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Energy Analysis of a Large-Scale Plastic Industry: A Case Study of Panar Limited, Kano Nigeria

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Abstract

The study analyzed the energy consumption pattern of a large-scale plastic manufacturing facility in Kano, Nigeria, over five years (2017-2021). The objective was to identify inefficiencies, establish an energy baseline, and estimate potential savings, along with the corresponding CO_2 emissions. Results showed electricity consumption of 8,730,673.30 kWh and diesel use of 661,613.93 liters, representing 71% electricity cost and 29% diesel cost respectively, amounting to ₦ 540,808,037 with a production output of 88,014,099.58 kg (2017-2021). The industry's capacity is 63,000 metric tons/year. The extrusion section was the highest energy consumer (36%), while the administrative block was the lowest energy consumer (5%). The calculated energy intensity was 1.16 GJ/m², confirming high energy use, while the Normalized Performance Indicator (NPI) (0.93 GJ/m²) was rated "Satisfactory". Carbon emissions were dominated by diesel use, highlighting environmental challenges. The study concludes that improved energy management, retrofitting, and integration of renewable energy could yield average cost savings of ₦ 108,666,877.8 per year with an average four-year payback period while reducing the industry's carbon footprint. Findings underscore the economic and environmental benefits of energy conservation in Nigeria's plastic sector.

Keywords: *Energy intensity, energy efficiency, energy audit, payback period, normalized performance indicator.*

1.0 Introduction

Energy is the driving force for the industrial and economic sectors and has a significant impact on our socio-economic life. The main challenges of industrialization in the 21st Century are environmental constraints and energy. Improving the energy efficiency in the industrial sector has been identified as a strategy to reduce greenhouse gas (GHG) emissions and also promote sustainable development through reliable and low-carbon energy use (Pachauri & Meyer, 2014; Waheed et al., 2017).

Accurate knowledge of machine and process performance is highly recommended in order to improve energy utilization in manufacturing. Energy auditing is a tool for identifying inefficiencies, reducing fossil fuel use, and lowering operating costs (Hassanbeigi & Price, 2021; Mbaye, 2022). The plastic sector is energy intensive, accounting for about 4% of global energy demand, which is driven by processes such as the melting of raw material, the extrusion process, cooling, and driving peripheral equipment (Kulkarni et al., 2020).

In Nigeria and across much of Africa, published energy audit studies for the plastic industry are limited, so targeted audits can help cut costs and emissions while improving operational performance (UNFCCC, 2015; UNIDO, 2022).

1.1 Problem Statement

The unstable power supply is a major problem faced by most parts of Africa, Nigeria in particular. The plastic industry is inherently energy-intensive; therefore, energy is often wasted due to their inefficient practices, use of outdated technologies, and poor energy management so optimizing energy is not only a cost saving strategy but also an environmental necessity (Waheed et al., 2017; UNIDO, 2022).

This research addresses inefficiency and excessive energy consumption in a large–scale Nigerian plastic industry by conducting a comprehensive energy audit with the goal of improving energy efficiency for improved sustainability and cost effectiveness. The analysis identifies energy loss, proposes energy saving opportunities, and recommends actionable strategies.

1.2 Aim and Objectives

The research aims to analyze the energy consumption of a large-scale plastic industry in Kano, Nigeria, with the goal of reducing the excessive and inefficient energy usage, thereby cutting down the possible carbon footprint. The objectives include:

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a. To investigate the energy use pattern of a large-scale plastic industry.
b. To determine possible energy savings and minimize the environmental impact of the industry's operation (GHG emission reduction), thereby optimizing energy utilization in the plastic industry.
c. To establish an energy baseline that will serve as a benchmark for future comparison.

