13.07%	0.17	1201.47
May	26.37%	0.31	2436.48
June	-4.34%	-0.07	-413.65
July	4.99%	0.07	447.36

August	33.66%	0.38	2845.22
September	15.38%	0.20	1446.95
October	29.43%	0.34	2796.99
November	16.85%	0.22	1536.01
December	23.76%	0.29	2055.36
TOTAL	**20.36%**	**0.25**	**22305.51**

Table 2: factory A Electricity inefficiency measures

Table 2 exhibited significant electricity consumption inefficiency throughout 2024, with a total annual inefficiency cost of 22,305.51 (EGP). The average monthly electricity consumption per 10,000 pieces (9972.66 kWh) was 20.36% above the target of 8285.82 kWh per 10,000 pieces. The most inefficient months were January (49.05% above target, costing 4456.85) and February (41.15% above target, costing 3496.48). Notably, March saw the factory meeting its efficiency target precisely, and June was the only month where the factory performed better than the target (-4.34%), resulting in a cost saving of 413.65. The persistent high levels of inefficiency for most of the year suggest underlying issues in energy management or equipment efficiency that require attention. The monthly cost attributed to inefficient electricity consumption per kWh consumed averaged 0.25 (EGP) for Factory A over the year. This indicates that, on average, 16.7% (0.25/1.5) of the electricity cost was due to consumption exceeding the target. The fluctuation in monthly inefficiency, ranging from a 49.05% overshoot in January to a 4.34%

improvement in June, highlights variability in operational performance or conditions impacting energy use.



2-Factory B analysis:

Figure 3: Graph

Figure 3 illustrates Factory B's monthly electricity consumption and production output for the year 2024. Overall, production levels remained relatively steady throughout the year, ranging between approximately 5,300 and 6,200 units per month. In contrast, electricity consumption fluctuated significantly, indicating inconsistencies in energy efficiency. Notably, in August and December, electricity usage spiked sharply—reaching approximately 7,500 to 8,000 kWh—despite production levels remaining relatively unchanged, suggesting considerable inefficiencies during those months. Conversely, July showed the lowest electricity consumption relative to production, indicating a period of higher energy efficiency. These discrepancies imply that operational factors or external influences, such as equipment usage, maintenance schedules, or environmental conditions, may have significantly impacted energy performance in Factory B throughout the year.

Based on figure 3 analysis, the following calculations for electricity inefficiency will be taken place.

Electricity consumption per month (in 2024)	*% difference between company values and target (D)*	*Cost (in local currency) of inefficient electricity consumption per kWh consumed in given month (U)*	*Total costs (in local currency) of inefficient electricity consumption per month (M)*
January	33.46%	0.38	2384.52
February	3.30%	0.05	253.66
March	10.69%	0.14	813.29
April	29.94%	0.35	2187.45
May	0.00%	0.00	0.00
June	23.49%	0.29	1789.02
July	-9.44%	-0.16	-706.22
August	38.63%	0.42	3136.70
September	27.03%	0.32	2268.54
October	17.37%	0.22	1460.90
November	15.84%	0.21	1156.95
December	47.77%	0.48	3674.75
TOTAL	**19.87%**	**0.25**	**18419.55**

Table 3: factory B Electricity inefficiency measures

Table 3 incurred a total annual cost of 18,419.55 (EGP) due to inefficient electricity consumption in 2024. Its average electricity consumption per 10,000 pieces (10533.43 kWh) exceeded its specific target (8787.12 kWh per 10,000 pieces) by an average of 19.87% over the year. The highest inefficiency was recorded in December (47.77% above target, costing 3674.75) and August (38.63% above target, costing 3136.70). Factory B demonstrated periods of better performance: May saw the factory meeting its target exactly, and July showed a significant efficiency gain with consumption 9.44% below target, leading to a saving of 706.22. The average cost of inefficient electricity consumption per kWh consumed for Factory B was 0.25 (EGP) for the year. Similar to Factory A, this suggests that a considerable portion of energy costs could be avoidable. The target for Factory B (8787.12 kWh per 10,000 pieces) is slightly higher than Factory A's, meaning it has a more lenient baseline for efficiency. Despite this, its overall percentage above target is comparable to Factory A's. The wide range, from 47.77% over target in December to 9.44% under target in July, indicates substantial inconsistency in energy performance.

