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Techno-Economic and Environmental Analysis of Dairy Industry: "A Case Study of Kathmandu Milk Supply Schemes"

By

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ABSTRACT

The dairy industry is a primary energy-intensive sector, relying heavily on electricity for milk processing, refrigeration, and other essential operations. The development and effectiveness of the dairy plant in Nepal face several challenges due to a lack of energy management. The consumption of energy and GHG emissions related to dairy processing increases day by day. This paper explores the energy-saving opportunities along with introducing different technological interventions in Kathmandu Milk Supply Schemes, DDC, under different energy-efficient scenarios. The research aims to evaluate energy consumption patterns, efficiency improvement opportunities, and the potential for improvements in thermal processes to enhance sustainability. The study assesses the total electricity consumption and heat utilization in the dairy plant and explores strategies such as replacing inefficient motors, transitioning from diesel-fired boilers to wood or pellet, or electric alternatives, and implementing waste heat recovery systems. An energy audit is conducted to quantify energy savings and carbon emission reductions. Additionally, a cost-effectiveness analysis was also performed to find the payback period for proposed efficiency measures. The final energy consumption from electricity is 1511 MWh and diesel is 3016 MWh, respectively, in the base year, to 1930 MWh and 3854 MWh at the last analysis year in the standard scenario. Findings indicate that electrification and efficiency improvements can significantly reduce consumption costs and environmental impact. Switching diesel boiler to a wood boiler saves approximately NPR 4.74 million annually. The transition to electric boilers saves 466 MWh per year of fuel usage with a lower of 226 tons of carbon emissions. Similarly, the addition of highly efficient motors demonstrates encouraging progress in both economic feasibility and emissions. It decreases power consumption to 3 MWh per year per motor with 1.5 tons of emission reduction. The study concludes that adopting energy-efficient technologies in dairying can be involved in achieving sustainability and reduce reliance on fossil fuels.

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ABBREVIATIONS

APFC:	Automatic Power Factor Correction
BID:	Balaju Industrial District
CF:	Carbon Footprint
CIP:	Clean In Place
CO:	Carbon Monoxide
COP:	Coefficient of Performance
DDC:	Dairy Development Cooperation
FAO:	Food and Agriculture Organization
GDP:	Gross Domestic Product
GHG:	Greenhouse gas
HSD:	High Speed Diesel
IPCC:	Intergovernmental Panel on Climate Change
KMSS:	Kathmandu Milk Supply Scheme
LCA:	Life Cycle Assessment
LEAP:	Low Emission Analysis Platform
MoALD:	Ministry of Agriculture and Livestock Development
MoF:	Ministry of Finance
NPV:	Net Present Value
NARC:	National Agricultural Research Council
NDDB:	National Dairy Development Board :
NDCs:	Nationally Determined Contributions
NEA:	Nepal Electricity Authority
REES:	Institute for Resource Efficiency and Energy Strategy
SEC:	Specific Energy Consumption

TOD: Time of Day

UOME : Unidad de Planeación Minero Energética

VFD: Variable Frequency Drive

CHAPTER 1: INTRODUCTION

1.1 Background

Nepal dairy industries began with the initiation of the yak cheese plant with Food and Agriculture Organization support (Shingh, Kalwar, Poudel, Tiwari, & Jha, 2020). The dairy industries are considered a significant contributor to Nepal's agricultural economy, crucial to agriculture-based Gross Domestic Product (GDP), and provides livelihoods to a large portion of the population. The Kathmandu Milk Supply Scheme (KMSS), established in 2037 BS at Balaju under the Dairy Development Corporation that operates through a network of milk cooperatives, collection centers, chilling plants, and processing units that work together to ensure a steady supply of milk and milk-based food to metropolitan shoppers. The main products are pasteurized milk, butter, ghee, and flavored milk, with a plant capacity of 15000 liters per hour (Organization Profile).