2.0 Literature Review

2.1 Energy Efficiency in Plastic Processing

Several studies have examined energy efficiency in industries. Research conducted by Ribeiro et al. (2021) on extrusion-based polymer processing which identified motors, cooling, and heating as key energy consumers, thereby providing global Specific Energy Consumption (SEC) benchmarks for comparison. Similarly, Smith & Adeyemi (2023) outlined SEC ranges for injection molding and emphasized the importance of machine design, maintenance, and material properties in determining efficiency. A study by Abrue et al. (2022) showed how the design of experiments can optimize injection molding processes, reducing energy use by up to 15%. Zhang et al. (2024) applied machine learning in their paper to forecast injection molding energy consumption with high accuracy, supporting predictive energy management. In a more practical context, a recent article in the trade publication *Plastics Technology* (2025) showed how retrofitting extrusion machines with induction heating, variable speed drives, and waste heat recovery can cut extrusion energy use by 25-40% (Plastic Technology, 2025).

These studies show both the applied and theoretical potential of energy consumption reduction in plastic production.

2.2 Energy Audits Management Frameworks

Some research stresses the role of systematic audits and energy management. For instance, Mbaye (2022) highlighted the benefits, barriers, and opportunities associated with energy audits.. This aligns with international recommendations, such as the U. S. Department of Energy's (U. S. DOE) *Strategy for plastics innovation* (DOE, 2023), which calls for a combined approach that includes efficiency, recycling, and new technologies. This indicates that audits should not only measure energy but also provide actionable pathways for sustainable energy savings.

2.3 Life-Cycle Assessments and Environmental Perspectives

Also, several authors have considered plastics from a life-cycle and emissions perspective, highlighting high energy consumption and environmental burden. The authoritative paper by Geyer, Jambeck, and Law (2017) provides a comprehensive analysis of plastic production and fate. The findings underscore that efficiency improvements in production must be developed simultaneously with recycling and waste management. Similarly, a 2025 article in *Plastics Technology* reported on a study commissioned by Plastic Energy that showed chemical recycling can reduce emissions by 78-89% compared with incineration (Plastics Technology, 2025). Lee, Martinez, and Chen (2023) provided a life-cycle assessment of plastic waste and energy recovery, concluding that LCA is a valuable tool for comparing different waste management methods. Some studies have also shown that recycling processes vary widely in energy intensity, stressing the importance of selecting optimal technologies (Kent, 2018). These findings underscore the environmental significance of industrial energy optimization. Furthermore, global efforts to improve waste management are agencies like the United Nations Environment Programme (UNEP).

2.4 The Nigerian Plastic Context

Nigeria-focused research reveals specific gaps. The United Nations Industrial Development Organization's (UNIDO) (2022) value-chain analysis traced the national plastic trends (2009-2020), which provided industrial and energy-use baselines, while Ezeudu et al. (2024) in *Sustainability* examined national production, consumption, and waste management, identifying persistent inefficiencies and poor end-of-life practices. Abubakar et al. (2022) reviewed plastic pollution in Nigeria, linking industrial production and inadequate energy management to environmental degradation. Despite these contributions, comprehensive energy audits of Nigeria's plastics industry remain scarce.

Synthesis and Research Gap

From the reviewed literature, three key themes emerge:

I. Plastic production is highly energy-intensive
II. Energy audits provide practical efficiency frameworks
III. Nigerian plastics industry lack comprehensive large-scale energy analysis

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This study contributes by filling that gap in conducting a five-year energy analysis of a large-scale plastic industry in Kano state, providing both benchmarking and practical recommendations for sustainable energy management.

3.0 Materials and Methods

3.1 Study Area

This study was conducted in a large-scale plastic industry located in Kano, Nigeria (11.747^0N, 8.5247^0E) Google Earth pro (2023). The facility comprises of the administrative and production sections powered by both Kano Electricity Distribution Company (KEDCO) through two transformers (1000KVA and 1100KVA) and diesel generators as backup. The satellite image of the industry was obtained using Google Earth pro (2023) (figure 1), while the plan is shown in figure 2.

