UNIVERSITY OF RWANDA

College of Science and Technology (CST)

ENERGY AUDIT AND CONSERVATION FOR INDUSTRY SECTOR IN RWANDA

Case Study: SULFO Rwanda Industries ltd

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Thesis to be submitted in partial fulfillment of the requirements of the award of the degree of the Master of Science in Electrical Power Systems Engineering in the college of science and technology (CST).

3rd October, 2025

DECLARATION

I, NIYIREMA Jonas do hereby declare to the Senate of University of Rwanda that the Thesis work presented is my original work and has not been submitted for any degree award in any other University.

Signature……………………………… Date: 03/10/2025

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APPROVAL

Date of submission: 03/10/2025

This Thesis proposal has been submitted for examination with our approval as the university supervisor.

Signature………………………………

Assoc. Prof. Getachew Biru

Thesis Advisor

DEDICATION

This work is truly dedicated to my beloved Partner **Mrs. Esther NYIRANDORIMANA** and **my Kids.**

ACKNOWLEDGMENTS

In everyday life, people get struggle to achieve the desired target. Keeping in mind that some enormous challenges and obstacles might hinder any achievement we have to fight endlessly.

Following the above, I would like to take this great opportunity to express my sincere appreciations to both my supervisor Assoc. Prof. Getachew Biru, for their precious guidance to reach this great step. Many thanks go to the entire ACEESD staff especially lecturers among others for their sacrifices to deliver knowledge to us.

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“God Bless you all!”

ABSTRACT

Energy efficiency is a fundamental pillar of industrial sustainability, directly influencing both operational costs and environmental impact. This study explores energy audit and conservation practices in Rwanda's industrial sector, with a particular focus on SULFO Rwanda Industries Ltd. The research addresses the pressing issue of inefficient energy consumption, largely attributed to outdated equipment, inadequate maintenance, and the absence of systematic energy management. Through comprehensive data collection, energy consumption analysis, benchmarking against global standards, and simulations using RET Screen Expert software, this study evaluates the potential for improving energy efficiency. The findings highlight significant inefficiencies, with energy consumption in PET bottle production and soap manufacturing exceeding international benchmarks by 92.8% and 5.66%, respectively. By implementing targeted measures such as upgrading motors, optimizing lighting systems, and refining production processes, the study identifies opportunities for substantial energy savings estimated at 20,317 kWh annually alongside a cost reduction of approximately 2,499,005 RWF. These insights underscore the critical need for industries to integrate energy-efficient technologies and adopt real-time energy monitoring systems. The study concludes that fostering collaboration between industries and policymakers, enforcing regulatory energy audits, and investing in sustainable technologies can drive Rwanda's industrial sector toward greater energy efficiency and long-term economic and environmental sustainability. The recommendations presented offer a strategic framework that can be adapted to similar industrial settings, supporting Rwanda's broader transition to a green economy.

Keywords: Energy Audit, Energy Conservation, Industrial Efficiency, Sustainability, Renewable Energy, Rwanda.

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ABBREVIATION LIST

Abbreviation	**Definition**
CST	College of Science and Technology
EPS	Electrical Power Systems
REG	Registration Number
SULFO	SULFO Rwanda Industries Ltd
PET	Polyethylene Terephthalate (material used in bottle production)
kWh	Kilowatt-hour (unit of electrical energy consumption)
kVA	Kilovolt-ampere (unit of apparent power)
kVAr	Kilovolt-ampere reactive (unit of reactive power)
AVR	Automatic Voltage Regulator
RETScreen Expert	Energy analysis and simulation software
RWF	Rwandan Franc (currency)
O&M	Operation and Maintenance
PV	Photovoltaic (solar energy technology)
IE3	International Efficiency Standard – Level 3
IE4	International Efficiency Standard – Level 4
O&M	Operation and mentainance
RWF	Rwandan francs
MT	Mega tones
UE	Usage energy
OH	Operating hours
A_R	Area in square meter
W	Watts
REG	Rwanda Energy Group
EDCL	Energy Development and Corporation Limited

CHAPTER 1. INTRODUCTION

1.1. Background

Energy is the ability to accomplish work, and work is the transfer of energy from one form to another. Energy comes in numerous forms - heat (thermal), light (radiant), mechanical, electrical, chemical, and nuclear energy. Given that they took three million years to produce, fossil fuels like coal are expected to run out very soon. We have used up 60% of all resources in the last 200 years. We must implement energy-efficiency measures in order to achieve sustainable development. 85% of the world's primary energy currently originates from fossil and non-renewable sources (coal, oil, etc.). With rising use, these reserves are steadily depleting and won't last for future generations [1].

Any country should strive to reduce its energy waste because doing so increases national income. Saving money on energy bills is beneficial for businesses, industries, and individual consumers as these expenses consume a significant portion of their revenue and have a significant effect on their economies. Therefore, it is crucial to act to stop energy waste in order to reduce energy costs. One procedure that can assist prevent energy waste and evaluate the accuracy of energy use is energy auditing [2].

The purpose of an energy audit for commercial buildings and factories, is to provide clarity on the factory's current state of energy use. Increasing the effectiveness of energy use decreases energy loss by enhancing energy management, updating machinery, and altering procedures [3].

The non-structural energy conservation approach's fundamental idea is changing people's behavior. According to the Dictionary of Energy, a behavioral shift refers to a person's or an organization's actions that have an impact on the degree of energy conservation, either favorably (such as turning off lights when not in use) or negatively (such as replacing a clothesline with an electric dryer). Examples of energy-saving practices include, but are not limited to, turning off lights that aren't needed, adjusting the thermostat, shutting off the monitor when it's not in use, use properly sized motors and only run when needed; use high efficiency motors; check power factor regularly and improve with capacitor banks, putting the computer in sleep mode when it's not being used for an extended length of time, using the stairs rather than the elevator whenever feasible, and making the most of natural lighting. All of these energy conservation actions can reduce energy usage dramatically [4].

A crucial component of energy conservation measures is human behavior. Energy conservation is a duty that humanity cannot avoid. The key to attaining energy efficiency is people. Numerous researchers have reported on the significance of this method [4]. A 10% reduction in energy costs can be attained by consumers who use less energy, and a 5%–10% reduction can be attained by changing the behavior of energy users. Consequently, making behavioral adjustments that promote energy conservation can result in a cumulative amount of energy cost savings [4], [5].

1.2. Statement of the Problem

The rapid industrial growth in Rwanda has significantly increased energy consumption, highlighting critical challenges in achieving sustainable development. SULFO Rwanda Industries Ltd, a prominent player in the country's manufacturing sector, exemplifies the energy inefficiencies prevalent in Rwandan industries. Despite its pivotal role in economic development, SULFO Rwanda Industries Ltd faces substantial energy wastage due to outdated equipment, inefficient processes and lack of systematic energy management practices. This inefficiency not only inflates operational costs but also exacerbates environmental impacts, conflicting with Rwanda’s commitment to sustainable industrial practices. The absence of comprehensive energy audits and conservation measures further compound the issue, leaving significant opportunities for energy savings untapped. By adopting a systematic approach, the study aims to provide actionable insights that can help SULFO Rwanda Industries Ltd, optimize energy use, reduce operational costs, and minimize environmental impact. The findings are expected to serve as a benchmark for other Rwandan industries, promoting broader adoption of energy-efficient practices and contributing to the country's sustainable industrial development goals.

1.3. Objectives

Energy efficiency is a crucial factor for the sustainable economic growth of Rwanda, a country with limited energy resources and a growing industrial sector. By optimizing energy use, industries can significantly reduce operational costs, enhance productivity, and improve their competitive edge in the market. Thus, this study focuses on assessing the energy efficiency of SULFO Rwanda Industries Ltd and identifying potential energy saving methods and technologies.

SULFO Rwanda Industries Ltd, being a major manufacturing entity, represents a significant portion of industrial energy consumption in Rwanda. This makes it an ideal case study for understanding the broader implications of energy inefficiency and the potential benefits of implementing energy conservation measures. Conducting an energy audit at SULFO Rwanda Industries Ltd, will provide detailed insights into current energy use patterns, identify inefficiencies, and propose practical solutions tailored to the specific needs of the industry.

1.3.1. Major Objectives

The major objectives of the study include:

- Conduct an energy audit at SULFO Rwanda Industries Ltd,
- Identifying energy conservation opportunities to decrease energy consumption per unit of product output and reduce operational costs.

1.3.2. Specific Objectives

The specific objectives are:

- Collect relevant data on energy use in the company.
- Conduct the analysis of energy use in the industry to identify gaps in the energy utilization.
- Identify and evaluate potential energy savings methods and measures.
- Conduct the cost benefit analysis of the energy audit measures.
- Draw conclusions and relevant recommendations for further implementation.

1.4. Scope of the Study

This study focuses on conducting a comprehensive energy audit and conservation analysis at SULFO Rwanda Industries Ltd. It will involve detailed data collection on energy consumption, site inspections, and benchmarking against industry standards to identify inefficiencies. The study aims to analyze specific areas where energy costs can be minimized without affecting production output. It will assess the efficiency of energy-intensive equipment, operational practices, and identify potential energy-saving opportunities. Practical recommendations for energy conservation measures tailored to the factory's needs will be provided, aiming to reduce operational costs and environmental impact. This study will ultimately create the required knowledge and information to enhance the energy efficiency and sustainability of SULFO Rwanda Industries Ltd.

1.5. Expected Outcomes and Significance of the Study

1.5.1. Expected Outcome of the Study

With the successful completion of this research, it is expected that:

- ❖ Identification of key areas where energy costs can be significantly reduced at SULFO Rwanda Industries Ltd.
- ❖ Creation of a comprehensive energy audit report detailing current energy consumption patterns, inefficiencies, and opportunities for improvement.
- ❖ Recommend actionable energy-saving measures, ranging from low-cost operational changes to

potential investments in energy-efficient technologies.

These recommendations are expected to be used by the industry with the following impacts:

- Result in quantifiable reductions in energy costs, enhancing the overall energy efficiency of the factory.
- Reduce the environmental impact of the factory’s operations by lowering greenhouse gas emissions and other pollutants.
- Provide roadmap for sustainable energy management, contributing to both economic savings and environmental sustainability.

1.5.2. Significant of the Study

The nation's present generation resources are unable to keep up with the rate of demand growth, which is placing pressure on power generation due to the ongoing increase in energy needs. Energy is one of the major production inputs for large firms like SULFO Rwanda Industries Ltd, therefore conducting energy audits and finding areas where waste may be minimized will be economically advantageous for both the company and the nation's energy sector. This will help the business create a solid energy management plan from the ground up.

By identifying and implementing energy-saving measures, the company can significantly reduce operational costs and enhance profitability, while also minimizing its environmental impact through reduced greenhouse gas emissions. This research supports Rwanda's sustainable development goals by promoting efficient resource management and energy security. Moreover, the findings can serve as a benchmark for other Rwandan industries, encouraging broader adoption of energy-efficient practices. The study's insights can inform policy formulation, contribute to sustainable industrial growth, and enhance corporate social responsibility, ultimately benefiting the broader community and the nation's economy.

1.6. Manuscript Thesis Outline

Chapter 1: Introduction: This chapter introduces the research background, problem statement, objectives, significance, and scope of the study.

Chapter 2: Literature Review: A review of existing studies, theories, and relevant research on energy consumption, production efficiency, and benchmarking standards.

Chapter 3: Data collection: This chapter outlines the research approach, data collection methods, tools used, and analysis techniques applied for the study.

Chapter 4: Model and simulation: Presents collected data on production, energy consumption, and specific energy benchmarks, followed by analysis and interpretation.

Chapter 5: Discussion of Results: Discusses the findings of the study, comparing results with benchmarks and identifying gaps or inefficiencies.

Chapter 6: Conclusion and Recommendations: Provides a summary of findings, conclusions drawn, recommendations for energy optimization, and suggestions for future research.

CHAPTER 2. LITERATURE REVIEW

2.1. Theoretical background

2.1.1 Introduction

Energy conservation and efficiency have become paramount in addressing the global challenges of rising energy demand, environmental degradation, and the depletion of natural resources. These efforts aim to reduce energy consumption without compromising productivity, economic growth, or the quality of services. One of the most effective ways to achieve this is through the implementation of energy audits. An energy audit is a systematic process that analyzes energy use within an organization or facility, identifying inefficiencies, wastage, and areas for potential improvement [6], [7].

This chapter explores the methodologies and practices of energy audits in the context of energy conservation and efficiency. It highlights the economic and environmental benefits of conducting energy audits, drawing on best practices and case studies from various sectors. By adopting energy audits, industries and organizations can play a significant role in advancing energy efficiency and contributing to global sustainability efforts

2.1.2. Energy conservation area

Energy conservation implies reducing energy usage while maintaining the amount and quality of production [8]. It may be characterized as the replacement of energy with capital, labor, materials, and time. This concept also includes the substitution of limited energy (e.g., coal, oil) with plentiful energy (e.g., solar, wind) or the substitution of energy for convenience. People, for example, will turn lights off while they are not in their homes [9]. The process of using energy in a more efficient and productive way. While any kind of energy may be preserved, electricity is the one most frequently associated with conservation [9].

The economic effectiveness of energy conservation/efficiency measures is well known, since one unit of energy saved at the consumer end saves about 2.5 to 3 times the amount of capacity augmentation owing to plant load factor, plant availability, auxiliary power usage, T&D losses, and so on. Energy savings realized via energy efficiency and conservation not only save the investment necessary for extra capacity, but also prevent capital expenditure in fuel, mining, transportation, water, and land required for power plants. The potential of energy-efficient choices, which save expenses for the customer, utility, and society as a whole, must be fully tapped [10].

2.1.2.1. Energy Conservation in Electric Motors and Drives

Industry uses electricity for motive power, such as electric motors, melting and heating, lighting, and electrolysis. Electric motors in industries use between 70 and 80 percent of the electricity used. A motor's best fit for a given application depends on a number of parameters, such as the driven equipment's requirements, the service environment, the motor's efficiency, and its power factor. Effective energy management involves using the motor and its parts in a way that uses the least amount of energy [13].

2.1.2.2. Energy Conservation in Illumination

Lighting in industries rarely uses more electricity than 5% of overall usage. There can be some savings, nevertheless, if proper design selection and maintenance are followed. It is important to consider the following elements [11].

- ✓ The appropriate illumination levels for various work areas,
- ✓ The choice of light sources, and
- ✓ Effective maintenance and control.

There is debate on the true use of varying lighting levels for various work areas. The amazing natural lighting that Rwanda offers year-round should be utilized to its fullest potential. Lighting needs to be carefully maintained and controlled.

2.1.3. Energy Efficiency

Energy efficiency refers to reducing energy losses without negatively impacting economic development and growth. It entails raising the effectiveness of energy production, transmission, and distribution as well as optimizing energy use at the end of the process [12]. Energy conservation and efficiency savings prevent capital expenditures in fuel, mining, transportation, water, and land needed for power plants, in addition to saving the money needed for extra capacity. The potential of energy efficient options, which save costs to the consumer, utility and society as well, has, therefore, to be fully harnessed [13]. Energy Conservation by enhancing energy efficiency gives impetus to the socio-economic development [13].

2.1.4. Energy Audit

Energy auditing is a method of reconciling energy input and usage in order to make educated decisions about energy management. It is a technique that attempts to balance inputs and outputs while also assisting in the identification of energy utilities and streams inside the company. The energy conservation act, 2001, defines energy Audit as;

"The verification, monitoring and analysis of use of energy…for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption."