3-Factory C analysis:

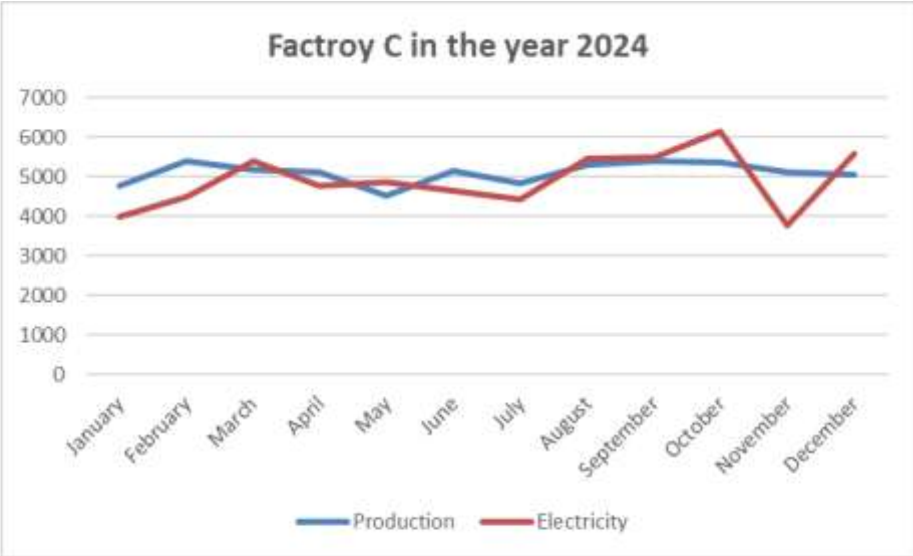


Figure 4: Graph

Figure 4 presents Factory C’s production and electricity consumption trends throughout 2024. Production remained relatively consistent, fluctuating moderately between 4,800 and 5,700 units per month. Electricity consumption followed a generally parallel trend, showing signs of effective energy management for most of the year. Notably, February through September reflect a close alignment between electricity use and production output, suggesting periods of optimized energy efficiency. However, a significant spike in electricity usage occurred in October, reaching nearly 6,200 kWh, without a corresponding increase in production—indicating a substantial inefficiency. In contrast, November showed a sharp drop in electricity use despite stable production, marking a period of exceptional energy performance. Overall, Factory C demonstrates relatively stable and efficient electricity usage with a few isolated deviations that warrant further investigation.

Based on figure 4 analysis, the following calculations for electricity inefficiency will be taken place.

Electricity consumption per month (in 2024)	*% difference between company values and target (D)*	*Cost (in local currency) of inefficient electricity consumption per kWh consumed in given month (U)*	*Total costs (in local currency) of inefficient electricity consumption per month (M)*
January	0.06%	0.00	3.35
February	0.00%	0.00	0.00
March	25.78%	0.31	1664.06
April	11.89%	0.16	761.74
May	28.97%	0.34	1641.39
June	8.50%	0.12	545.76
July	10.22%	0.14	617.70
August	23.55%	0.29	1562.58
September	22.49%	0.28	1515.99
October	37.42%	0.41	2516.21
November	-11.13%	-0.19	-709.06
December	33.32%	0.37	2099.33
TOTAL	**15.98%**	**0.21**	**12219.07**

Table 4: factory C Electricity inefficiency measures

Table 4 demonstrated the best performance among the three factories in terms of managing electricity consumption inefficiency, with the lowest total annual inefficiency cost of 12,219.07 (EGP). Its average electricity consumption per 10,000 pieces (9650.30 kWh) was 15.98% above its target of 8321.01 kWh per 10,000 pieces. The most inefficient month was October, with consumption 37.42% above target, resulting in a cost of 2516.21. Factory C also had months of exemplary performance: February saw the factory meeting its target, and November showed consumption 11.13% below target, leading to a saving of 709.06. January was also very close to target with only a 0.06% deviation. The average cost of inefficient electricity consumption per kWh consumed for Factory C was 0.21 (EGP) for the year, lower than Factories A and B. This implies that, on average, 14% (0.21/1.5) of its electricity cost was due to inefficiency. Factory C's target (8321.01 kWh per 10,000 pieces) is marginally higher than Factory A's but lower than Factory B's. Its ability to operate below target in November and meet the target in February, coupled with a lower overall percentage difference, suggests a comparatively better control over energy consumption, although significant inefficiencies still occurred in some months like October and March.

b. Questionnaire analysis

Factory	General Energy Management Practices	Operational Factors and Impact	Awareness	efficiency percentage	inefficiency percentage	Inefficiency Costs L.E
A	2.736	2.92	2.584	79.64%	20.36%	22305.51
B	3.1	3.18	2.94	80.13%	19.87%	18419.55
C	3.95	3.35	3.75	84.02%	15.98%	12219.07

Table 5: Average Score of Questionnaire Vs. Quantitative measures

Interpretation and Hypothesis Testing

Table 5 presents a synthesis of the results derived from the questionnaire in conjunction with the electricity efficiency measures, as detailed below:

H1: There is a significant positive relationship between energy management practices and electricity efficiency measures in packaging SMEs.