Figure 1: Satellite image of Panar Limited Kano as selected site considered for analysis
Source: *Google Earth pro* (2023)

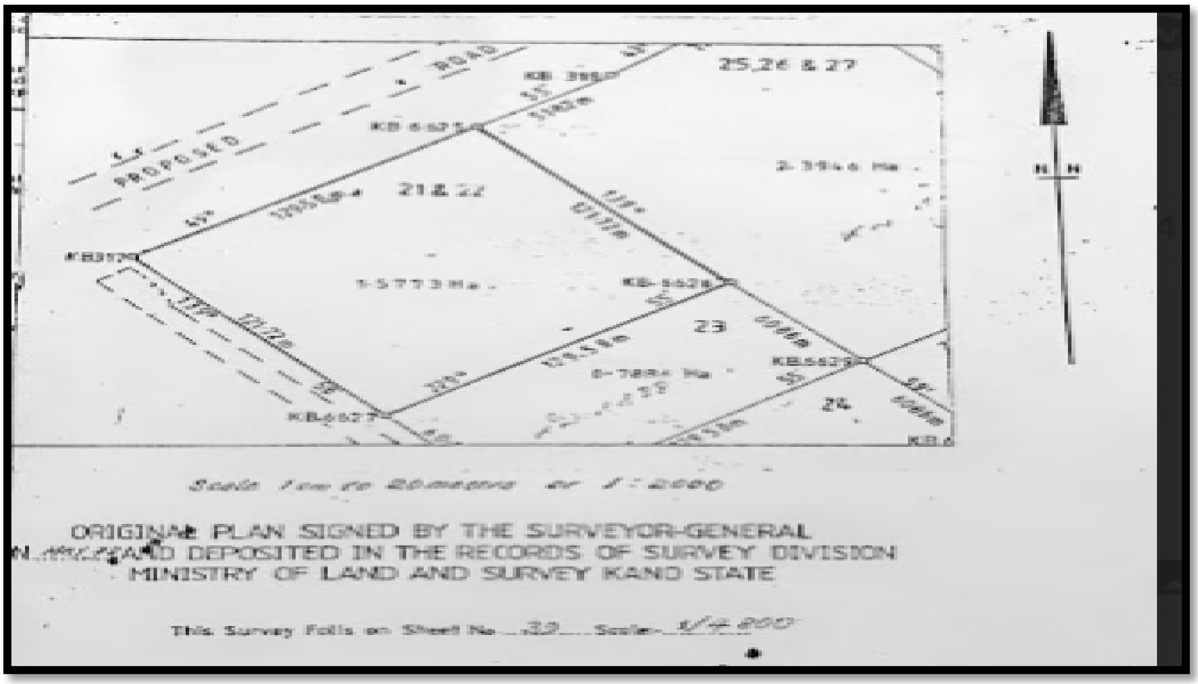

Figure 2: Plan of the Plastic Industry
Source: *Author's field survey* (2025)

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3.2 Methodology

The methodology combined data collection, and analysis to evaluate energy performance.

Data collection: A preliminary (walkthrough) audit was conducted, and the data collected includes; monthly electricity consumption (kWh) from grid supply (2017-2021), monthly diesel consumption (liters, converted to kWh for further calculations) (2017-2021), monthly production output, working hour per day, cost of energy, power rating on equipment name plate (for injection, extrusion, (Poly Ethylene Terephthalate (PET blowing))), record of daily operating hours and appliance inventory.

Data Analysis: The analysis was conducted manually, using Microsoft Excel and Plant Energy Profiler Excel (PEPEx) software where the following metrics were computed:

a. **Absolute Consumption** (Sum total of the energy consumption from national grid and diesel generator) kWh and the monthly production output (kg) of the period of study for the machines and appliances kWh/month.
b. **Percentage (%) breakdown** of the total energy consumption across all sections.
c. **Energy-savings opportunity** and payback periods.
d. **Specific Energy Consumption (SEC)** through regression analysis between production output (kg) and energy consumption (kWh) (Ribeiro et al. 2021.)
e. **Energy Performance Indicators** (EPI/KPI) for benchmarking.
f. **Carbon emissions** estimated using standard formula from UNEP, 2017, with Department of Environment, Food & Rural Affairs and Department of Energy & Climate Change. (DEFRA/DECC), 2012 emission factors:
    a. Grid electricity= 0.439kgCO_2/kWh
    b. Diesel= 2.64kgCO_2/kWh

3.2.1 Calculations

The sum total of the annual energy consumed (grid & diesel) from all sections for five years was computed using the (Mendenhall & Sincich, 2012) relations as seen in equations (1-6).