Among all operational expenditures, energy systems offer the most potential to reduce running costs in an industry. As a result, this is the primary emphasis for lowering operational costs. As a result, energy audits are a valuable tool for energy management since they identify areas where savings may be made and provide an action plan for enterprises to run at peak efficiency. It serves as a baseline for energy management while also laying the groundwork for optimal utilization by identifying energy waste and how to eliminate it from the process.

2.1.5. Types of Energy Audits

The energy audit approach would lead to a decrease in energy bills, which would improve production and encourage economical utility operations by requiring appropriate preventive and cost-effective maintenance as well as quality control programs. The kind of energy audit that needs to be done depends on the industry or function [14].

There can be three types of energy audit:

- Preliminary energy audit
- General energy audit
- Detailed energy audit

2.1.5.1. Preliminary Energy Audit

The simplest and fastest kind of audit is the preliminary energy audit, often known as a walk-through audit or a simple audit screening audit. It focuses on the main energy supply and demands and is completed in a constrained amount of time. It attempts to take the essential actions for an establishment to adopt an energy saving program. It entails actions pertaining to gathering, organizing, presenting, and analyzing existing data in order to determine the best course of action for implementing energy conservation. It entails gathering the relevant information, conducting a limited number of interviews with site operators, quickly reviewing facility electric bills and other operational data, and pinpointing obvious instances of energy waste or inefficiency [14] During this kind of audit, only the most significant issues are usually found, corrective actions are succinctly explained, and rapid estimates of implementation costs, possible operating cost reductions, and straightforward payback times are given. This degree of information is sufficient to prioritize energy-efficient projects and identify the need for a more thorough audit, but it is insufficient for making a final decision on the implementation of suggested measures.

2.1.5.2. General Energy Audit

There are several names for the general energy audit, including micro audit, site energy audit, and complete site energy audit. By gathering more specific data about facility operations and conducting a more thorough assessment of the energy-saving measures found, it builds on the preliminary audit. In order to enable the auditor to assess the facility's energy/demand rate structure and energy usage profiles, utility bills are gathered for a duration of 12 to 36 months. To augment utility data, further metering of particular energy-consuming installations is frequently carried out. To gain a deeper understanding of the main energy-consuming systems and to gain insight into fluctuations in daily and annual energy consumption and demand, in-depth interviews with facility operational people are done. Given the facility's operating characteristics, this kind of audit will be able to discover any energy-saving methods that are suitable for it. Every measure undergoes a thorough financial analysis that considers the customer's investment objectives, site-specific operating cost savings, and comprehensive implementation cost estimates. Enough information is given to support the project's execution [14]

2.1.5.3. Detail Energy Audit

Comprehensive audits and investment grader audits are other names for detailed energy audits. It goes beyond the basic energy audit. It includes estimating the energy input for various operations, gathering historical production level data, and focusing on particular energy usage. It is an extensive action plan for energy audits that the industry must effectively implement. It offers a live representation of the facility's current energy use characteristics as well as every energy-saving option found. In order to give a realistic baseline against which to calculate operating savings for suggested solutions, the building model is calibrated against actual utility data. A great deal of focus is placed on comprehending not only the operational features of all energy-consuming systems, but also the circumstances that lead to variations in the load profile on both annual and daily basis. Submetering of the main energy-consuming systems and system operating characteristic monitoring are added to the existing utility data. As a result, the goal of this audit is to develop a comprehensive plan based on quantitative and control evaluation and to explore solutions for detailed engineering that can lower the overall energy expenses and consumption of the manufactured good. Eight to ten percent savings is the target, and a thorough audit study must be finished in three weeks from the start date. After then, three weeks will pass before the preparation of the energy audit reports is finished Boilers, furnaces, air conditioning systems, refrigeration or cold rooms, etc., power generation and distribution systems, compressed air generation systems, pumping systems, and electric motor driven systems are the main systems found in the industries for which an energy audit is required [14].

2.1.6. Overview of Energy Audit Procedures

A preliminary audit contains a number of the identical steps of the procedure shown in Figure 2-1, but the depth of the information collection and analysis could be different looking on the scope and objectives of the audit. Overall, there are four main steps each of which has several sub-steps [15], [16], [17].

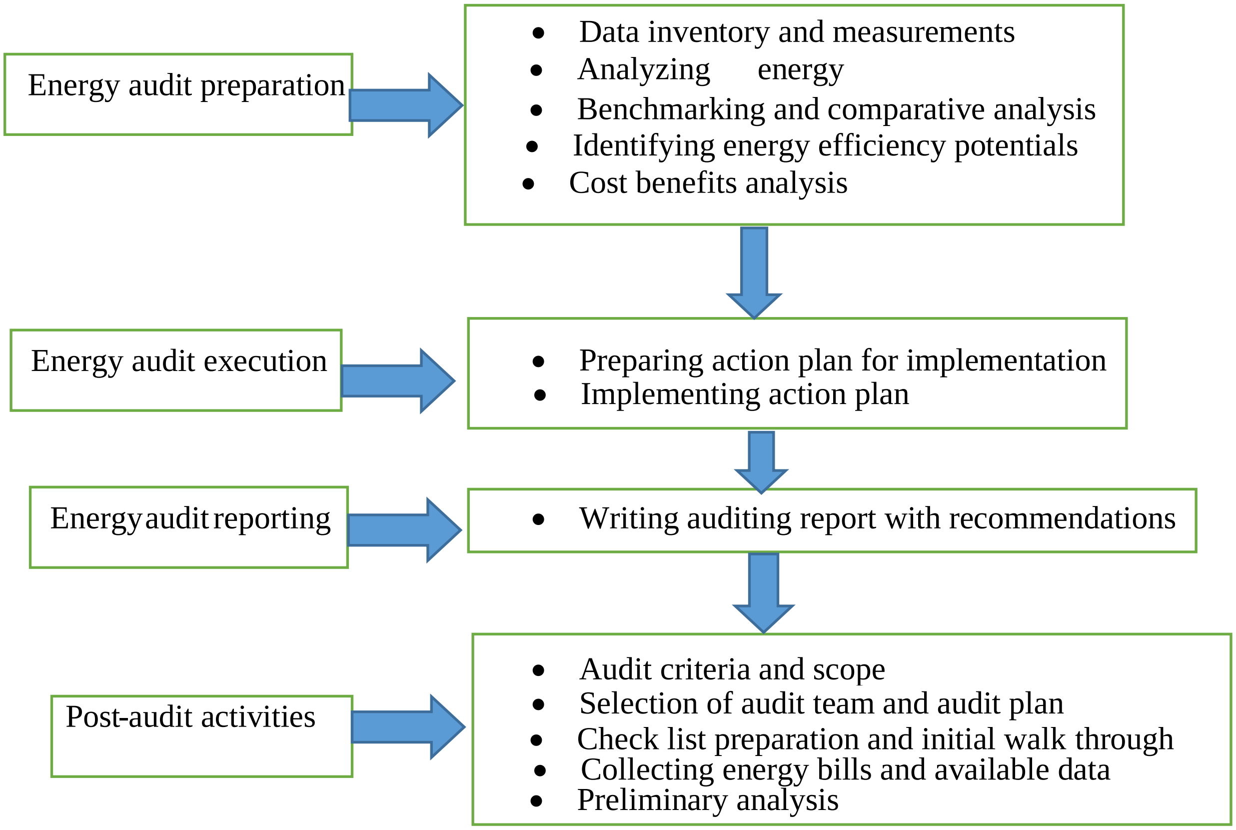


Figure 2-1: Energy Audit Procedures

2.1.6.1. Defining the audit criteria

Before starting the energy audit, the criteria against which the audit will be conducted should be defined[15] The following criteria should be taken into consideration:

- Audit objective
- Audit type
- Audit methodology and standards
- Staff involvement
- Site or utility boundary
- Timeline
- Reporting requirements

2.1.6.2. Defining the audit scope

The audit scope must consider the resources that are at hand, including personnel, time, boundaries for the audit, the level of analysis, the anticipated outcomes, the amount of detail, and the budget for carrying out the energy audit. The goal of the particular audit will determine the audit scope, which may also be established by a firm or government audit program as a whole. Along with defining the degree of detail and comprehensiveness for the final recommendations, it should also specify the percentage of processes included in the audit of the plant's overall energy use [15].

2.2. Review of Relevant Papers

Energy has become a vital resource due to socioeconomic growth. However, as the world's industrial/economic growth and population expand, energy consumption vastly outstrips supply. This energy dilemma is unprogressive for emerging nations. Rwanda, for example, is a third-world country whose economy is heavily reliant on imports. This dependence is caused by a variety of factors, the most significant of which is the energy sector, where demand far outstrips supply, choking upcoming manufacturing industries as well as other established industries with high energy rates charged by the Power Company, resulting in high manufacturing/production costs. Over the last few decades, actions attempted to supply this need have caused massive environmental concerns. Measures to mitigate these consequences have called for green energy generating methods, and while there is a need for increased generation, it has shown beneficial to also control and reduce energy end use in order to limit energy waste and demand. This report focuses on the detailed energy audit of SULFO Rwanda Industries Ltd. It focuses on the usage and control of industrial energy at SULFO Rwanda Industries Ltd. The study's findings, on the other hand, may be utilized to provide a comprehensive picture of the energy situation in Rwandan enterprises with similar business areas. To provide the groundwork for this research, it is critical to examine a quick outline of Rwanda's power grid, since it is the major source of energy for companies, as well as an overview of SULFO Rwanda Industries Ltd.

To ensure accurate energy evaluation and avoid energy waste at SULFO Rwanda Industries Ltd, energy auditing is a helpful practice. A comprehensive examination of an industry's energy usage, the expenses related to it, and a list of suggested modifications to operational procedures or energy-hungry machinery are all included in an energy audit's recommendations for lowering energy expenses. Energy audit and conservation is widely conducted in many countries:

- To reduce energy/fuel shortage
- To reduce peak demand shortage

- To save fuel, natural resources and money
- To reduce environmental pollution
- Provides Energy security

2.2.1. A Comparative Analysis of Industrial and Institutional Applications, Review of Research Papers Contributions and Gaps

Paper reviewed are summarized and illustrated in Table 2-1 that provides valuable insights on research done lately on energy saving and efficiency in industries. Many of the studies lack specific case studies that demonstrate the practical application of energy audit methodologies, which could enhance its credibility. Additionally, there is limited discussion on the integration of new technologies and alternative energy resources, which are crucial in modern energy management. The paper also does not adequately address the behavioral aspects of energy consumption, which can significantly impact conservation efforts. Furthermore, while it mentions capital investment analysis, a more detailed economic analysis of the cost-effectiveness of energy conservation measures is missing. The regulatory and policy frameworks influencing energy audits are not discussed, which could provide a broader context for the findings. Lastly, the integration of renewable energy sources within the energy audit process is not explored, leaving a gap in understanding how audits can facilitate the transition to sustainable energy solutions. Addressing these gaps could significantly enhance the paper's relevance and applicability in promoting energy efficiency.

Table 2-1: Gaps in different research about energy audit

Author	Title	Major research contribution	Research gap
Vishal Thakur Babita Kumari Kumar Pallav	ENERGY CONSERVATION USING ENERGY AUDIT	• Definition of 'Energy Audit' as per Energy Conservation Act 2001	• Lack of focus on specific industries for energy audit analysis. • Limited discussion on the economic impact of energy conservation strategies.
Nitin Kumar Jitender Singh	ENERGY AUDIT OF A COLLEGE CAMPUS by Nitin Kumar, Jitender Singh	• Energy audit process to study building energy consumption for savings.	• Limited discussion on energy-efficient equipment and technology advancements.

Author	Title	Major research contribution	Research gap
Mehulkumar Panchal Ved Vyas Dwivedi Rajendra Aparnathi	The Case study of Energy Conservation & Audit in Industry Sector	• Significance of approach reported by many researchers.	• Lack of awareness on energy efficiency gains by industry managers. • Shortage of energy management education and training opportunities.
Manu Sharma Anish Koushik	Energy Audit: Case Study of A Wheel Manufacturing Industry	• Energy conservation measures in industrial sector for efficiency. • Importance of energy audit for cost reduction and savings.	• Lack of focus on renewable energy integration in industrial sector. • Limited discussion on behavioral change impact on energy conservation.
Varun Jadhav Vishnu Bhandankar Jayesh Priolkar	Energy Audit of an Industry for Energy Conservation and Economical Operations	• Detailed energy audit types: preliminary, general, and detailed audits. • Use of LED lamps, capacitor banks, and NCES for energy savings.	• Absence of comparison with similar industry energy audit studies.
Mehulkumar Panchal Ved Vyas Dwivedi Rajendra Aparnathi	The Case study of Energy Conservation & Audit in Industry Sector	• Significance of approach reported by many researchers.	• Lack of awareness on energy efficiency gains by industry managers. • Shortage of energy management education and training opportunities. • Slow progress in standardizing energy consumption levels in equipment.
R Virendra, B Sudheer Prem Kumar, J Suresh Babu, D Rajani Kant, Pre Calciner	Detailed Energy Audit and Conservation in a Cement Plant	• Thermal and electrical energy contributions in cement production. • Share of thermal energy sources and use by different fuels.	• Future research: Latest technologies like high pressure roller mills. • Potential gaps: Variable frequency drives for all grate cooler fans.
Karlis Grinbergs is the author of the research paper.	ENERGY AUDIT METHOD FOR INDUSTRIAL PLANTS	• Regulations lack specific action plans for industrial energy audits.	• Lack of knowledge on energy efficiency in industrial facilities. • Absence of specific action plans in existing industrial energy audit regulations.

Based on the identified research gaps, this research contributed to bridging the existing knowledge voids by offering a comprehensive examination of energy audit practices tailored to specific industrial and institutional contexts. It will address the lack of focus on renewable energy integration and technological advancements in energy-efficient equipment by incorporating detailed case studies and real-world applications. Additionally, this research will provide a deeper understanding of industry-specific challenges and behavioral impacts on energy conservation, offering actionable insights for enhancing energy management strategies. By comparing different regional approaches and standardizing energy audit procedures, your work aims to establish best practices that can be adapted across various sectors, contributing to more effective energy conservation and efficiency measures.

2.3. Overview of Rwanda's Electricity System

Rwanda's Electricity market is monopolized by the state-owned company, Rwanda Energy Group Ltd. The Rwanda Energy Group Limited (REG) and its two subsidiaries; The Energy Utility Corporation Limited (EUCL) and The Energy Development Corporation Limited (EDCL) entrusted with energy development and utility service delivery. The company runs the national grid with operations from generation, transmission and distribution. The generating capacity is entirely hydropower with more capacity, thermal, methane, peat, solar and imports with the potential capacity of 311.1 MW (installed capacity) and 213.4MW (Available capacity) by 2024, and now the countries forecast demand is about 1286.3 MW by 2050 [18], [19] Refer to appendix 1 for more details [7].

2.3.1. Share of installed capacity by generation source

The Figure 2-2 displays the energy mix in Rwanda, showing the proportion each energy source contributes to the country's power generation. Hydro power leads at 34%, indicating the significant role of renewable water resources in Rwanda's energy supply. Peat follows with 27%, highlighting reliance on non-renewable, local resources. Thermal sources, likely fueled by diesel or heavy oil, contribute 19%, which is costly and less sustainable. Methane, another local resource, makes up 10%, potentially from Lake Kivu's methane extraction, offering a cleaner alternative to traditional fossil fuels. Solar energy only contributes 4%, despite Rwanda's favorable sunlight conditions, indicating untapped potential for more extensive solar investments. Additionally, 6% of the energy supply comes from imports, reflecting some dependence on neighboring countries. This energy mix reveals both strengths in renewable hydro sources and areas for improvement, particularly in solar expansion and reducing dependency on imports and non-renewable sources.