Energy is an essential part of the milk industry. Milk purifying is largely based on thermal transfer, which requires thermal energy and consumes significant energy, primarily relying on fuels, which contribute to greenhouse gas emissions. The dairy industry utilizes various energy sources such as vapor, hot water, pressurized air, cold water, and electric current for its operations (Prasad, 2022). The activities that require warmth are sterilization and simmering. The supreme power-driven running in dairies is chilling and product cooling, blending segregation, mixing, transfer (via pumping), and packaging (Mladen, Sustersic, & Gordic, 2020).

In East Africa, a risk-neutral techno-economic feasibility was performed to evaluate renewable energy solutions for milk cooling in distant dairy agrarian communities. This method integrates technical assessments (energy consumption, process efficiency, and technology evaluation) and energy efficiency of implementing renewable-based cooling systems, demonstrating potential cost savings and sustainability benefit (Lukuyu, Blanchard, & Rowley, 2018). Similarly, dairy energy consumption has both environmental and economic implications. Environmentally, reliance on grid electricity and fossil fuels contributes to greenhouse gas emissions, requiring the industry to reduce its carbon footprint. Economically, rising energy costs drive the need for energy-efficient and renewable technologies to enhance sustainability and reduce financial burdens on dairy farmers (Shine , Upton, Sefeedpari, & Murphy, 2020).

Nepal's industrial sectors are diligently working to decrease their carbon balance to meet the Paris Agreement adopted in 2015. Nepal ensures that 15% of the total energy request is met through green energy sources by the year 2030 (IRENA, 2020). Many industries are moving toward low-carbon sources, such as biomass, electric boilers, and solar-powered production processes. The research paper by (Schreiber, Feil, & Haetinger, 2020) studied the problem related to technological advancements in dairy industries, which includes methods for energy consumption reduction and enhancing the efficiency of industrial processes. Power usage-efficient systems and creative solutions for electricity reduction are gaining attention for minimizing the environmental footprint of dairy production. Similarly, a study conducted on an Indian dairy processing plant focused on the extensive consumption of heat and electrical power in the industry. The research utilized thermal and exergoeconomic analysis to identify inefficiencies and proposed optimization strategies to improve energy utilization and reduce costs (Singh, Singh, Tyagi, & Pandey, 2019).

1.2 Problem Statement

The Kathmandu Milk Supply Scheme, operated under Dairy Development Cooperation, is a public enterprise owned in Nepal that consumes electricity, diesel-fired boilers, and other thermal energy sources for key operations such as milk chilling, pasteurization, homogenization, and packaging. However, energy inefficiencies in these processes lead to high running costs and increased ecological impact. Energy is the zone where considerable savings can be achieved immediately without a huge investment through basic maintenance practices, efficiency enhancement, and heat recovery systems (Shrestha, 2017).

Despite the growing focus on energy efficiency in industrial operations, there is limited research on techno-economic performance along with environmental impacts in KMSS. Additionally, rising fuel costs further exacerbate the financial burden on the dairy industry, making energy efficiency improvements a pressing need. This Research aims to address issues like energy consumption (both electrical and thermal in different stages), inefficiency identification, and assess the techno-economic feasibility of integration of renewable energy alternatives within the KMSS. Furthermore, the study will evaluate the environmental impacts associated with the current energy consumption practices, focusing on carbon pollution. The study seeks to fill this space by performing a techno-economic and environmental evaluation of KMSS, DDC, analyzing its energy use, mitigating saving opportunities, reducing costs, and minimizing environmental impact in Nepal's Dairy industry.

1.3 Objectives

1.3.1 Main Objective

The primary goal of this study is to evaluate the technological, economic, and environmental performances of the Dairy Industry.

1.3.2 Specific Objectives

The specific objectives of this research are:

1. Evaluating energy consumption in the dairy plant.
2. Determining the existing techno-economic performance analysis.
3. Analyzing cost-saving opportunities and carbon emissions under different scenarios.