Equation (1): Total annual energy consumption from grid/diesel generator in the production section

$$(\mathrm{ET_{ac}})_{2017-2021,\mathrm{grid/diesel}} = \sum_{n=1}^{12} (\mathrm{E_{mc}})_{\mathrm{ext,inj,PETblowing}}$$

$$(\mathrm{ET_{ac}})_{\mathrm{j}} = \sum_{n=1}^{12} (\mathrm{E_{mc}})_{\mathrm{i}} \qquad (1)$$

Equation (2): Total annual energy consumption from grid/diesel generator in the administrative section

$$(\mathrm{ET_{ac}})_{2017-2021,\mathrm{grid/diesel}} = \sum_{n=1}^{12} (\mathrm{E_{mc}})_{\mathrm{Admin}}$$

$$(\mathrm{ET_{ac}})_{\mathrm{y}} = \sum_{n=1}^{12} (\mathrm{E_{mc}})_{\mathrm{A}} \qquad (2)$$

Equation (3): Total annual energy consumption from grid/diesel generator for lighting and Heat Ventilation and Air Conditioner (HVAC)

$$(\mathrm{ET_{ac}})_{2017-2021,,\mathrm{grid/diesel}} = \sum_{n=1}^{12} (\mathrm{E_{mc}})_{\mathrm{light,HVAC}}$$

$$(\mathrm{ET_{ac}})_{\mathrm{k}} = \sum_{n=1}^{12} (\mathrm{E_{mc}})_{\mathrm{L}} \qquad (3)$$

where $(\mathrm{ET_{ac}})_{\mathrm{j}}$ is the total annual energy consumption from the grid/diesel for a period of 5 years; j represents the period of study (2017-2021), $(\mathrm{E_{mc}})_{\mathrm{i}}$ is energy consumed in a month by each machine type, i (extrusion, injection molding and PET blowing machine), $(\mathrm{ET_{ac}})_{\mathrm{y}}$ is the total annual grid/diesel consumption for year y (2017-2021), $(\mathrm{E_{mc}})_{\mathrm{A}}$ = energy consumption in a month by section A (administrative block), $(\mathrm{ET_{ac}})_{\mathrm{k}}$ is the total annual energy consumed by light and HVAC for year k.

Equation (4): Percentage breakdown of energy (grid/diesel) consumption in the production section

$$(\mathrm{EP_{ec}})_{\mathrm{j}} = \frac{(\mathrm{ET_{ac}})_{\mathrm{j}}}{\sum_{n=1}^{12} (\mathrm{E_{mc}})_{\mathrm{i}}} \times 100\% \qquad (4)$$

Equation (5): Percentage breakdown of energy (grid/diesel) consumption in administrative block

$$(\mathrm{EP_{ec}})_{\mathrm{y}} = \frac{(\mathrm{ET_{ac}})_{\mathrm{y}}}{\sum_{n=1}^{12} (\mathrm{E_{mc}})_{\mathrm{A}}} \times 100\% \qquad (5)$$

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Equation (6): Percentage breakdown of energy (grid/diesel) consumption by lighting and HVAC

$$(\mathrm{EP_{ec}})_k = \frac{(\mathrm{ET_{ac}})_k}{\sum_{n=1}^{12}(\mathrm{E_{mc}})_L} \times 100\% \qquad (6)$$

where $(\mathrm{EP_{ec}})_j$ is percentage share of energy consumed for year j, n is number of months in a year (12 month) in the production section, $(\mathrm{EP_{ec}})_y$ is the percentage share of energy consumed in the admin section, $(\mathrm{EP_{ec}})_k$ is the percentage share of energy consumed by light and HVAC.

Energy intensity (GJ/m^2 of factory floor area)

$$Total\ energy\ consumed\ (GJ) \Big/ Floor\ area\ (m^2) \qquad (7)$$

Normalized Performance Indicator (NPI) for building energy performance (kanase & Patil, 2019).

$$NPI = Total\ Energy\ Consumed\ (GJ) \Big/ Floor\ area(m^2) \times \text{Hours of use factor} \qquad (8)$$

$$Hrofusefactor = Standard\ Working\ Hour \Big/ Actual\ Hours\ in\ Use$$

GHG emissions based on the activity data and emission factors (UNEP, 2017; DEFRA/DECC, 2012).
All results are presented in chapter 4.