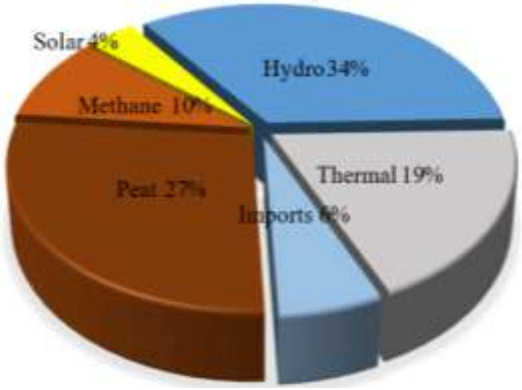


Figure 2-2: Current Energy Mix

Rwanda, like other emerging nations, is experiencing rapid expansion, with energy growth reaching 8.9 and 10 percent per year, respectively [18]. Figure 2-3 depicts the load prediction and energy demand from 2028 to 2050, indicating the need for an urgent increase in generation as current economic trends suggest a growth in industries investment, as well as other new industrial facilities, which are gradually realizing this forecast. As a result, if the country's producing capacity is not boosted, it will soon be outpaced, and its reliance on hydropower puts the country at danger during droughts, necessitating the development of alternative sources of energy. This Figure 2-3 shows a projection in an increase in energy and maximum demand.

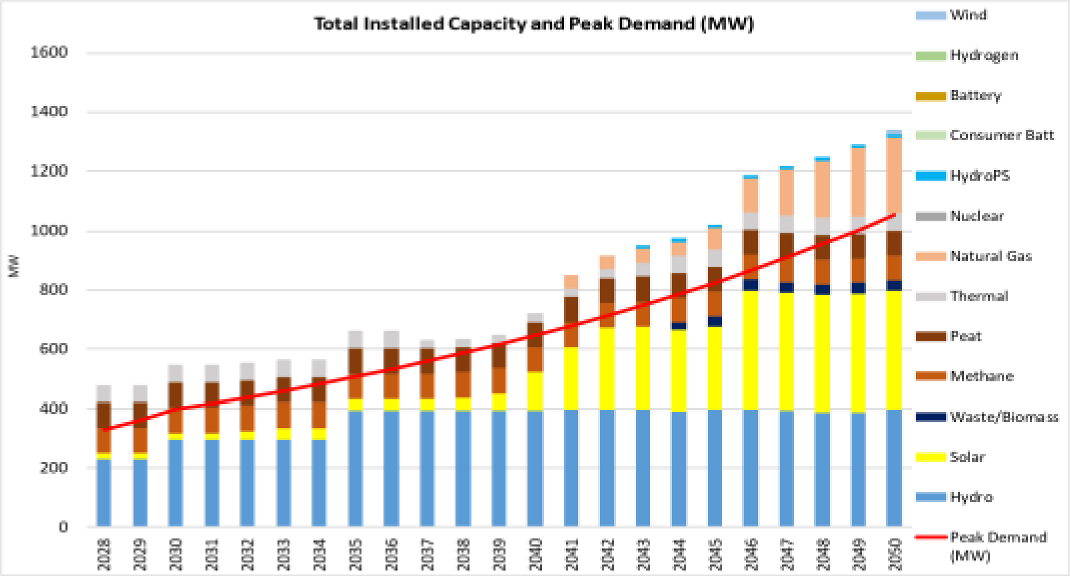


Figure 2-3: Total Installed Capacity (MW) in the longer term 2028 – 2050.

CHAPTER 3. DATA COLLECTION AND ANALYSIS

3.1. Introduction

The purpose of this research methodology is to outline the approach for conducting an energy audit at SULFO Rwanda Industries Ltd, identify energy conservation opportunities, and analyze strategies to decrease energy consumption per unit of product output while reducing operational costs.

3.2. Methodology

Important data are collected to have more understanding on the energy auditing and conservation of the energy intensive equipment of **SULFO Rwanda Industries ltd**. Data have been collected from many sources like on-site data collection from equipment name plates, industry records, personal conversations and interviews. It includes also documents and records obtained from the industry, websites and other historical records relevant for the research.

The following major data are collected:

- Average electrical energy consumption and specific energy consumption from 2022 up to July 2024,
- Specific electric motors energy consumption, (from motor name plate, measurement and calculations).
- Lighting system energy use.

3.3. Collected data

3.3.1. Electrical consumptions of SULFO Rwanda Industries Ltd

The power consumption data for SULFO Rwanda Industries Ltd reveals a steady increase in energy usage from 2021 to 2024. In 2021, electricity consumption fluctuated moderately, peaking at 89,430 kWh in September. However, 2022 marked a notable rise, with March recording the highest consumption of 93,270 kWh. This upward trend continued into 2023, where August saw a significant peak at 99,872 kWh, the highest in the entire period. By 2024, energy usage remained high, ranging between 82,030 kWh and 91,570 kWh in the first seven months, showing a general increase compared to the earlier years. From the Figure 3-1, Monthly electricity bills followed a similar pattern, correlating with the consumption trends. In 2022, the bills experienced a surge in costs, with bills crossing 9.7 million RWF in some months. The trend continued in 2023, where August saw the highest bill of 10.3 million RWF, driven by the peak consumption. As of 2024, the bills remained high, with May recording 9.5 million

RWF. This indicates a sustained rise in operational costs, likely influenced by increased production demands and higher energy prices over time.

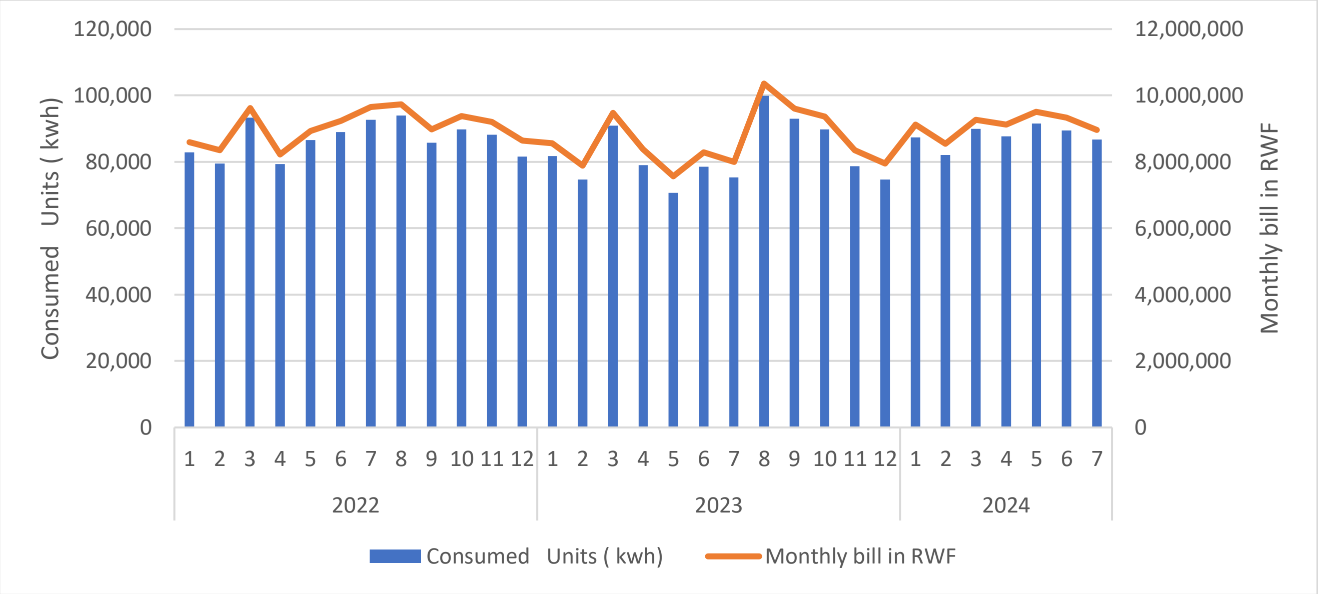


Figure 3-1: The power consumption and monthly bill data for SULFO Rwanda Industries

3.3.2. Active energy consumption, reactive energy consumption and power factor

The whole power (kVA) utilized by the economic or industrial facility has components:

- ✓ Active Power (kW) which produces work
- ✓ Reactive Power (kVAr) which generates the magnetic fields required in inductive electric devices (AC automobiles, transformers, inductive furnaces, ovens, etc.), which produces no effective work.
- ✓ The ratio of Productive Power (kW) to Total Power (kVA) is Power Factor and is represented as a percentage or a decimal.

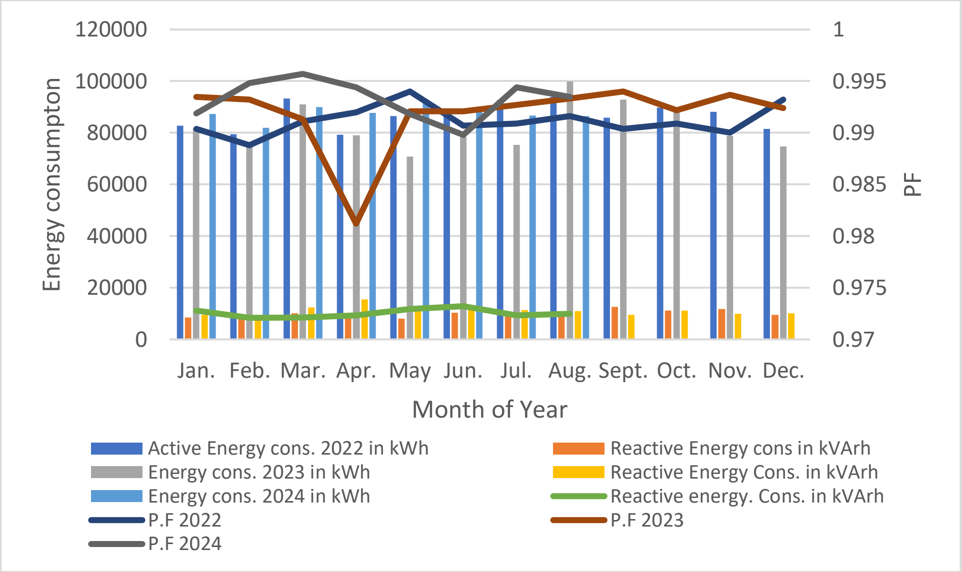


Figure 3-2: Energy consumption and power factor

SULFO Rwanda Industries Ltd has demonstrated a commitment to energy efficiency and cost savings through the implementation of power factor improvement measures. Based on the factory's data presented in Figure 3-2, the Real and Reactive Energy consumption in three years indicate that the power factor for the entire plant varies from 97% to 99%. This value aligns with industry best practices, as outlined in the Power Factor Correction: A Guide for the Plant Engineer, which states that maintaining a power factor of 95% or above delivers maximum benefits [20]. SULFO Rwanda Industries Ltd has installed appropriate power factor correction devices to achieve this high level of efficiency, optimizing energy usage and reducing energy costs.

3.3.3. Production verse consumption

SULFO Rwanda Industries Ltd experienced a notable decline in both production and energy consumption across soap, PET bottle production, and bottle filling operations from 2022 to 2024. Soap production dropped significantly, by about 59% over the three years, accompanied by a reduction in electric consumption. However, the specific electric consumption per kg of soap increased in 2023, indicating a decline in energy efficiency, before slightly improving in 2024. PET bottle production and bottle filling remained steady between 2022 and 2023 but saw a significant reduction in 2024, with electric consumption following the same trend. Despite these decreases, the specific electric consumption per unit for PET bottles increased steadily, showing higher energy use per piece as shown in Table 3-1.

Table 3-1: Soap and water production and Energy Consumption Data for 32 months of SULFO

RWANDA Industries Ltd

No	**Item**	**Production years**			**Average**
		2022	**2023**	**2024**	
1	Soap production (Kgs)	3,760,789	2,836,797	1,697,728	2,765,105
2	Bottles Production PET (Pieces)	16,172,980	16,185,737	12,743,667	15,034,128
3	Bottles filling [food+ RO] (Pieces) PET	16,172,980	16,185,737	12,743,667	15,034,128
4	Electric consumption (kWh) (SOAP)	434,580	335,096	201,476	323,718
5	Electric consumption (kWh) for Bottles Production PET (Pieces)	157,346	165,897	123,031	148,758
6	Electric consumption (KWh) PET Bottles filling [food+ RO] (Pieces)	374,851	386,353	322,373	361,192
7	Specific Elec. Consumption (SOAP) (kWh/Kg)	0.1156	0.1181	0.1187	0.1175
8	Specific Elec. Consumption Bottles Production PET (KWh/pieces)	0.0232	0.0239	0.0253	0.0241
9	Specific Elec. Consumption Bottles filling [food+ RO] (kWh/pieces) PET	0.0097	0.0102	0.0097	0.0099

Overall, the company’s operations suggest a scaling back in production, but energy efficiency fluctuated. In some areas, like PET bottle production, the increase in specific electric consumption points to a higher energy intensity per unit produced, even as overall production decreased. While the bottles filling process saw energy efficiency stabilize by 2024, SULFO Rwanda Industries' performance over these years reflects challenges in maintaining energy efficiency while scaling down production.

From the observations in Table 3-2, it is seen that:

i. Soap production decreased significantly (54.85%), while electricity consumption fell at a slower rate (54%).
ii. PET production dropped by 21% in 2024, while electricity consumption for PET slightly increased in 2023, indicating higher energy intensity.
iii. Bottles filling production dropped by 21% in 2024, while electricity consumption showed similar trends as PET.

Table 3-2: Production versus electricity consumption for SULFO Rwanda Industries Ltd from 2022 to 2024

Year	Soap Production (kg)	Soap Electricity Consumption (kWh)	PET Bottle Production (pieces)	PET Bottle Electricity Consumption (kWh)	Bottles Filling Production (pieces)	Bottles Filling Electricity Consumption (kWh)
2022	3,760,789	434,580.10	16,172,980	374,850.90	16,172,980	157,346.40
2023	2,836,797 (-24.57%)	335,096.3 (-22.9%)	16,172,980 (0.0%)	386,353.0 (+3.1%)	16,172,980 (0.0%)	165,897.3 (+5.4%)
2024	1,697,728 (-54.85%)	201,476.2 (-53.6%)	12,743,667 (-21.2%)	322,373.4 (-14.0%)	12,743,667 (-21.2%)	123,031.0 (-21.8%)

3.3.4. Cost of electrical energy consumption from 2022 to 2024

The observed reduction in Table 3-3, the cost of electrical energy consumption at SULFO Rwanda Industries between 2022 and 2024 appears to be primarily driven by a decline in production volumes, rather than by the implementation of innovative energy-saving measures. It is important to note that the 2024 production data were collected only for the period from 1 January to 31 August, which naturally contributes to the apparent drop in production output. For example, the data indicate that soap production decreased by 54.85% during this period, and a corresponding reduction in energy consumption of 53.6% was recorded. Similar proportional declines were observed in the PET bottle production and bottle filling processes, where energy consumption decreased in line with lower output levels.

If significant energy efficiency innovations or technological improvements had been the primary cause of reduced energy costs, one would expect to see a reduction in energy consumption that is not directly tied to a proportional decrease in production volumes. However, in this instance, both production output and energy consumption have decreased in parallel, strongly suggesting that the primary factor influencing the reduction in energy costs is the lower production level as partly reflected by the limited data period in 2024 rather than substantial improvements in energy efficiency.