- Interpretation: The correlation between General Energy Management Practices and Inefficiency % is -0.98, which is a strong negative correlation.
- Explanation: This supports H1. A higher score in energy management corresponds to lower inefficiency, implying improved electricity efficiency. Although the hypothesis states a "positive relationship with electricity efficiency," note that inefficiency % is the inverse — so a negative correlation confirms a positive effect on efficiency.

H2: Operational efficiency factors are significantly related with lower electricity consumption in packaging SMEs.

- Interpretation: Correlation = -0.86, still a strong negative relationship, but weaker than the other hypotheses, because:
  - Operational variability: Operational practices might vary day-to-day or shift-to-shift, reducing their consistent impact.
  - Maintenance lag effect: Maintenance improvements often have a delayed impact on electricity consumption.

H3**:** Awareness initiatives for energy efficiency are positively related to electricity efficiency measures in packaging SMEs.

- Interpretation: Correlation = -0.98 — same as general energy management, because factories with higher awareness scores show markedly lower inefficiency % and higher electricity efficiency.

H4: Packaging SMEs that implement energy efficiency measures have significantly lower energy consumption per unit of output.

- Interpretation: the data illustrates that greater implementation of energy efficiency measures is associated with significantly lower energy consumption per unit of output. This is clear through Factory C, which achieved the highest implementation level of energy efficiency measures—evident from its top scores in

General Energy Management Practices (3.95), Operational Factors (3.35), and Awareness (3.75)—also reported the lowest inefficiency percentage (15.98%) and lowest energy inefficiency cost (L.E 12,219.07). These results strongly suggest that Factory C consumes less energy per unit of output, reflecting superior energy performance.

	General Energy Management Practices	Operational Factors and Impact	Awareness	inefficiency percentage
General Energy Management Practices	1			
Operational Factors and Impact	0.940261298	1		
Awareness	0.999981895	0.942292915	1	
inefficiency percentage	-0.981204186	-0.856890164	-0.980025233	1

Table 6: Correlation matrix

Strong Positive Correlations Among Management Dimensions:

- There is a very strong positive correlation between General Energy Management Practices and Awareness (r = 0.9999), indicating that factories with well-developed energy management strategies also tend to have high levels of employee awareness regarding energy efficiency.
- Similarly, Operational Factors are also strongly correlated with both General Energy Management Practices (r = 0.94) and Awareness (r = 0.94). This suggests a tightly interlinked relationship where effective operational

practices align with both strategic planning and staff engagement.

Strong Negative Correlations with Inefficiency Percentage:

- All three management-related variables show strong negative correlations with Inefficiency Percentage:
  - General Energy Management Practices and Inefficiency Percentage: r = -0.981
  - Awareness and Inefficiency Percentage: r = -0.980
  - Operational Factors and Inefficiency Percentage: r = -0.857

These negative correlations indicate that as management practices, operational controls, and awareness improve, the percentage of energy inefficiency significantly decreases. General Energy Management Practices and Awareness have the strongest inverse relationships with inefficiency, highlighting them as the most influential factors in improving electricity efficiency.

Main Findings

The following findings represent the primary observations regarding energy consumption and measures of inefficiency: All three factories demonstrated significant annual energy inefficiency, consistently operating above their targets.

- Factory B: Averaged 23.95% above target, indicating the highest relative inefficiency despite having the most lenient target.
- Factory A: Averaged 20.36% above target.
- Factory C: Averaged 19.87% above target, showing the best relative performance among the three.

- Peak Inefficiencies: Highlight substantial place for improvement:
  - Factory A: 49.05% in January.
  - Factory B: 47.77% in December.
  - Factory C: 37.42% in October.
- Variable Performance: All factories showed monthly variations, with instances of meeting or exceeding targets (e.g., Factory A in March & June, Factory B in May & July, Factory C in February & November). This suggests that optimal operational states are achievable.
- Consistent Unit Cost: A uniform electricity cost of 1.5 EGP/kWh allows for direct financial comparison of inefficiencies.

- Factory C as a Benchmark: Factory C consistently showed higher agreement scores (indicating stronger implementation) across most questions related to effective energy management strategies, employee training, data monitoring, and management commitment.
- Factory A: Areas of Weakness: Generally had the lowest

scores across most positive energy management practices and indicated higher susceptibility to increased energy use from equipment breakdowns.