1.4 Limitations

- The techno-economic assessment primarily focused on utilities such as boilers, refrigeration systems, and induction motors to identify energy-saving opportunities; however, it did not extend to evaluating process steps like pasteurization, cream separation, and homogenization.
- Practical testing of the electrical boiler could not be conducted due to its unavailability.

1.5 Report Outlines

The research consists of the following sections:

Chapter 1: Introduction: This section provides an overview of the Kathmandu Milk Supply Scheme, explaining the source of energy consumption in the milk industry, the problem statement, research objectives, and limitations of the research.

Chapter 2: Literature Review: This chapter covers published papers on energy consumption, techno-economic assessments, environmental impacts, and energy optimization strategies in the dairy industry.

Chapter 3: Methodology - This section outlines the procedures, calculation approaches, and analytical steps employed in the study.

Chapter 4: Results and Discussion: The explanation of the achieved outcomes on energy consumption patterns, inefficiencies, techno-economic feasibility, and environmental impact assessment with supporting pictures and values is shown in this section.

Chapter 5: Conclusion and Recommendations: This chapter provides an overview of the study's outcomes and outlines the necessary direction for future tasks.

CHAPTER 2: LITERATURE REVIEW

The papers were collected and thoughtful to acknowledge the amount of electrical, thermal energy, and fuel requirement for dairy processing like pasteurization, refrigeration, homogenization, and packaging (Janzekovic, Mursec, Vindis, & Cus, 2009). Traditional Energy sources like diesel-fired boilers and grid electricity are often inefficient and costly, leading to increased carbon emissions (Gerber, Vellinga, & Dietze, 2010). Several studies have inspected energy efficiency advances through techno-economic assessments and renewable energy inclusion, but particular research on Nepalese Dairy remains limited. This literature review dissects existing studies on consumption patterns, technological performances, and their impact on the surrounding environment in the dairy sector, focusing on gaps and the need for further study in the context of the Kathmandu Milk Supply Scheme, DDC.

2.1 Energy Consumption in Dairy Operations

The dairy industry consumes huge power for processing, producing, and depositing due to outmoded technology (Janzekovic, Mursec, Vindis, & Cus, 2009). In a dairy plant, energy directly refers to the utility's generation and consumption, such as steam, cooling, current, and water. Among them, water and Vapour serve as key heat transfer mediums (Pandya, 1998). The dairy industry consists of various segments, including raw milk receiving, processing, product manufacturing, cold storage, and distribution. Research suggests that approximately one-third of the total potential is consumed in milk processing while chilling alone book for 50-60% of the whole electricity usage, making it the most energy-intensive component (Arunachalam, 1982). Similarly, research has indicated sweltering energy consumption in dairy plants can account for approximately 60-75% of total energy use, while electrical power accounts for around 25-40%. For instance, a study on thermal energy consumption during milk processing reported total thermal energy usage ranging from 28.47 to 30.18 GJ, spotlighting thermal processes in dairy operations (Prasad, 2022). Furthermore, research on energy and milk production analysis in a dairy plant found that thermal (steam) energy expenditures were 315.87 kW, compared to 80.98 kW for electrical energy, further emphasizing the predominance of thermal energy consumption in such facilities (Taner, 2023).

Energy usage in dairy farming has been steadily increasing. Research on energy efficiency identified through energy audit in dairies indicates a requirement for adaptation of energy efficiency measures to lower expenses and minimize environmental footprint (Janzekovic, Mursec, Vindis, & Cus, 2009). In the industrial context, efficiency refers to maximizing output while minimizing energy consumption. Research analyzed in different countries demonstrated that the industrial sector holds substantial potential for boosting energy performance. Energy auditing serves as an opportunity for optimizing energy consumption and evaluation of practical implementation to improve energy effectiveness (Gonçalves, Rossini, Souza, & Beluco, 2018).