Table 3-3: Cost of Electrical Energy Consumption (2022-2024)

Item	Bills in a year in RWF		
	2022	2023	2024
Soap production	45,232,847.90	35,232,093.30	20,923,006.30

Item	Bills in a year in RWF		
	2022	2023	2024
Bottles Production PET (Pieces)	39,038,700.40	40,642,526.60	33,477,997.00
Bottles filling production [food+ RO](Pieces)	16,386,786.50	17,443,955.30	12,776,595.00
Total cost	100,658,334.80	93,318,575.20	67,177,598.30
Average consumption cost per year.	**97,932,940.61**		

3.3.5. Power supply at SULFO Rwanda industries

SULFO Rwanda Industries ltd uses one main power supply of 15kV from REG with an emergency power backup generator. The voltage from changeover is stabilized by Automatic Voltage Regulator (AVR) as shown in Figure 3-3.

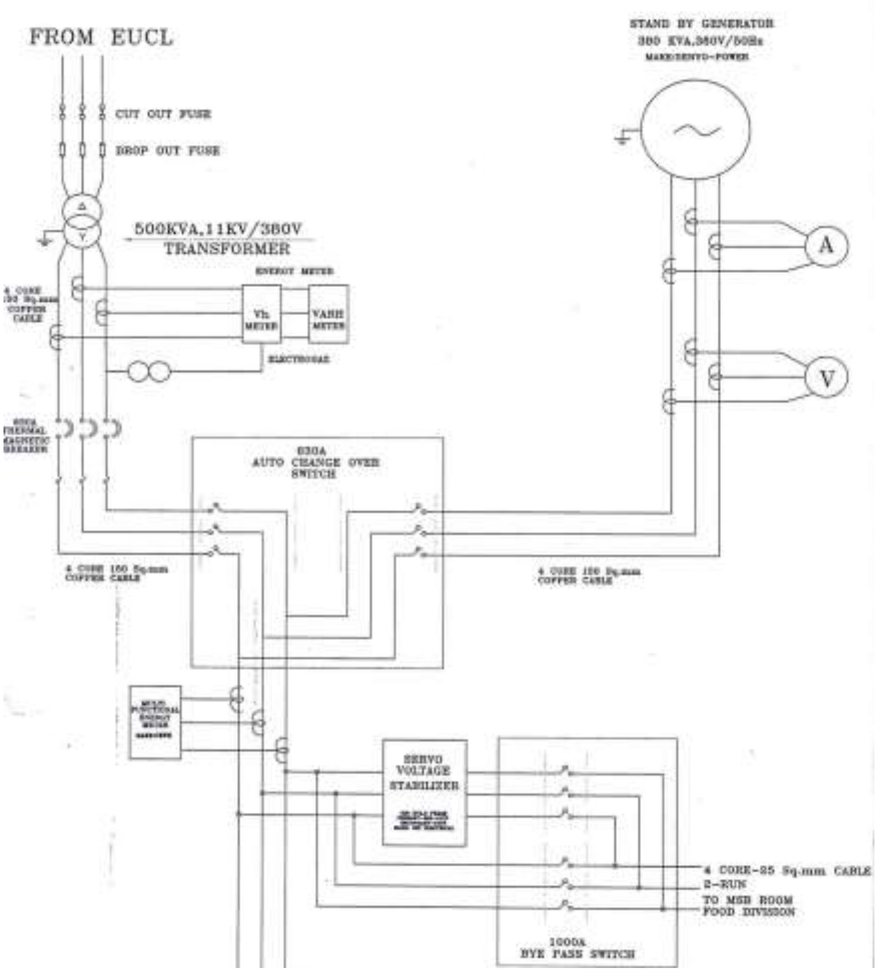


Figure 3-3: Three-line diagram of Power supply at SULFO Rwanda industries

3.3.6. Load at SULFO

3.3.6.1. Lighting System

The lighting system of the factory is not well designed. The illumination level at different departments does not fit with the required illumination level (lux). There are around 213 florescent lamps T8 currently each of 40W installed in Production, store and utility room while 17 lamps each of 80W of 4 tubes are installed in offices. The number of lamps, total power consumption, room area, and operating hours of the lamps are listed in Table 3-4.

Table 3-4: Summary of collected lighting system data

No.	***Location/Department***	**No. L**	**Power [W]**	**Total Power [W]**	**A_R(m^2)**	**OH (hrs.)**	**UE (wh/d)**
1	*Generator control room*	6	40	240	44	12	2,880
2	*Administration block*	9	160	1400	218	8	11,200
3	*Engineering Office*	8	160	1200	200	24	28,800
4	*Workshops*	3	40	120	100	12	1,440
5	*Raw Material store*	15	40	600	180	24	14,400
6	*Packing & transporting area*	40	40	1600	214	12	19,200
7	*Breaching kettle area*	15	40	600	144	12	7,200
8	*Soap store*	10	40	400	135	12	4,800
9	*Boiler and mixing area*	22	40	880	182	12	10,560
10	*Substation control room*	4	40	160	40	24	3,840
11	*Crushing*	10	40	400	82	12	4,800
12	*Chiller*	6	40	240	38	12	2,880
13	*Confirwa*	50	40	2000	420	12	24,000
14	*Guard room and outside*	10	40	400	25	12	4,800
15	*Pump room*	5	40	200	72	12	2,400
16	Water treatment area	7	40	280	52	12	3,360
17	Water store	10	40	400	140	12	4,800
	TOTAL	229		11,120			151,360

3.3.6.2. Electric Motor Systems

In SULFO Rwanda Industries, motors play a critical role in powering various machinery and equipment used in production processes such as soap manufacturing, bottle production, and filling operations. Motors drive pumps, conveyors, mixers, compressors, and other essential mechanical components that keep production lines running smoothly. Their usage is widespread across different stages of production, from mixing raw materials to packaging finished products. Due to their extensive operation, motors contribute significantly to the overall energy consumption of the industry.

However, the energy efficiency of motors in SULFO Rwanda Industries depends largely on their type, age, and maintenance. Older, outdated motors tend to consume more electricity due to inefficiencies in their design and wear over time. On the other hand, modern energy-efficient motors, such as those classified under IE3 or IE4 standards, consume significantly less energy while delivering the same performance. By replacing outdated motors with energy-efficient alternatives and ensuring proper maintenance, the industry could reduce its energy consumption and operational costs, making motors more efficient consumers of electricity.

The Table 3-5 below shows that the basic electric motors data were collected from SULFO Rwanda industries Ltd production processes with different name plate of operating parameters and actual measured value of the existing electric motors of the factory. Those motors are selected from the motors that exist.

Table 3-5: Collected electric motors data installed on the machine

		Name plate			**Actual measurement**			
NO.	**Description of motor**	**Rated power (kW)**	**R. effic (%)**	**Speed (rpm)**	**% loading**	**PF**	**Voltage (V)**	**Current drawn (A)**
1	Breaching kettle 1	7.5	90.5	2900	54%	0.98	395	6.1
2	Breaching kettle 2	7.5	87	2920	72%	0.96	400	8.2
3	Breaching kettle 3	5.5	75	2900	47%	0.95	397	4
4	Stapping machine 1	0.55	78	1405	59%	0.96	395	0.5
5	Stapping machine 2	5.5	83.4	960	65%	0.92	400	5.7
6	Conveyor belt 1	0.37	76	1370	50%	0.90	397	0.3
7	Cutting machine	0.37	76	1370	87%	0.95	396	0.5
8	Weber machine	18.5	92.6	1473	80%	0.98	399	21.9

		Name plate			**Actual measurement**			
NO.	**Description of motor**	**Rated power (kW)**	**R. effic (%)**	**Speed (rpm)**	**% loading**	**PF**	**Voltage (V)**	**Current drawn (A)**
9	Comega machine 1	18.5	92.6	1473	78%	0.98	398	21.6
10	Comega machine 2	18.5	92.6	1473	64%	0.96	400	18.1
11	Vacuum weber	15	87	1460	60%	0.91	395	14.4
12	Comega machine 3	3	80	940	54%	0.91	399	2.6
13	Deposit machine	5.5	87	2900	46%	0.92	399	4
14	Acid mixing	7.5	90.2	2900	50%	0.92	400	6.1
15	Water injection pump	7.5	75	2920	45%	0.96	399	5.1
16	Breaching kettle 4	3.7	81	2850	50%	0.92	399	2.9
17	Boiler 1	11	78	2910	64%	0.92	399	11.2
18	Boiler 2	2.2	79	1400	64%	0.98	399	2.1
19	Compressor 2	30	92.5	1470	57%	0.91	400	27.4
20	Compressor 3	15	86	1470	66%	0.97	397	14.9
21	Compressor 4	15	92.1	1470	62%	0.92	398	14.6
22	Compressor 5	15	89.4	1460	60%	0.93	399	14.1
23	Compressor 6	15	89.4	1448	62%	0.97	396	14.1
24	Compressor 7	15	89.4	1460	63%	0.98	398	14.1
25	Compressor 8	15	92.1	1470	65%	0.98	395	14.6
26	Cooling tower 1	11	79	2900	46%	0.93	398	8
27	Cooling tower 2	11	79	2900	47%	0.96	396	7.9
28	Vccum of comega	18.5	90.5	1460	61%	0.97	399	17
29	Conveyor belt 2	1.5	85.3	1430	57%	0.90	397	1.4
30	Crusher for omega	90	85	1450	38%	0.94	396	53.4
31	Crusher for Weber	37	75	1000	68%	0.91	398	40.3

3.4. Conclusions on the result of data analysis

The data analysis highlights significant inefficiencies in energy usage at SULFO Rwanda Industries Ltd, particularly in relation to production trends. While soap production decreased by 54.85% and PET bottle production by 21.2% between 2022 and 2024, electricity consumption is not reduced proportionally. For example, electricity usage for soap production decreased by only 54%, and PET bottle production saw a consumption reduction of just 14%. This mismatch indicates increasing specific energy consumption for both soap (from 0.1156 kWh/kg to 0.1187 kWh/kg) and PET bottles (from 0.0232 kWh/piece to 0.0253 kWh/piece) over the period, underscoring declining energy efficiency in key production processes.

The lighting system and electric motors also contribute significantly to inefficiencies. The factory’s 229 fluorescent lamps consume substantial energy while failing to meet optimal illumination levels across departments. Moreover, outdated and underloaded motors, such as the "Crusher for Omega" motor with only 38% loading, further increase energy wastage. Simulations suggest that replacing these inefficient motors with modern energy-efficient alternatives could yield annual savings of up to 20,317 kWh and reduce energy costs by 2,499,005 RWF. Similarly, upgrading to LED lighting systems can enhance illumination while significantly lowering electricity consumption.

Overall, these findings point to the need for a comprehensive approach to improving energy efficiency. SULFO Rwanda Industries Ltd should prioritize equipment upgrades, conduct regular energy audits, and implement real-time energy monitoring systems to optimize energy usage. In addition, staff training on energy-efficient practices can support the sustained adoption of these measures. Addressing these inefficiencies will not only reduce operational costs but also align the company’s practices with Rwanda’s green economy goals, contributing to both economic and environmental sustainability.

CHAPTER 4. MODELING AND SIMULATION

4.1 Introduction

The modeling and simulation in this study aim to analyze energy consumption patterns and propose efficiency improvements for SULFO Rwanda Industries Ltd. Using historical energy data (2022–2024) and equipment specifications, the study identifies inefficiencies and evaluates the impact of proposed upgrades on energy savings and operational costs. Inputs for the simulation include production data for soap, PET bottles, and bottle filling; equipment parameters such as motor efficiencies and load factors; and benchmark energy standards. The simulation outputs provide actionable insights into energy savings, cost reductions, and environmental benefits, with a focus on optimizing specific energy consumption across key processes.

The analysis leverages **RET Screen Expert**, a specialized software for energy audits and conservation in industrial settings. RETScreen enables precise modeling of baseline and proposed scenarios, offering tools to calculate energy savings, financial impacts, and emissions reductions. The software's comprehensive capabilities support cost-benefit analyses and feasibility assessments for measures such as motor upgrades, lighting optimizations, and compressor replacements. By integrating these simulations, the study provides a prioritized action plan to enhance energy efficiency, reduce costs, and align operations with sustainable industrial practices.

4.2. Lighting System Analysis and Proposed Upgrades

The analysis of the lighting system compares the current (base case) and proposed upgrade scenarios, focusing on energy consumption, cost, and savings. The base case reflects existing energy use across various facility areas, while the proposed case aims to reduce consumption through efficiency improvements. The proposed lighting system significantly lowers energy usage by 14,682 kWh/year , translating into substantial cost savings. Despite initial capital costs, the upgrade yields financial benefits, with total energy cost savings of 1,805,856 RWF/year as presented in Figure 4-1 and additional maintenance savings. These findings highlight the upgrade's effectiveness in enhancing sustainability and reducing operational costs.