4.0 Results and Discussion

The analyzed data set was evaluated respectively, and the results for the base year (2017) and subsequent years (2018-2021) were presented in this chapter.

4.1 Energy Consumption (2017)

National grid electricity consumption in 2017 was highest in March (83,272.75 kWh) as seen in Figure 3, corresponding to a production output of 520,345 kg with low efficiency, as the cost peaked at ₦ 3.45 million. This suggests base load inefficiencies and reliance on grid consumption (NERC, 2021).

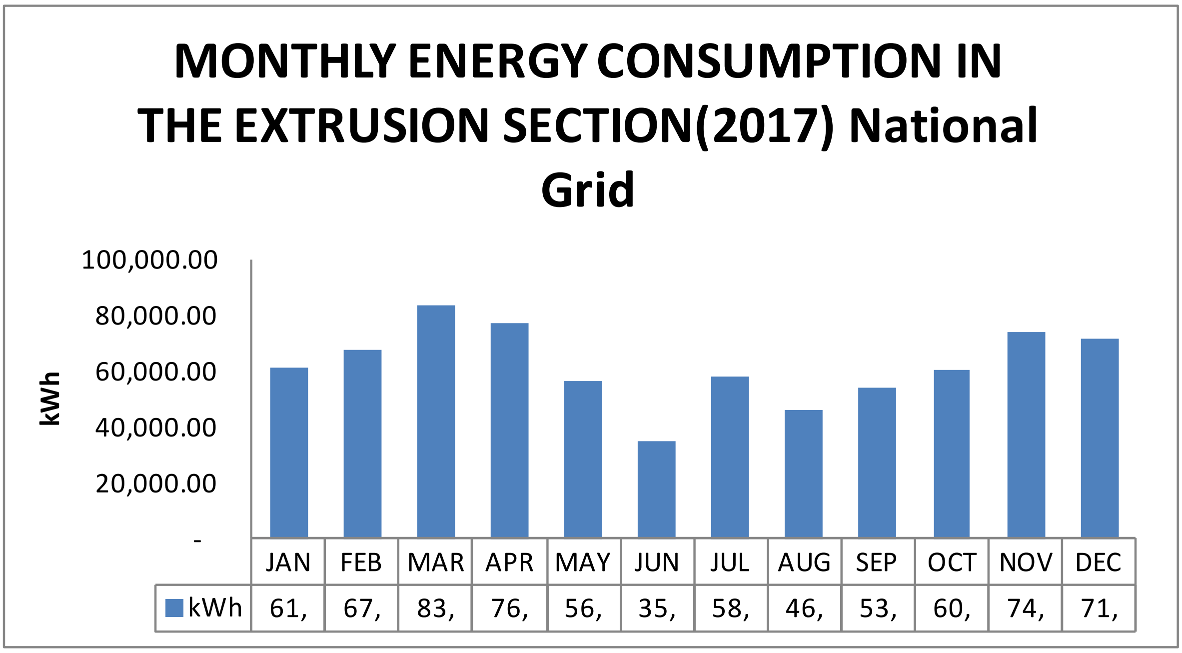

Figure 3: Monthly energy consumption of Plastic Industry (2017)
Source: *Author's field survey (2025)*

Regression analysis showed a strong correlation between energy use (kWh) and production output (kg) (R^2 = 0.85) with SEC value for extrusion machines at 0.1185 kWh/kg (Figure 4), which is well below benchmarks of 0.4-0.6 kWh (Do, 2019; Kent, 2018).