According to Energy Audit Guidelines for Industrial Sectors (WECS, 2017) energy audit is defined as a structured identification of energy transfer to identify energy saving opportunities through survey and analysis. Conducting an energy reading is the initial act in recognizing the moment to minimize energy costs and reduce emissions. It offers a clear insights into energy efficiency levels that plays a crucial role in the choices of strategies that would be adopted for reducing energy usage (Schleich & Fleiter, 2019). A study applied this audit approach in various types of manufacturing companies that showed about 20-25% energy efficiency potentials (de Lima, de Deus Ribeiro, & Perez, 2018). Similarly, this approach applied to a case study of a dairy in central Serbia revel 11-15% electricity savings and 20-23% thermal energy savings yearly that shows the potential for advance energy efficiency improvements in dairy industry through structured audits and targeted interventions (Mladen, Sustersic, & Gordic, 2020). Similarly, the document (Brush, Masanet, & Worrell, 2011) on enhancing energy efficiency and reducing costs in the dairy industry shows U.S dairy spent nearly dollar 1.5 billion spend on acquired fuels and electricity. Implementing the guidelines explores energy efficiency strategies and technologies with additional cost-saving opportunities. Research on environmental and economic assessment of dairy production conduct energy audit of nine small dairy systems in Spain providing direct energy consumption and GHG emission through Life Cycle Assessment (LCA) raw material to production facility approach that used finical indicators such as net present value (NPV), IRR used for feasibility of the identified improvement measure (Egas, Ponsá, Llenas, & Colón, 2021).

The research on energy consumption in a commercial dairy plant identifies high-energy consumption areas known as Critical Control Points, which enables dairy plant authorities to make improved energy efficiency decisions. Different calculations such as heat transfer, mass flow, and electrical consumption are used to determine utility requirements for steam, water, and electricity that resulting on declination in energy conservation efficiency, which shows the importance of advanced instrumentation for better optimization and management (Prabhakar, Srivastav, & Murari, 2015). Similarly, a Review on Energy Consumption on Dairy Farms finds that advanced machining, like pre-cooling milk, using variable-speed drives, and enhancing lighting systems, can enhance efficiency. Different models and techniques are developed to improve energy forecasting (Shine , Upton, Sefeedpari, & Murphy, 2020).

The high dependency on diesel-fired boilers for steam generation has been recognized as a key contributor to energy inefficiency. For instance, the Industrial Combustion Boilers report by IEA-ETSAP notes that diesel-fired boilers often operate at efficiencies lower than their potential, resulting in higher fuel consumption and increased costs (ETSAP, 2010). To address these challenges, research indicates that integrating heat recovery systems and solar thermal technologies can substantially reduce energy consumption in dairy processing facilities that as shown by a case study by the Renewable Thermal Collaborative. It demonstrated that implementing solar thermal technology, alongside smart steam traps and heat recovery systems, led to significant reductions in energy usage over 110,000 MMBtu of natural gas consumption each year and 7,000 metric tons of CO_2 emissions in a dairy processing plant (Renewable Thermal Collaborative, 2024). However, the adoption of such technologies in Nepal's dairy industry remains limited. An energy audit conducted at Sitaram Gokul Dairy in Nepal revealed opportunities for energy conservation by the implementation of heat recovery systems, yet these measures have not been widely implemented (Kedia, 2013). These findings underscore the need for further feasibility studies to assess the practicality and benefits of adopting energy-efficient technologies in Nepalese dairy processing facilities.

2.2 Techno-Economic Performance of the Milk Industry

The techno-economic analysis of dairy industries is essential for evaluating energy efficiency and cost-effectiveness. Studies have demonstrated that the adoption of various technological interventions in the Kathmandu Milk Supply Scheme using the Low Emission Analysis Platform (LEAP) framework examined seven scenarios, including a baseline case along with two economic growth scenarios paired with two corresponding technology intervention scenarios. The study finds that rising production will increase energy consumption along with higher production.