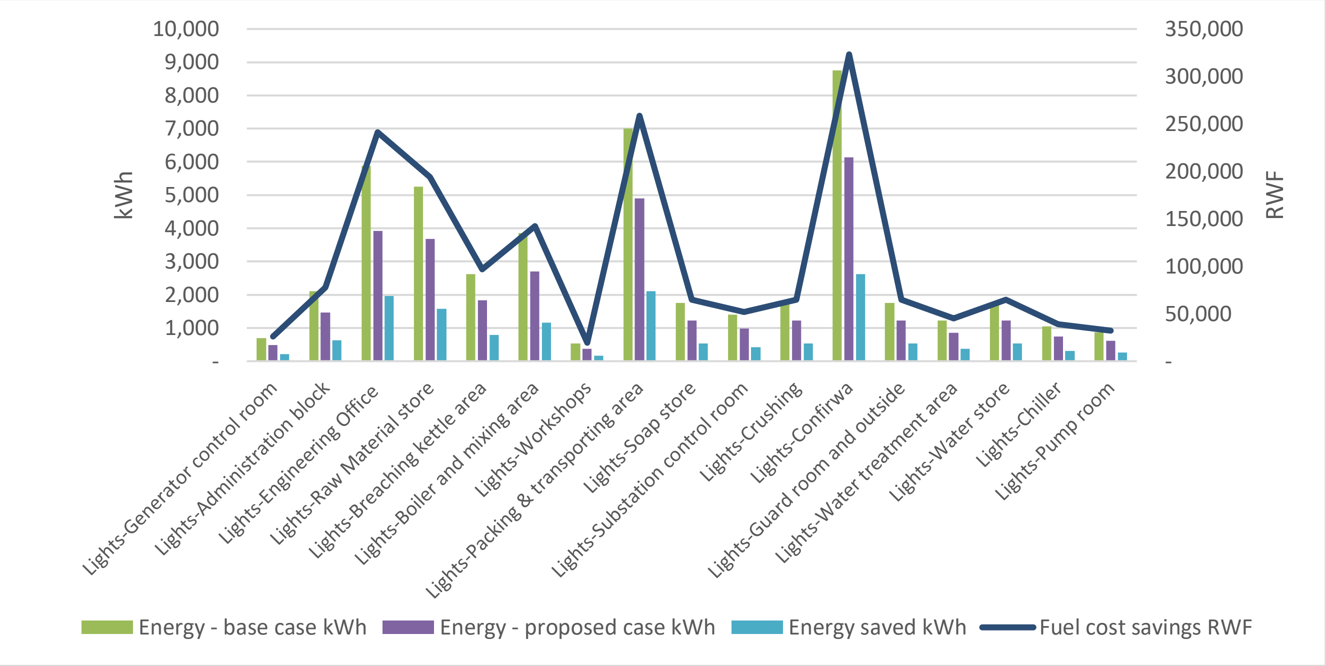


Figure 4-1: Energy saving for lighting system

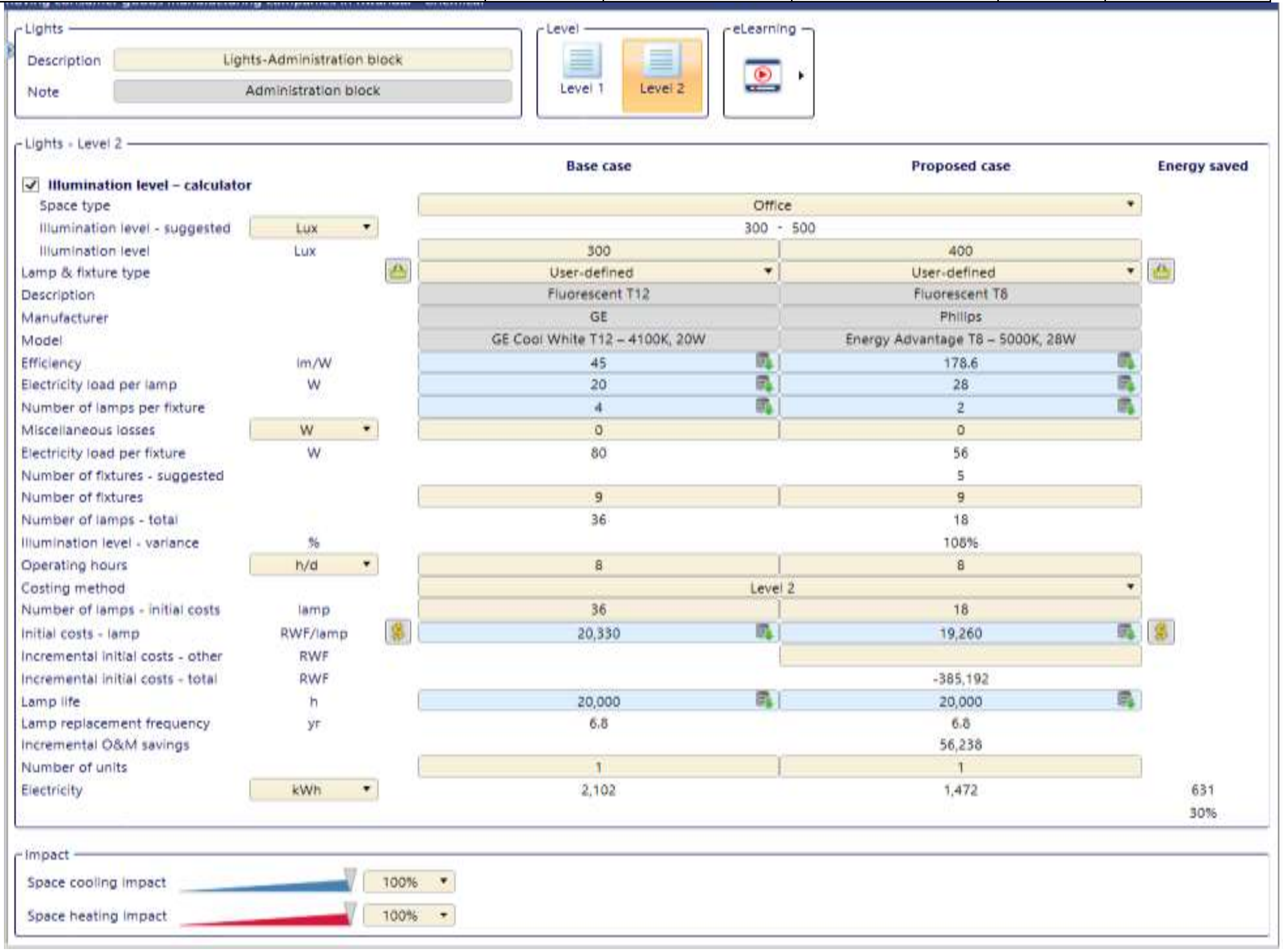
4.2.1. Energy Use Improvement by Enhancing Illumination Efficiency

The Table 4-1 and Figure 4-3 shows a comparison between the base and proposed lighting systems across different areas in the facility, highlighting changes in the number of lamps, base lux levels, and proposed lux levels as percentages of standard lux levels. In the proposed lighting system, the number of lamps has been reduced in some locations (such as the generator control room, administration block, and engineering office), while maintaining or improving light coverage and intensity. For instance, the generator control room decreases from 8 to 4 lamps, increasing its lux level to 178% of the standard. In other areas like the raw material store, soap store, and pump room, the base lux percentage is significantly enhanced in the proposed system, meeting or exceeding the standard lux level, reaching up to 163%. These adjustments aim to optimize energy use by reducing the number of lamps where feasible, while increasing illumination efficiency and ensuring adequate lighting for safe and effective operations.

Table 4-1: Lighting system analysis

	No. Lamps-Base case	No. Lamps-Proposed	Standard Lux level	Base Lux %	Proposed Lux %
Lights-Generator control room	8	4	200	57%	178%
Lights-Administration block	36	18	300-500	62%	108%
Lights-Engineering Office	32	16	300-500	46%	50%
Lights-Raw Material store	15	15	100	60%	163%
Lights-Breaching kettle area	15	15	300	51%	76%

	No. Lamps-Base case	No. Lamps-Proposed	Standard Lux level	Base Lux %	Proposed Lux %
Lights-Boiler and mixing area	22	22	300	46%	76%
Lights-Workshops	3	3	300	47%	76%
Lights-Packing & transporting area	40	40	300	46%	76%
Lights-Soap store	10	10	200	67%	163%
Lights-Substation control room	4	4	200	43%	54%
Lights-Crushing	10	10	300	56%	76%
Lights-Confirwa	50	50	300	58%	163%
Lights-Guard room and outside	10	10	100	69%	58%
Lights-Water treatment area	7	7	300	44%	76%
Lights-Water store	*10*	*10*	*200*	53%	137%
Lights-Chiller	6	6	300	59%	76%
Lights-Pump room	5	5	200	60%	163%



Description: Lights-Administration block

Note: Administration block

☑ **Illumination level – calculator**

		Base case	Proposed case	Energy saved
Space type		Office		
Illumination level - suggested	Lux	300 - 500		
Illumination level	Lux	300	400	
Lamp & fixture type		User-defined	User-defined	
Description		Fluorescent T12	Fluorescent T8	
Manufacturer		GE	Philips	
Model		GE Cool White T12 – 4100K, 20W	Energy Advantage T8 – 5000K, 28W	
Efficiency	lm/W	45	178.6	
Electricity load per lamp	W	20	28	
Number of lamps per fixture		4	2	
Miscellaneous losses	W	0	0	
Electricity load per fixture	W	80	56	
Number of fixtures - suggested			5	
Number of fixtures		9	9	
Number of lamps - total		36	18	
Illumination level - variance	%		108%	
Operating hours	h/d	8	8	
Costing method		Level 2		
Number of lamps - initial costs	lamp	36	18	
Initial costs - lamp	RWF/lamp	20,330	19,260	
Incremental initial costs - other	RWF			
Incremental initial costs - total	RWF		-385,192	
Lamp life	h	20,000	20,000	
Lamp replacement frequency	yr	6.8	6.8	
Incremental O&M savings			56,238	
Number of units		1	1	
Electricity	kWh	2,102	1,472	631 30%

Space cooling impact: 100%

Space heating impact: 100%

Figure 4-2: Simulation of lighting system for administration block by RET screen

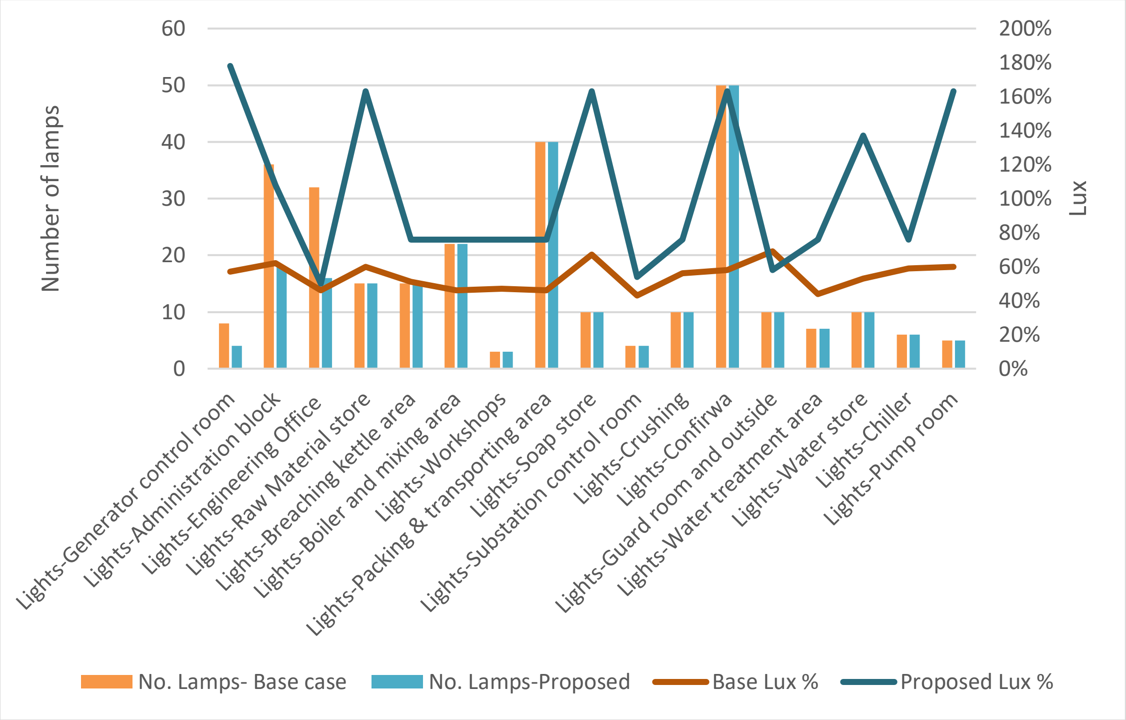


Figure 4-3: Improved illumination for lighting system

4.2.2. Analysis of energy consumption and cost savings for the lighting system

The Table 4-2 presents a detailed analysis of energy consumption and cost savings for the lighting system, comparing the base and proposed cases. The "Energy - base case" column shows the current energy consumption for lighting in each area, totaling 48,285 kWh. Under the "Energy - Proposed" column, energy usage is reduced to 33,603 kWh, resulting in an "Yearly Energy - Saved" total of 14,682 kWh. The "Incremental Initial Costs" column reflects the capital investment required for the proposed upgrades; many areas show a negative value, indicating cost reductions rather than additional expenses. The "Energy Cost Savings" column highlights the monetary savings achieved through reduced energy consumption, with a total savings of 1,805,856 RWF/year. Additionally, the "Incremental O&M Savings" column shows operational and maintenance cost reductions, amounting to 279,315 RWF/year. This analysis suggests that the proposed lighting system not only reduces energy usage but also significantly cuts both capital and operational costs, providing substantial financial benefits in the long run.

Table 4-2: Analysis of energy consumption and cost savings for the lighting system,

	Energy - base case	**Energy - Proposed**	**Energy - Saved**	**Investment costs**	**Energy cost savings**	**Incremental O&M savings**
	kWh	**kWh**	**kWh**	**RWF**	**RWF**	**RWF**
Lights-Generator control room	701	491	210	- 124,117	25,860	27,182
Lights-Administration block	2,102	1,472	631	- 385,192	77,579	56,238
Lights-Engineering Office	5,887	3,924	1,962	- 342,392	241,356	149,968
Lights-Raw Material store	5,256	3,679	1,577	- 16,050	193,946	7,030
Lights-Breaching kettle area	2,628	1,840	788	48,149	96,973	- 10,545
Lights-Boiler and mixing area	3,854	2,698	1,156	- 23,539	142,227	5,155
Lights-Workshops	526	368	158	- 3,210	19,395	703
Lights-Packing & transporting area	7,008	4,906	2,102	- 12,840	258,595	9,373
Lights-Soap store	1,752	1,226	526	- 42,799	64,649	9,373
Lights-Substation control room	1,402	981	420	- 4,280	51,719	1,875
Lights-Crushing	1,752	1,226	526	- 10,700	64,649	2,343
Lights-Confirwa	8,760	6,132	2,628	- 53,499	323,244	11,716
Lights-Guard room and outside	1,752	1,226	526	- 10,700	64,649	2,343
Lights-Water treatment area	1,226	858	368	- 7,490	45,254	1,640
Lights-Water store	1,752	1,226	526	- 10,700	64,649	2,343
Lights-Chiller	1,051	736	315	- 6,420	38,789	1,406
Lights-Pump room	876	613	263	- 5,350	32,324	1,172
Total	**48,285**	**33,603**	**14,682**	**- 1,011,128**	**1,805,856**	**279,315**

4.3. Conclusion on the result

The proposed lighting system upgrades lead to significant energy savings of 14,682 kWh, achieved by optimizing lamp usage and improving illumination efficiency. These reductions result in substantial energy cost savings of 1,805,856 RWF, offsetting the initial capital investment and delivering long-term financial benefits. Additionally, the upgrade contributes to operational and maintenance savings of 279,315 RWF, stemming from reduced lamp replacements and less frequent maintenance, further enhancing its cost-effectiveness.

Beyond the financial gains, the upgrade ensures efficient resource use by reducing the number of lamps in certain areas while maintaining or improving lighting intensity. This optimization not only meets or exceeds standard lux levels in key areas but also supports sustainable operations by reducing the facility's overall energy demand. In conclusion, the proposed lighting system upgrades offer a clear path to significant cost reductions and improved energy efficiency, making it a financially viable and environmentally beneficial investment.

4.3. Equipment Analysis and Proposed Upgrades

4.3.1. Analysis of energy consumption and cost savings for computers

Table 4-3 shows the energy consumption of computers under a base case and a proposed case scenario. In the base case, 10 computers operate 8 hours per day with a load of 150 watts each, running at 80% of their duty cycle. This results in a total energy consumption of 3,504 kWh annually. In the proposed case, the duty cycle is reduced to 50%. The duty cycle is reduced by adjusting the operating pattern of computers, ensuring they run at full capacity only for half of their operating time. This can be done using power management software, minimizing idle time, and scheduling non-essential tasks during off-hours. These adjustments lower the overall energy consumption. The result is a 37.5% energy saving, keeping all other parameters constant. This change lowers the total energy consumption to 2,190 kWh annually, resulting in an energy saving of 1,314 kWh or approximately 37.5%.