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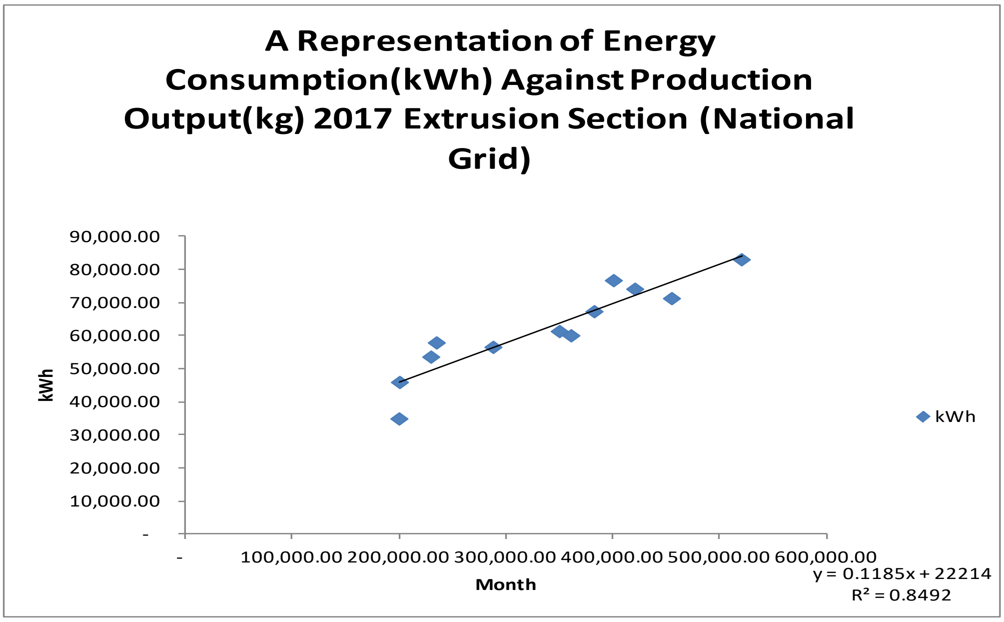

Figure 4: Energy consumption (kWh) vs. production output (kg) for the extrusion section (2017)
Source: *Regression Analysis using Excel*

Table 1 shows that carbon emissions from diesel was nearly three times higher than that from electricity (877,615 $kgCO_2$vs. 327,317 $kgCO_2$), confirming diesel as the largest environmental burden (UNEP, 2017; DEFRA/DECC, 2012).

Table 1: Carbon emission from grid and diesel sources (2017)

S/N	Sections	Grid Emission $kgCO_2$	Diesel Emission $kgCO_2$	SEV CO_2
1	Extrusion machine	327,317.26	877,615.20	0.189
2	PET blowing machine	257,819.56	849,024.00	0.423
3	Injection molding machine	306,637.83	1,186,336.8	0.196
4	Total	891,774.65	2,912,976.0	0.81

Source: *Author's field work analysis (2025),* (UNEP, 2017; DEFRA/DECC, 2012).

4.2 Total Energy Consumption and Cost (₦) from all Sources (2017-2021)

The analysis showed that between 2017 and 2021, grid consumption totaled 8.73 million kWh, at ₦ 372.5 million, while diesel accounted for 6.62 million kWh at ₦ 147.9 million as seen in Figure 5.