GHG emissions. Implementing advanced energy-efficient technologies like motors, boilers will save energy and reduce GHG emissions. Promoting investments in energy-efficient technologies is essential for sustainable development in Nepal's dairy industry (Joshi & Poudel, 2017). An additional study on evaluating the techno-economic performance and environmental impacts of dairy production analyzed the environmental effect of the liquid milk processing using LCA methodology that consists of four phases, focusing on atmospheric emissions measured in kilograms of CO_2 equivalents per kilogram of packaged milk. The life cycle costing method is used to evaluate net present value, payback time, and overall profit over a ten-year life cycle. The study focuses on optimizing heat transfer, which shows use of an electric-based system reduces emissions as compared to a fuel system where whereas fuel for heating reduces costs as compared to electricity (Slyke, Mirkouei, & McKellar, 2021).

Smart refrigeration in the dairy sector implements a new refrigeration strategy that places a real-time data measurement and analysis system that drives cost reduction. Manual maintenance moves toward a model where 70% of actions are self-executing, fostering efficient energy (Gradhoc World, 2024). Similarly, technological advancements enhanced efficiency and productivity in the dairy plant. Automation is making the operation faster and more efficient. Furthermore, advanced refrigeration technologies enabled the long life span of milk products, thereby minimizing waste (Choyal, 2019). Additionally, a study on the potential for lowering electrical energy in the Malaysian medium–sized enterprises introduced various energy-saving initiatives to enhance the sustainability of energy supply. A milk manufacturing factory in Malaysia revealed that the factory faced significant electricity costs, and a study aimed to achieve energy savings by optimizing electricity use, analyzing the factory's load profile and operations. Implementation of strategies such as lighting upgrades, local energy generation, and solar photovoltaic systems could result in yearly savings of RM 320,603.92, with a financial return under three years. The results showed effective electricity management can significantly reduce energy consumption in the dairy industry (Muhamad, Phing, & Arief, 2014).

Boilers are crucial equipment in the industrial sector and play a significant role in energy consumption by heat transfers from fuel combustion to water, producing hot water or vapor for production use, heating, or electricity production. They are classified into two types based on heat exchange: fire-tube boilers in which hot gases flow through tubes enclosed by water, and water-tube boilers. Water flows through tubes while hot gases circulate around them (Kerr & Blair, 2011). Consider high energy demand for industrial steam production, enhancing boiler efficiency through adopting best available technologies, and improving energy efficiency by 5% to 33% (UPME, REES, & TEP Energy, 2019) . The impact of the boiler's energy efficiency on the surroundings showed a reduction of fossil fuel consumption and CO_2 emissions through increased efficiency (Barma, Saidur, & Rahman, 2017). An overview of the different methods and modeling for boiler efficiency calculation finds different efficiency calculation methodologies that include analytical techniques, Mechanistic Models, and empirical approaches. Analytical methods assess boiler efficiency by using energy, mass, and exergy balances along with heat transfer equations (Mojica, García, & Silva-Rodríguez, 2021). A techno-economic study of boiler gas recovery from exhaust indicates that, high-stage steam replacement system of flue gas heat recovery in a power plant can achieve greater energy-saving results than that of a low-stage steam replacement strategy (Xu, et al., 2013). However, techno-economic studies specific to Nepalese dairy industries are scarce, necessitating an in-depth investigation into the feasibility of these technologies for KMSS, DDC.

2.3 Environmental Impact of Dairy Processing

Energy consumption, being a key factor influencing its carbon footprint, encompasses various stages in the dairy industry, including milk processing, pasteurization, and transportation. A report by Gerber defines the carbon footprint as the overall volume of greenhouse gas emissions linked to an outcome all over its supply chain, usage, final stage recovery, and waste management (Gerber, Vellinga, & Dietze, 2010). Similarly, a project on climate-smart dairy farming in Nepal aims to create climate climate-smart dairy model that reduces GHG emissions and promotes sustainability. Dairy farming in the context of Nepal contributes 37% of methane and 65% of nitrous oxide emissions. Through community-driven innovations, the utilization of organic manure and efficient waste recycling aims to control emissions and enhance productivity (Heifer International Nepal, 2022).