Table 4-3:Energy consumption of computers under a base case and a proposed case

Electrical equipment

Description	Electrical equipment
Note	Computers

Electrical equipment

		Base case				Proposed case			
Description	Electricity load - typical W	Quantity	Operating hours h/d	Electricity load W	Duty cycle %	Quantity	Operating hours h/d	Electricity load W	Duty cycle %
Computer	200 - 300	10	8	150	80%	10	8	150	50%

Total

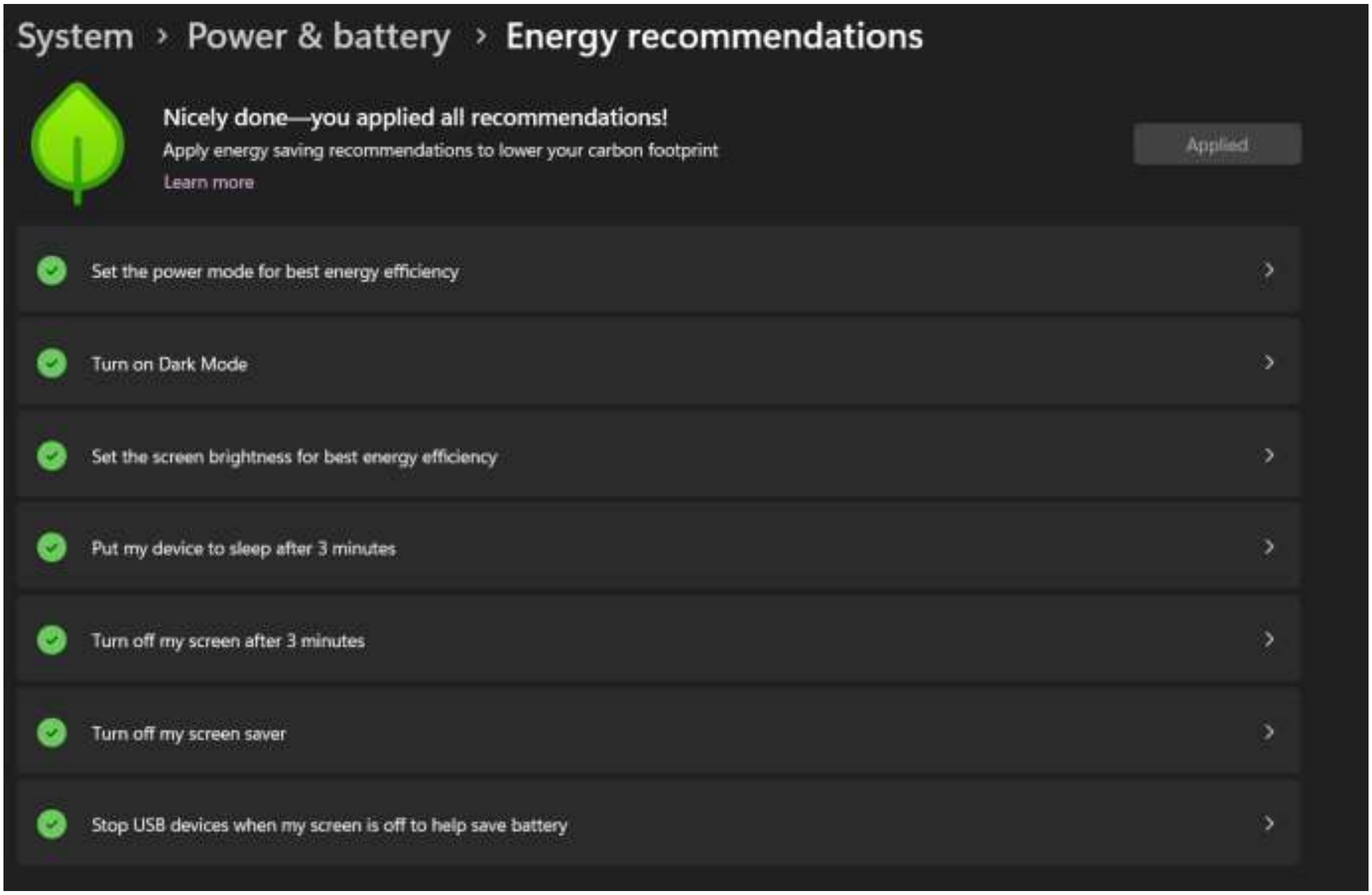
		Base case	Proposed case	Energy saved
Incremental initial costs	RWF		0	
Incremental O&M savings	RWF			
Electricity	kWh	3,504	2,190	1,314 37.5%

Impact

Space cooling impact	100%
Space heating impact	100%

The proposed case highlights a significant opportunity for energy savings by reducing the duty cycle, likely through power management settings that put the computers in low-power or sleep mode during idle periods. This adjustment can reduce operational costs and energy use, aligning with energy efficiency goals without incurring additional initial costs.

To enhance energy efficiency, it is recommended to set the computers to automatically enter sleep mode and turn off the screens during idle periods that exceed three minutes, more details are shown in Figure 4-4. This strategy will reduce power consumption by minimizing active hours and idle energy use, especially during times when computers are not actively being used.


System › Power & battery › Energy recommendations

Nicely done—you applied all recommendations!

Apply energy saving recommendations to lower your carbon footprint

Learn more

- ✓ Set the power mode for best energy efficiency
- ✓ Turn on Dark Mode
- ✓ Set the screen brightness for best energy efficiency
- ✓ Put my device to sleep after 3 minutes
- ✓ Turn off my screen after 3 minutes
- ✓ Turn off my screen saver
- ✓ Stop USB devices when my screen is off to help save battery

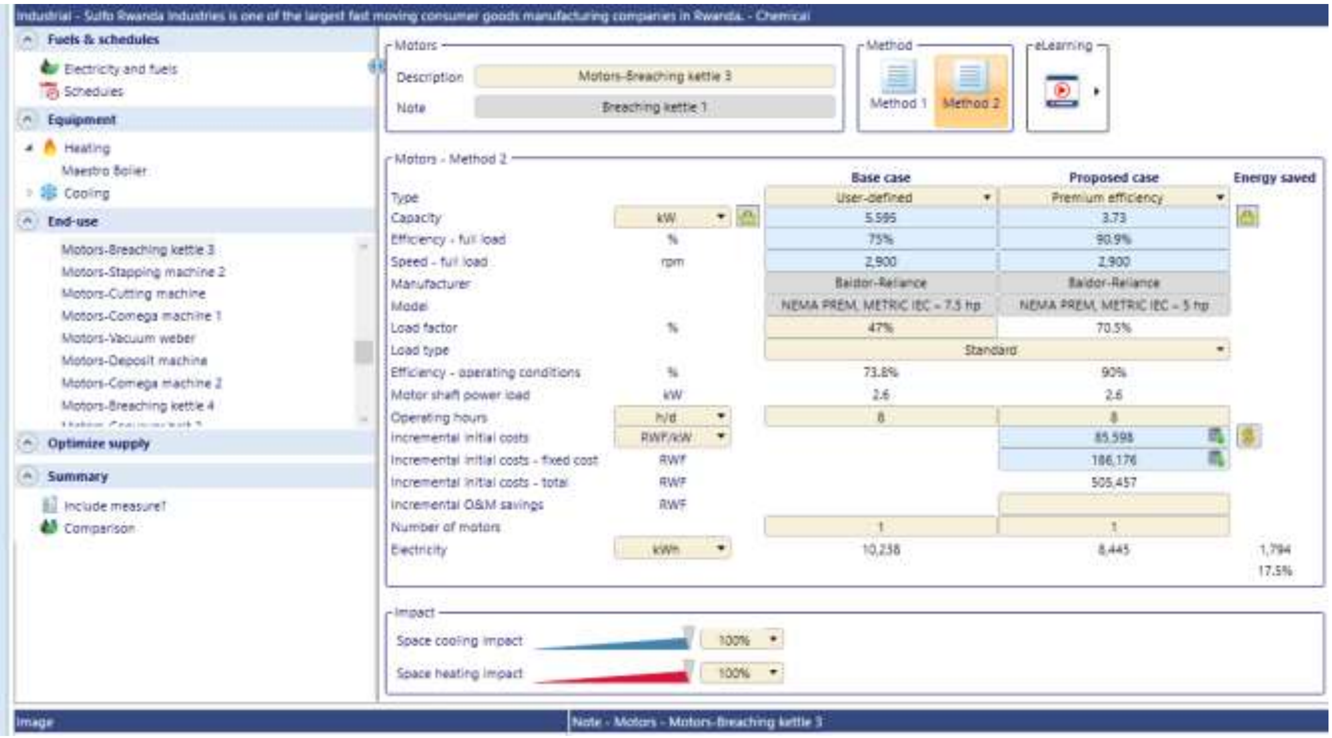
Figure 4-4: Energy saving tips for computers

By implementing these settings, each computer will consume less power without compromising functionality, leading to substantial cumulative energy savings over time. This approach is simple to implement, incurs no extra costs, and can contribute significantly to the energy-saving goals of the organization. Additionally, reducing unnecessary screen and system activity helps extend the equipment's lifespan, leading to further operational benefits.

4.4. Analysis of Motors Energy Use and Recommended Upgrades

4.4.1. Energy Consumption and Savings Analysis of Motors Installed on Machinery

The Table 4-4, Figure 4-5 and Figure 4-6 compares energy consumption and costs for various motors across machines in the factory, revealing key insights into energy efficiency improvements. While some motors, such as those in Breaching Kettle 2 and the Crusher for Omega, show significant energy savings of 866 kWh and 11,289 kWh respectively, others like Breaching Kettle 1 experience increased consumption.



Motors

Description: Motors-Breaching kettle 3

Note: Breaching kettle 1

Motors - Method 2

		Base case	Proposed case	Energy saved
Type		User-defined	Premium efficiency	
Capacity	kW	5.595	3.73	
Efficiency - full load	%	75%	90.9%	
Speed - full load	rpm	2,900	2,900	
Manufacturer		Baldor-Reliance	Baldor-Reliance	
Model		NEMA PREM, METRIC IEC - 7.5 hp	NEMA PREM, METRIC IEC - 5 hp	
Load factor	%	47%	70.5%	
Load type		Standard		
Efficiency - operating conditions	%	73.8%	90%	
Motor shaft power load	kW	2.6	2.6	
Operating hours	h/d	8	8	
Incremental initial costs	RWF/kW		85,598	
Incremental initial costs - fixed cost	RWF		186,176	
Incremental initial costs - total	RWF		505,457	
Incremental O&M savings	RWF			
Number of motors		1	1	
Electricity	kWh	10,238	8,445	1,794 17.5%

Impact

Space cooling impact: 100%

Space heating impact: 100%

Figure 4-5: Simulation result for motors-breaching kettle 3

Table 4-4: Energy consumption and costs for various motors

All	**Energy - base case**	**Energy - proposed case**	**Energy saved**
	kWh	**kWh**	**kWh**
Motors			
Motors-Breaching kettle 1	13,140	13,140	-
Motors-Breaching kettle 2	18,029	18,029	-
Motors-Stapping machine 1	1,236	1,236	-
Motors-Conveyor belt 1	711	619	92
Motors-Weber machine	46,670	46,670	-
Motors-Comega machine 1	45,503	45,503	-
Motors-Acid mixing	12,075	11,906	168
Motors-Breaching kettle 3	10,238	8,445	1,794
Motors-Stapping machine 2	12,733	12,733	-
Motors-Cutting machine	654	569	85
Motors-Comega machine 1	24,502	24,592	- 90
Motors-Vacuum weber	30,046	30,046	-
Motors-Deposit machine	8,589	8,265	324
Motors-Comega machine 2	37,336	37,336	-
Motors-Breaching kettle 4	6,723	6,035	688
Motors-Conveyor belt 2	2,911	2,911	-

All	Energy - base case	Energy - proposed case	Energy saved
	kWh	kWh	kWh
Motors-Crusher for omega	117,487	106,198	11,289
Motors-Comega machine 3	5,913	5,913	-
Motors-Vccum of comega	36,505	36,505	-
Motors-Crusher for Weber	80,155	80,155	-
Total	**511,154**	**496,804**	**14,349**

The Figure 4-6 compares energy consumption between a base case and a proposed case for various motors. It shows that most motors have little to no change in energy consumption between the two cases, with the bars representing their energy consumption being similar in height. However, some motors, like the Breaching Kettle 3, Crusher for Omega, Deposit Machine, and Acid Mixing, exhibit significant energy savings in the proposed case, represented by the orange bars. Conversely, the Comega Machine 1 shows a slight increase in energy consumption, indicating a rise in energy use in the proposed scenario. This graph provides insights into potential energy efficiency improvements and highlights areas where upgrades or replacements might be necessary to maximize energy savings. The chart suggests that a systematic approach to replacing or optimizing motors can yield substantial energy savings, particularly for machines with higher power demands.