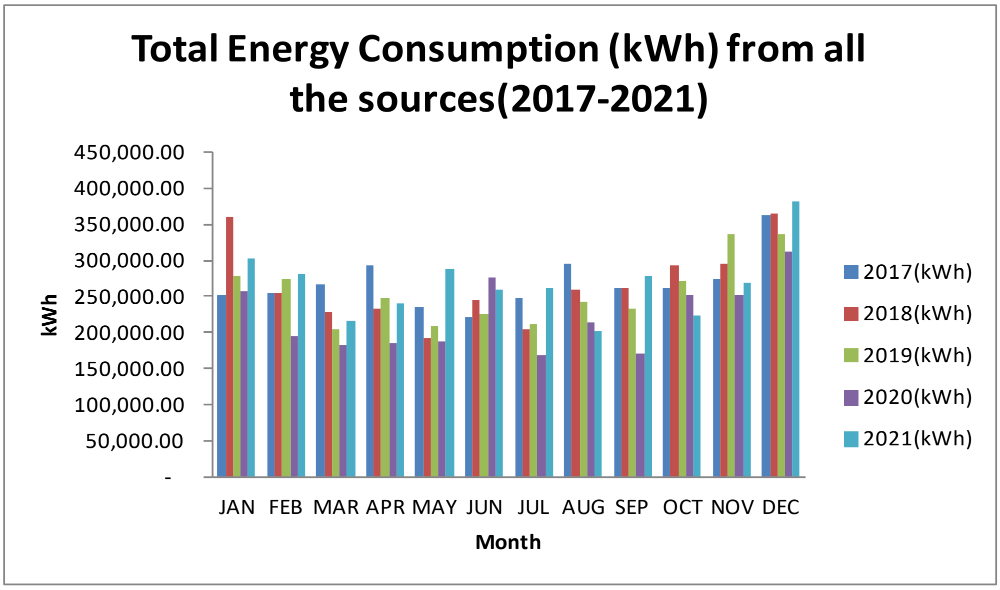

Figure 5: Total Energy consumption (kWh) from all the sources (2017-2021)
Source: *Author's field data analysis* (2025)

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Energy use was relatively low in 2017-2018, spiked in 2019, dropped during Coronavirus Disease 2019 (COVID-19) in 2020, and sharply rose again in 2021. The high dependency on grid highlights the need for alternative sources like solar integration.

4.3 Financial Analysis

Energy savings of 15% ($\sim 1.23\ million\ kWh/year$) and cost reductions of ₦108.7 million/year with an average 4-year payback can be achieved (as seen in Table 2) by adopting more energy efficient machines (International Energy Agency, 2024), solar integration can also provide 20% additional savings.

Table 2: Energy and cost savings from all sections (2017)

S/N	Sections/Savings	Energy Saving kWh/year 15%	Energy Saving (Solar Panel) kWh/year 20%	Annual Cost Savings ₦/year	Payback Period (year)
1	Extrusion machine	756,000	1,008,000	155,872,080.0	6
2	Injection machine	604,800	806,400.0	124,694,664.0	5
3	PET Blowing machine	665,280	887,040.0	137,167,430.4	2
4	Admin	82,128.9	109,505.2	16,933,336.6	3
5	Average	527,052.2	702,736.3	108,666,877.8	4

Source: *Author's field work analysis* (2025)

4.4 Normalized Performance Indicator (NPI)

The value of the calculated NPI for the facility is $0.93\ \mathrm{GJ/m^2}$and ranked "Satisfactory" category (0.8-1.0), suggesting room for improvement through energy management (Kanase & Patil, 2019).

4.5 Energy Intensity

The industry's energy intensity was $1.16\ \mathrm{GJ/m^2}$, this value is higher than global averages ($0.9\ \mathrm{GJ/m^2}$) but placed within Nigeria's typical range of $1.2 - 1.4\ \mathrm{GJ/m^2}$ (IEA, 2020; Energy Commission of Nigeria, 2021). The high intensity is linked to the use of outdated equipment and diesel dependency.

$$\frac{\text{Total Energy Consumption (kWh)}}{\text{Floor area } (\mathrm{m^2})} = \frac{15{,}346{,}512.60\ \mathrm{kWh}}{47{,}603\ \mathrm{m^2}} = \frac{322.39\ \mathrm{kWh}}{\mathrm{m^2}} = \sim 1.16\ \mathrm{GJ/m^2}$$

4.6 PEPEx Software analysis

Simulation analysis revealed high baseline energy consumption which was linked with idle machines and the use of outdated equipment. Although, diesel was the most used source, their cumulative cost was found to be less than grid electricity due to differences in tariff rate. Implementing energy management strategies and retrofits, such as installing variable frequency drives (VFDs), could lower this baseline energy consumption.

5.0 Conclusion

The study confirms plastics manufacturing as highly energy intensive, with diesel being the highest emitter. The use of energy-efficient equipment, solar integration, and operational measures (load shifting, Light Emitting Diode; LED lighting, and staff training) can reduce energy use by 15-25%. This aligns with DOE (2023) and UNIDO (2022) recommendations, offering a framework for cleaner, cost-effective industrial energy management.

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