- Factory B: Mixed Performance: Often positioned between Factory A and C. While better than A in some areas, it significantly lagged behind C in crucial aspects and showed specific issues with seasonal variations impacting energy consumption.

Based on the aforementioned findings, an action plan will be developed. This action plan will be formulated in accordance with recommendations from the Operations Department and aligned with established Operations strategies.

Strategic Pillar	Action	Findings	Recommendation	Key Metrics	Timeline
A. Enhancing Energy Management Strategies & Practices	1. Develop and Disseminate Energy Guidelines	Factory A & B lack formal guidelines	Create and communicate clear energy-saving procedures	Number of documented guidelines implemented	2026
	2. Implement Mandatory Training Programs	Factory A & B score low on awareness and practices	Provide regular role-specific training on energy-saving techniques	% of staff trained, awareness score improvement	2026
	3. Establish Energy Management Teams	Factory A & B lack dedicated teams	Create cross-functional energy committees or appoint managers	Team formed, meeting frequency	2026
	4. Prioritize Energy-Efficient Equipment Investment	Factory C leads in equipment upgrades	Upgrade old machinery, focus on high-consumption areas	Value/number of upgrades completed	2026
B. Addressing Operational Factors & Inefficiencies	5. Improve Equipment Maintenance	Factory A & B face frequent breakdowns	Implement predictive/preventive maintenance plans	Breakdown reduction, ratio of planned vs. unplanned maintenance	2026 and continue
	6. Optimize Production Scheduling	Factory C optimizes schedules	Adjust schedules to reduce idle time and energy waste	Energy use per batch, off-hour consumption	2026
	7. Address Seasonal Energy Variations	Factory B impacted by seasonal shifts	Conduct analysis and mitigation (e.g., insulation, HVAC)	Variance in seasonal energy usage	2027

C. Improving Data Utilization & Continuous Improvement	8. Enhance Monitoring & Target Setting	Factory A & B weaker in data-driven practices	Install smart meters, analyze usage patterns, and set targets	Frequency of reviews, achievement of targets	2026
	9. Foster Management Commitment	Factory C shows stronger leadership	Engage top management in energy goals and reviews	Energy included in KPIs, budget allocated	Immediate start and continue
	10. Establish Continuous Improvement Loop	Factory C proactively uses data for change	Hold quarterly performance reviews and share best practices	Number of initiatives are implemented, % deviation reduced	Start 2027 and continue

Table 7: Action plan

Managerial implications

The findings of this research carry substantial implications for both scholars and practitioners.

For scholars:

- The consistent inefficiency across all factories reinforces the need for refined theoretical models explaining why some industrial settings fail to meet energy targets.
- The mixed results from Factory B, especially in relation to seasonal variation, highlight the need to incorporate external environmental and temporal factors into existing energy efficiency models, which often underemphasize such dynamics.
- The discrepancy between potential (i.e., months where targets were met) and actual performance opens the door to scholarly inquiries about implementation barriers, feedback loop failures, and transient organizational learning in industrial contexts.

For practitioners:

- Factory C should be analyzed in greater depth and potentially used to create internal benchmarks. Managers at A and B should initiate knowledge transfer programs to replicate C's success in areas such as training, monitoring, and leadership involvement.
- Each factory has months with exceptionally poor performance. Managers should investigate these peaks for root causes—such as equipment failure, demand surges, or staffing issues—and develop contingency plans or predictive maintenance protocols.
- Since each factory had months where targets were met or exceeded, this suggests that operational excellence is within reach. Managers should perform comparative analyses of "high-performance months" to replicate those conditions consistently.
- The standardized electricity cost allows managers to directly tie inefficiency to financial loss. This can be used to build strong business cases for energy-saving investments, justify the cost of new technologies, or redesign incentive structures for energy conservation.
- Stronger data systems and continuous monitoring appear to correlate with better outcomes. Practitioners should prioritize

investments in Internet of things (IoT)-enabled energy monitoring and analytics platforms.

Avenues for further research

-The Role of Leadership Commitment and Organizational Culture in Achieving Industrial Energy Efficiency

-Employee Engagement and Energy Savings: Exploring Behavioral Drivers in High-Performing Industrial Settings

-Seasonal Variability in Industrial Energy Consumption: Causes, Impacts, and Mitigation Strategies

-Diagnosing Peak Energy Inefficiencies: An Operational Analysis of Monthly Performance Extremes in Manufacturing

-Translating Best Practices Across Industrial Sites: Challenges and Strategies in Energy Efficiency Knowledge Transfer

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