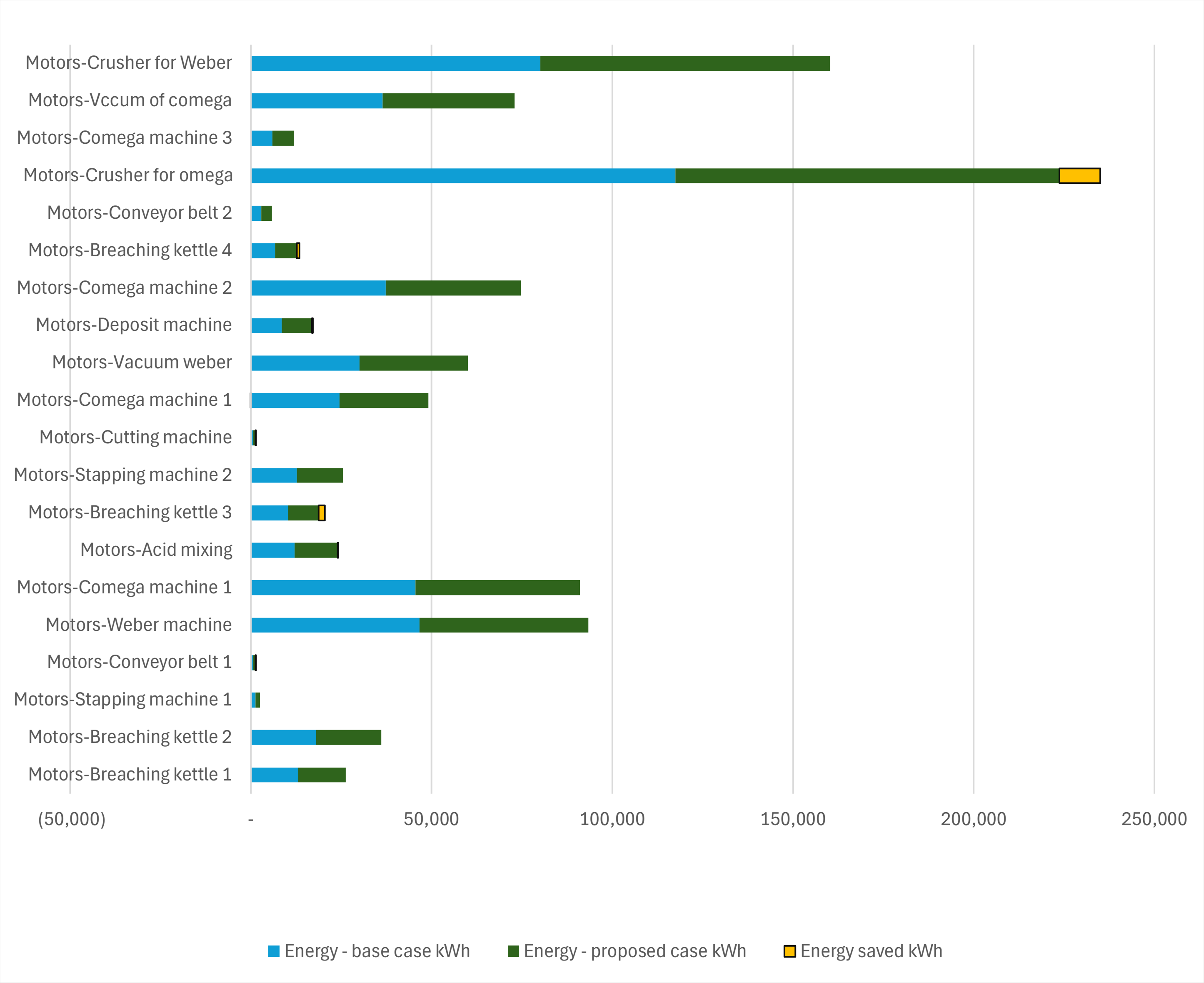


Figure 4-6: Energy consumption analysis for motors

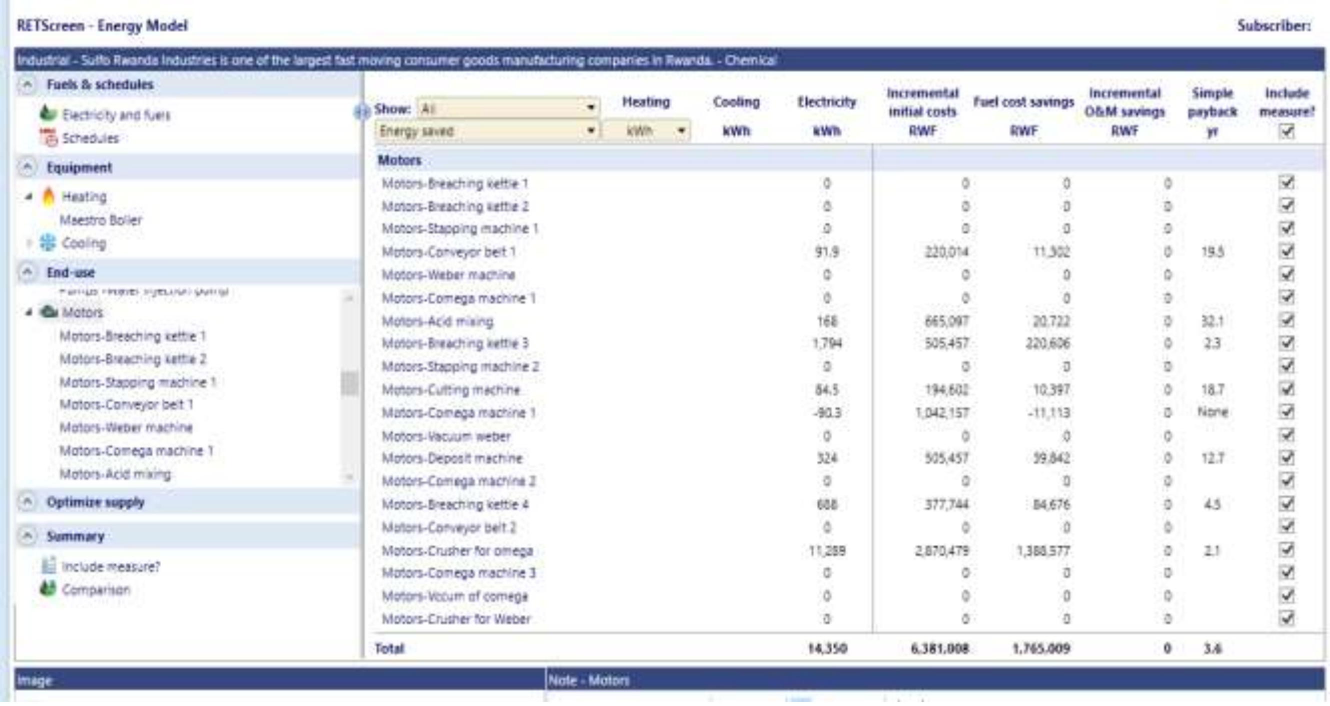
4.4.2. Discussion on energy consumption, potential savings, and costs of motors upgrading

This Table 4-5 compares the energy consumption, potential savings, and costs of upgrading motors across different machines. The analysis shows that for motors with a load factor greater than 50%, there is no need to replace them since they are operating efficiently within their optimal range. In such cases, both the base and proposed energy consumption remain the same, and thus, no savings in energy or costs are realized. For instance, motors in machines like Breaching Kettle 1, Stepping Machine 1, and the Weber machine do not yield any energy savings, as their load factors exceed 50%, indicating efficient utilization of motor capacity.

For motors with a load factor below 50%, where upgrades could improve efficiency, the Table 4-5 shows significant energy savings and associated fuel cost reductions. For example, replacing the motor in the Crusher for Omega machine results in an energy savings of 11,289 kWh per year and a fuel cost reduction of 1,388,577 RWF annually, despite the upfront incremental cost of 2,870,479 RWF. The total energy savings across all upgraded motors is 14,349 kWh annually, with a cumulative cost saving of 1,765,009 RWF per year. This simulation analysis confirms that strategic motor replacements for underloaded motors can effectively reduce energy consumption and operational costs, justifying the initial investment.

Table 4-5: Evaluation of Energy Savings and Cost Implications for Motor Upgrades

All	**Energy - base case**	**Energy - proposed case**	**Energy saved**	**Incremental initial costs**	**Fuel cost savings**
	kWh	**kWh**	**kWh**	**RWF**	**RWF**
Motors					
Motors-Breaching kettle 1	13,140	13,140	-	-	-
Motors-Breaching kettle 2	18,029	18,029	-	-	-
Motors-Stapping machine 1	1,236	1,236	-	-	-
Motors-Conveyor belt 1	711	619	92	220,014	11,302
Motors-Weber machine	46,670	46,670	-	-	-
Motors-Comega machine 1	45,503	45,503	-	-	-
Motors-Acid mixing	12,075	11,906	168	665,097	20,722
Motors-Breaching kettle 3	10,238	8,445	1,794	505,457	220,606
Motors-Stapping machine 2	12,733	12,733	-	-	-
Motors-Cutting machine	654	569	85	194,602	10,397
Motors-Comega machine 1	24,502	24,592	- 90	1,042,157	- 11,113
Motors-Vacuum weber	30,046	30,046	-	-	-
Motors-Deposit machine	8,589	8,265	324	505,457	39,842
Motors-Comega machine 2	37,336	37,336	-	-	-
Motors-Breaching kettle 4	6,723	6,035	688	377,744	84,676
Motors-Conveyor belt 2	2,911	2,911	-	-	-
Motors-Crusher for omega	117,487	106,198	11,289	2,870,479	1,388,577
Motors-Comega machine 3	5,913	5,913	-	-	-
Motors-Vccum of comega	36,505	36,505	-	-	-
Motors-Crusher for Weber	80,155	80,155	-	-	-
Total	**511,154**	**496,804**	**14,349**	**6,381,008**	**1,765,009**



Industrial - Sulfo Rwanda Industries is one of the largest fast moving consumer goods manufacturing companies in Rwanda. - Chemical

Show: All
Energy saved

	Heating kWh	Cooling kWh	Electricity kWh	Incremental initial costs RWF	Fuel cost savings RWF	Incremental O&M savings RWF	Simple payback yr	Include measure? ☑
Motors								
Motors-Breaching kettle 1			0	0	0	0		☑
Motors-Breaching kettle 2			0	0	0	0		☑
Motors-Stapping machine 1			0	0	0	0		☑
Motors-Conveyor belt 1			91.9	220,014	11,302	0	19.5	☑
Motors-Weber machine			0	0	0	0		☑
Motors-Comega machine 1			0	0	0	0		☑
Motors-Acid mixing			168	665,097	20,722	0	32.1	☑
Motors-Breaching kettle 3			1,794	505,457	220,606	0	2.3	☑
Motors-Stapping machine 2			0	0	0	0		☑
Motors-Cutting machine			84.5	194,602	10,397	0	18.7	☑
Motors-Comega machine 1			-90.3	1,042,157	-11,113	0	None	☑
Motors-Vacuum weber			0	0	0	0		☑
Motors-Deposit machine			324	505,457	39,842	0	12.7	☑
Motors-Comega machine 2			0	0	0	0		☑
Motors-Breaching kettle 4			688	377,744	84,676	0	4.5	☑
Motors-Conveyor belt 2			0	0	0	0		☑
Motors-Crusher for omega			11,289	2,870,479	1,388,577	0	2.1	☑
Motors-Comega machine 3			0	0	0	0		☑
Motors-Vccum of comega			0	0	0	0		☑
Motors-Crusher for Weber			0	0	0	0		☑
Total			**14,350**	**6,381,008**	**1,765,009**	**0**	**3.6**	

4.4.3. Energy and Cost Savings Analysis of Motor-Upgrades

Electric motors are typically built to operate effectively within a load range of 50% to 100% of their rated capacity. For instance, a 10-horsepower (hp) motor performs best between 5 to 10 hp, with its highest efficiency occurring at around 7.5 hp. However, it's important to note that a motor's efficiency can drop significantly when it runs below about 50% of its capacity. So, keeping a motor within this optimal range not only enhances its performance but also helps save energy [21].

The Table 4-9 compares existing and proposed motors for several machines, detailing the benefits of upgrading to more efficient motors with better load optimization. Each proposed motor has been selected to improve efficiency (η) and match the load percentage more closely to actual usage, resulting in reduced energy consumption across all machines. For instance, the Crusher for Omega machine achieves an energy savings of 11,289 kWh per year, while the Water Injection Pump saves 6,054 kWh annually. The total estimated energy savings across all machines reaches 20,317 kWh per year, highlighting the impact of motor efficiency and load matching on overall energy usage.

In addition to energy savings, the upgrades yield significant annual fuel cost reductions. These fuel cost savings, totaling 2,499,005 RWF per year, indicate that despite the incremental initial investment of 6,413,037 RWF for the new motors, the long-term savings contribute to recouping costs over time. This analysis illustrates how strategic motor upgrades can lower operating costs and improve energy efficiency, offering a sustainable approach for industrial operations to minimize energy consumption and reduce expenses.

Table 4-6: Energy and cost savings analysis of motor-upgrades

		Existing Motors			**Proposed motor**			**Simulation results**				
NO.	**Machines**	**[kW]**	**η [%]**	**Load [%]**	**[kW]**	**η [%]**	**Load [%]**	**Energy - base case [kWh/year]**	**Energy - proposed case [kWh/year]**	**Energy saved [kWh/year]**	**Incremental initial costs RWF**	**Fuel cost savings [RWF/year]**
1	Crusher for omega	90	85	**38%**	37.3	94	**92%**	117,487	106,198	11,289	2,870,479	1,388,577
2	Water injection pump	7.5	75	**45%**	3.73	90.9	**84%**	9,136	3,082	6,054	1,488,802	744,582
3	Deposit machine	5.5	87	**46%**	3.73	90.9	**69%**	8,589	8,265	324	505,457	39,842
4	Breaching kettle 3	5.5	75	**47%**	3.73	90.9	**70%**	10,238	8,445	1,794	505,457	220,606
5	Breaching kettle 4	3.7	81	**50%**	2.238	90.2	**83%**	6,723	6,035	688	377,744	84,676
6	Acid mixing	7.5	90.2	**50%**	5.595	91.5	**67%**	12,075	11,906	168	665,097	20,722
	Total							**164,248**	**143,931**	**20,317**	**6,413,037**	**2,499,005**

4.5. Energy Efficiency and Cost Savings Analysis for Compressor-Upgrades at SULFO Rwanda Industries Ltd

This Table 4-7 provides an analysis of energy and cost savings for upgrading compressors at SULFO Rwanda Industries Ltd, comparing existing and proposed setups for each compressor. The table evaluates the potential energy savings, initial costs, and simple payback periods for both piston and screw compressors. The energy savings for each unit are substantial, with upgrades leading to cumulative annual energy savings of 259,807 kWh. Notably, Screw Compressor 1 shows the highest individual energy savings at 89,041 kWh annually, contributing significantly to the total reduction.

Each compressor replacement has an associated incremental initial cost and estimated annual fuel cost savings, resulting in varied payback periods. For example, Air Compressor-Piston 1 has a short payback period of 1.5 years due to its high fuel cost savings (2,732,132 RWF) relative to the investment (4,016,959 RWF). Other compressors, like Piston 2 and Piston 3, have payback periods of around 4 years. Overall, the investment of 68,577,734 RWF across all compressors results in a total annual fuel cost saving of 31,956,249 RWF (Is that yearly?), indicating that most of these upgrades offer rapid cost recovery and enhanced energy efficiency, making them financially viable for the company.

Table 4-7: Compressor upgrades at SULFO Rwanda Industries Ltd

All	Energy - base case	Energy - proposed case	Energy saved	Incremental initial costs	Fuel cost savings	Simple payback
	kWh	kWh	kWh	RWF	RWF	yr
Air compressor-Piston 1	44,443	22,230	22,212	4,016,959	2,732,132	1.5
Air compressor-Piston 2	85,680	63,279	22,402	10,927,402	2,755,393	4.0
Air compressor-Piston 3	42,840	31,639	11,201	5,463,701	1,377,696	4.0
Air compressor-Piston 4	54,147	31,252	22,895	5,463,701	2,816,062	1.9
Air compressor-Piston 5	54,147	31,252	22,895	5,463,701	2,816,062	1.9
Air compressor-Piston 6	54,147	31,252	22,895	5,463,701	2,816,062	1.9
Air compressor-Piston 7	54,147	30,775	23,372	5,463,701	2,874,774	1.9
Air compressor-Piston 8	54,147	31,252	22,895	5,463,701	2,816,062	1.9
Screw compressor 1	198,044	109,004	89,041	20,851,166	10,952,005	1.9
Total	**641,741**	**381,934**	**259,807**	**68,577,734**	**31,956,249**	

4.6. Pumping system

A water pump's load factor should be above 80% to maximize energy efficiency. A load factor above 80% means that the measured peak demand was used by 80% or more of the meter. Load factors are usually multiplied by 100 and expressed as a percentage [22], [23].

As demonstrated in the Table 4-8, the base case energy consumption for the water injection pump is 9,136 kWh, while the proposed case reduces it to 3,082 kWh, achieving significant savings. The incremental initial costs amount to 6,054 RWF, with annual energy cost savings of 744,582.4 RWF. This leads to a simple payback period of approximately 2 years, highlighting an efficient investment for energy cost reduction.

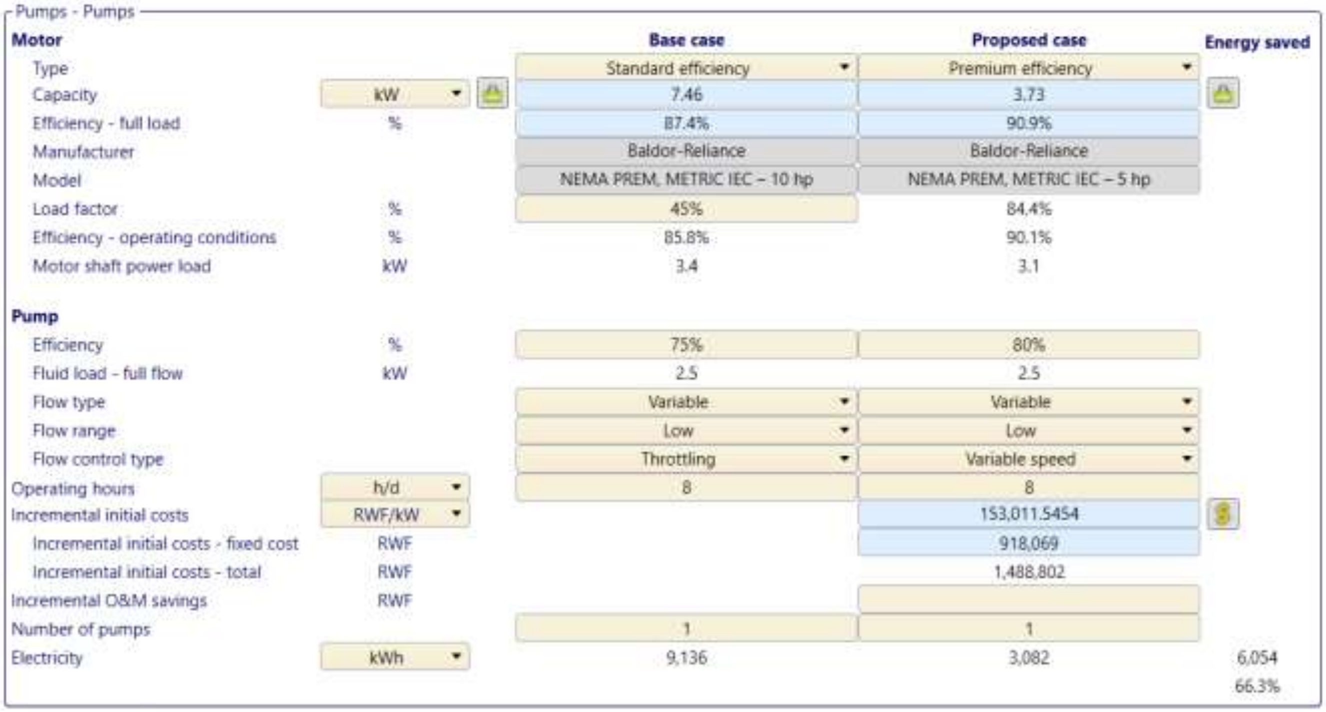
Table 4-8: Pumping system upgrade

Energy - base case	Energy - proposed case		Incremental initial costs	Energy cost savings	Simple payback
kWh			RWF	RWF	yr

Pumps -Water injection pump	9,136	3,082	6,054	1488802	744582.4	2 year

The Table 4-9 comparing the energy savings of using a standard efficiency motor vs. a premium efficiency motor in a pump system. The base case uses a standard efficiency motor with a capacity of 7.46 kW and an efficiency of 87.4%. The proposed case uses a premium efficiency motor with a capacity of 3.73 kW and an efficiency of 90.9%. The proposed case saves 6,054 kWh of electricity, which is 66.3% of the electricity used in the base case. The Table 4-9 also shows the incremental initial costs of the two options, as well as the incremental operating and maintenance costs. The analysis seems to favor the proposed case with premium efficiency motor as it saves a significant amount of energy and money in the long run.

Table 4-9: Energy Savings from Motor and Pump Efficiency Upgrades



Pumps - Pumps

Motor		**Base case**	**Proposed case**	**Energy saved**
Type		Standard efficiency	Premium efficiency	
Capacity	kW	7.46	3.73	
Efficiency - full load	%	87.4%	90.9%	
Manufacturer		Baldor-Reliance	Baldor-Reliance	
Model		NEMA PREM, METRIC IEC – 10 hp	NEMA PREM, METRIC IEC – 5 hp	
Load factor	%	45%	84.4%	
Efficiency - operating conditions	%	85.8%	90.1%	
Motor shaft power load	kW	3.4	3.1	
Pump				
Efficiency	%	75%	80%	
Fluid load - full flow	kW	2.5	2.5	
Flow type		Variable	Variable	
Flow range		Low	Low	
Flow control type		Throttling	Variable speed	
Operating hours	h/d	8	8	
Incremental initial costs	RWF/kW		153,011.5454	
Incremental initial costs - fixed cost	RWF		918,069	
Incremental initial costs - total	RWF		1,488,802	
Incremental O&M savings	RWF			
Number of pumps		1	1	
Electricity	kWh	9,136	3,082	6,054 66.3%

CHAPTER 5. RESULTS AND DISCUSSION

5.1. Introduction

This chapter presents the results obtained from the data analysis, simulation, focusing on production output, energy consumption, and specific energy usage across different production processes. The findings are discussed in relation to benchmark standards, identifying energy inefficiencies and gaps. Comparative analysis highlights areas for improvement, and insights are provided to optimize energy performance and enhance production efficiency.

5.2. Benchmarking of Energy

Table 5-1 provides an overview of energy consumption across different industrial sectors, detailing the annual production values and corresponding energy usage in both electrical (kWh) and thermal (MJ) units. The sectors included are cement, brick manufacturing, dairy products, pulp and paper, metal processing, soap and chemicals, cold storage, and hotels. For example, the cement industry, with clinker production of 7.1 million tons, consumes approximately 347.9 million kWh of electricity and 38.4 billion MJ of thermal energy. This highlights the high energy demands of sectors like cement and soap, emphasizing the potential for energy optimization and cost-saving strategies in such energy-intensive industries.

Table 5-1: Indexes for energy efficiency for different industries

INDUSTRIAL SECTOR		**ANNUAL PRODUCTION**		**ANNUAL ENERGY CONSUMPTION**	
		VALUE	**UNIT**	**ELECTRICAL (KWH)**	**THERMAL (MJ)**
Cement	Clinker	7,100,000	MT	347,900,000	38,418,100,000
	based				
	Limeston	400,000	MT	59,600,000	0
Brick	FC-BTK	5,140,000,000	pieces of brick	118,956,173	22,097,157,803
	VSBK			383,401	39,389,494
Dairy products		2,168,430	kltr	167,489,533	1,925,045,417
Pulp and paper		55,270	MT	51,787,990	853,037,180
Metal processing		842,270	MT	125,498,230	1,238,979,170
Soap and chemicals		157,224	MT	17,491,170	59,102,663,430
Cold storage		85,490	MT	24,238,979	0

Hotels	40,856	Rooms	786,028,642	707,871,056
Total			1,699 million kWh	124,382 million MJ

5.2.1. Worldwide Benchmarking for soap, PET bottle production and PET bottle filling

From [24] the bottle of 500ml weighs 19.71gr, while in [25] the average unit electricity consumption reaches the lowest value for mixing (0.64 kWh/kg=2.29MJ/kg of processed polymer), and the highest value for vacuum thermoforming (6.23 kWh/kg = 22.42MJ/kg). As presented in the research done by Isabel Anna, the Specific energy consumption of the main consumer for a time period of one week and an analysis of the consumption related to the operational behavior of the machines for a PET bottling plant revealed that the average specific energy consumption is 0.00559 kWh/pieces [26].

5.2.2. Energy Efficiency Analysis and Improvement Opportunities for SULFO Rwanda Industries

Table 5-2 provides a detailed analysis of production and energy consumption data for SULFO Rwanda Industries, focusing on soap production, PET bottle production, and PET bottle filling for the years 2022 to 2024. It compares actual specific energy consumption values against benchmarked values, highlighting gaps that indicate inefficiencies. For soap production, the average specific energy consumption is 0.1175 kWh/Kg, which exceeds the benchmark of 0.1112 kWh/Kg by 5.66%. Similarly, the specific energy consumption for PET bottle production averages 0.0241 kWh/Piece, almost double the benchmark of 0.0125 kWh/Piece, while PET bottle filling averages 0.0099 KWh/Piece, 43.75% above the benchmark of 0.0056 KWh/Piece. These disparities emphasize the need for energy efficiency improvements in SULFO Rwanda's operations.

The data also reveals a declining trend in production volumes across all categories, with soap production dropping from 3.76 million kg in 2022 to 1.7 million kg in 2024, and PET bottle production decreasing from over 16 million pieces in 2022 to 12.7 million pieces in 2024. Despite this decline, energy consumption has not reduced proportionally, pointing to inefficiencies in the production process. To bridge the energy consumption gaps, SULFO Rwanda Industries can implement advanced energy-efficient technologies, optimize equipment operations, and conduct regular energy audits. Such measures would align their specific energy consumption closer to benchmarked levels, reducing operational costs while improving sustainability.

Table 5-2: Benchmarking for production use of energy

No.	Item	2022 Value	2023 Value	2024 Value	Average Value	Bench mark Value	Gap in Energy Consumption	Potential Improvement Recommendation
1	Soap Production (Kgs)	3,760,789	2,836,797	1,697,728	2,765,105	-	-	-
	Electric Consumption (kWh) (SOAP)	434,580	335,096	201,476	323,718	-	-	-
	Specific Electric Consumption (KWh/Kg)	0.1156	0.1181	0.1187	0.1175	0.1112	**0.0063 kWh/Kg** (5.66% higher)	• Optimize production processes with energy-efficient motors and controls. • Conduct energy audits.
2	Bottles Production PET (Pieces)	16,172,980	16,185,737	12,743,667	15,034,128	-	-	-
	Bottles Production PET (Kg)	385,071	385,375	303,421	357,955	-	-	-
	Electric Consumption (KWh) for Bottles Production	157,346	165,897	123,031	148,758	-	-	-
	Specific Electric Consumption (kWh/Piece)	0.0232	0.0239	0.0253	0.0241	0.0125	**0.0116 kWh/Piece** (92.8% higher)	- Upgrade machinery to more efficient models. - Reduce idle running time.
3	Bottles Filling [Food + RO] (Pieces) PET	16,172,980	16,185,737	12,743,667	15,034,128	-	-	-
	Electric Consumption (KWh) for Bottles Filling	374,851	386,353	322,373	361,192	-	-	-
	Specific Electric Consumption (KWh/Piece)	0.0097	0.0102	0.0097	0.0099	0.0056	**0.0043 kWh/Piece** (43.75% higher)	- Automate filling systems with energy-efficient technologies. - Implement real-time energy monitoring.
4	Benchmarked Specific Electric Consumption (SOAP)	0.1112	0.1112	0.1112	0.1112	-	-	-
5	Benchmarked Specific Electric Consumption (Bottles Production PET)	0.0125	0.0125	0.0125	0.0125	-	-	-
6	Benchmarked Specific Electric Consumption (Bottles Filling PET)	0.0056	0.0056	0.0056	0.0056	-	-	-

5.3. Discussions on simulation results and benchmarked standards

The findings from this study highlight significant energy inefficiencies within SULFO Rwanda Industries and other industrial sectors in Rwanda, with specific energy consumption for processes such as PET bottle production and soap manufacturing exceeding global benchmarks by 92.8% and 5.66%, respectively. These inefficiencies increase operational costs, reduce competitiveness, and contribute to environmental challenges. Despite declining production volumes from 2022 to 2024, energy consumption has not decreased proportionally, emphasizing the need for optimized production processes. To address these challenges, Rwanda’s industrial sector must adopt energy-efficient technologies, implement sector-specific energy policies, conduct regular energy audits, and promote the integration of renewable energy sources. These measures will not only reduce costs and enhance productivity but also support Rwanda’s sustainability goals and improve its industrial competitiveness in regional and global markets.

CHAPTER 6. CONCLUSION AND RECOMMENDATIONS

6.1Conclusion

This study has provided an in-depth examination of energy consumption at SULFO Rwanda Industries Ltd by combining extensive data collection, rigorous analysis, and simulation-based evaluations. The key findings of the research can be summarized as follows:

6.1.1 Data Collection

- We gathered detailed energy consumption data from the core production processes—namely, soap production, PET bottle production, and bottle filling—through on-site measurements, review of historical records, and direct observations.
- This comprehensive dataset formed a solid foundation for analyzing energy usage patterns and identifying areas for improvement.

6.1.2 Data Analysis:

- **Soap Production:**
    - The analysis revealed an average energy consumption of 0.1175 kWh/kg, which is higher than the benchmark of 0.1112 kWh/kg.
- **PET Bottle Production:**
    - The specific energy consumption for **PET Bottle Production** was found to be 0.0241 kWh per piece, in contrast to the benchmark value of 0.0125 kWh per piece.
- **Bottle Filling:**
    - The energy consumption during bottle filling was measured at 0.0099 kWh per piece, compared to a benchmark of 0.0056 kWh per piece.
- These results highlight clear inefficiencies across all production processes and indicate a significant opportunity to improve energy management and process optimization.

6.1.3 Simulation Results:

- The simulation models have shown that by implementing targeted measures such as upgrading outdated equipment and refining production processes, it is possible to achieve notable energy savings.
- The simulations suggest that adopting advanced energy management systems can help realign actual energy consumption with established benchmarks, thereby enhancing

operational efficiency.

6.2Recommendations

Based on the insights derived from the study, we recommend the following actions to enhance energy efficiency and overall performance at SULFO Rwanda Industries Ltd:

6.2.1 Technological Enhancements and Process Optimization:

- **Upgrade Equipment:** Replace outdated machinery with energy-efficient alternatives to reduce unnecessary energy consumption.
- **Regular Energy Audits:** Establish a routine schedule for comprehensive energy audits to continuously monitor energy use and identify further opportunities for optimization.
- **Integrated Energy Management:** Implement a real-time energy management system that allows for continuous monitoring and control, ensuring that energy consumption is kept within optimal limits.

6.2.2 Improved Maintenance and Capacity Building:

- **Enhance Maintenance Practices:** Regular maintenance should be prioritized to ensure that all equipment is operating at its peak efficiency.
- **Staff Training:** Invest in training programs that educate employees about energy-saving techniques and the importance of efficient energy management, thereby fostering a culture of sustainability within the organization.

6.2.3 Renewable Energy Integration:

- **Adopt Renewable Solutions:** Explore the feasibility of integrating renewable energy sources, such as solar photovoltaic (PV) systems, to reduce reliance on conventional energy and further improve energy efficiency.

6.2.4 Future Research Directions:

- **Thermal Energy Analysis:** Conduct a more detailed examination of production processes relative to fuel consumption for thermal energy to identify further inefficiencies.
- **Alternative Energy Sources:** Investigate alternative fuel sources and energy recovery systems such as waste heat to optimize the use of thermal energy.
- **Advanced Monitoring and Analysis:** Utilize state-of-the-art monitoring technologies and perform thorough cost-benefit analyses to assess the long-term viability and

effectiveness of proposed thermal energy-saving measures.

By implementing these recommendations, SULFO Rwanda Industries Ltd has the potential to significantly reduce its energy consumption, bring production processes closer to international benchmarks, and improve overall operational efficiency. These changes will not only result in cost savings but will also contribute positively to environmental sustainability, setting a precedent for energy management practices in Rwanda's industrial sector.

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APPENDICES

Appendices 1. Existing lamp in offices and rooms

FLT24 T5 Fluorescent, 2 Feet, 4 Tube Grow Light System, White

Figure 6-1: Existing lamp in offices and rooms

Appendices 2. Existing lamp in production area and storage

High Output Fluorescent Philips T12 – 4100K, 40W

Figure 6-2: Existing lamp in production area and storage

Appendices 3. Proposed lamp to replace office and room lamps

Figure 6-3: LEDVANCE Fluorescent 48" 28W T8 Lamp, 5000K Daylight, 1 Pack

Table 6-1: Specifications

Brand	**LEDVANCE**
Light Type	Fluorescent
Wattage	28 watts

Bulb Shape Size	T8
Bulb Base	G12

Appendices 4. Data collection acceptance letter

SULFO RWANDA INDUSTRIES LTD
#12 KN 82 ST, B.P.90, KIGALI, RWANDA, EAST AFRICA
Tel.: (+250) 0252575457, 0252576472, 0788305979 Email: info@sulfo.com
Fax: (+250) 0252574573 eFax: +448701312350 Web: www.sulfo.com Company Code: 100028318

Ref: 353/SUL/DG/BC/24

Kigali,
7th June, 2024

Mr. NIYIREMA Jonas
Tel. 0783210412
College of Science and Technology

Re: Your request for research on "Energy audit and conservation in the Industry".

With reference to your letter, we are pleased to grant you permission to conduct your research on 10/06/2024 in our Maintenance Department.

During your research, you will be facilitated by our Engineer -Operations and Maintenance. However, it should be noted that confidentiality is needed for the data collected.

With kind regards,

for
H. Dharmarajan
Managing Director

CC:
-Engineer – Operations and Maintenance
-HR Department

Appendices 5. Pictorial presentation for field data collection at the facility

Table 6-2: Field data collection

		
		

Appendices 6. Simulation procedures used


BASE CASE
Fuels & schedules
Equipment
End-use
Optimize supply
Maximize efficiency
Minimize usage
PROPOSED CASE