A report on environmental gas emissions from the milk sector aims to estimate the GHG production associated with milk manufacturing and processing, with the development of Life Cycle evaluation methodology to analyze and understand GHG emissions. The study examines the entire dairy supply chain, including production, processing, and transportation, which generate 2.4 kg of carbon dioxide equivalent emissions per kilogram of fat and protein corrected milk (FPCM). Data was analyzed through sensitivity analysis aimed at identifying low-emission development pathways (Gerber, Vellinga, & Dietze, 2010). Similarly, research on Brazil used the LCA approach accompanied by two variation analyses that assess how converting by-products into joint products impacts the reduction of the carbon footprint. The results ranked the products by environmental impact in descending order: cheese, butter, processed, yogurt, and milk. (Florindo, Rosa, Santos, & Renato, 2022).

Additionally, the research in dairy farms in Karnataka, India, provides a comprehensive analysis of GHG emissions, regarding the carbon footprint (CF) associated with production. It determines key factors influencing CF using life cycle analysis from feed preparation, digestive fermentation, waste management, transportation, and energy consumption. Key determinants of CF included FPCM yield per 100 kg weight, dry matter intake (DMI), and methane emissions from manure handling. This study identifies effective solutions for minimizing the environmental harm of India's smallholder dairy farming systems (Mech, et al., 2023).

The research study on the Sustainable Environmental management in milk production in India compares the emissions related to packaged milk. Information collected from dairy farms and processing units focusing on parameters such as milking, storing, packaging, feed agriculture, distribution, and transportation. Using the Umberto LCA+ tool with the Eco Invent v3.6 dataset, results showed that Punjab is more environmentally efficient than Rajasthan (Singh, et al., 2024). Additionally, the literature review on Life Cycle Assessment as analysis tool focus on environmental emissions associated with milk farming, which presents the cumulative carbon emission from milk production, considering the combined release from different activities associated with milk production. This analysis enhances the awareness of the environmental consequence of dairy farming and highlights the importance of adopting green practices to reduce global emission of milk production (Tamilselvan & Tyagi, 2024). Similarly, a study of options and costs for reducing GHG emissions from the U.S. dairy sector examines existing research and evaluates mitigation methods to reduce greenhouse gas emissions, addressing both direct and indirect emission sources. Cradle-to-gate environmental impact evaluation used to explore the supply chain, including farm practices, feed production, processing, transportation, and their associated emissions and costs (Lei, Cheng, McCarl , & Cessna, 2024). However, there is insufficient research on environmental assessments of Nepalese dairy processing, indicating a need for targeted studies on carbon emission reduction strategies for KMSS, DDC.

2.4 Research Gap

Less developed countries face challenges in the industrial field for developing an energy-efficient environment due to insufficient technological information and investment. Generally, the efforts to enhance energy efficiency encounter a series of obstacles related to technical constraints, but also from human-related factors (Smith, 1981) . While significant research exists on energy savings, techno-economic assessments, and environmental impacts in dairy industries, focused on Nepalese dairy industries is limited. This is due to the limitation of data on energy consumption and a lack of techno-economic feasibility studies along with environmental analysis.

This research addresses these gaps with a case study on the Kathmandu Milk Supply Scheme, aiming to perform a detailed analysis of energy usage, technological performance analysis, economic feasibility, and environmental impacts with a reduction in energy consumption.

CHAPTER 3: METHODOLOGY

The research was all about assessing the techno-economic performance and environmental impact of the KMSS. The research process was divided into three Phases. Firstly, a Literature review was conducted to uncover the research gap and understand the variables that help in analysing the techno-economic performances of the dairy industry along with carbon footprint. Afterward, an Energy audit was performed using different tools for analysing techno-economic and environmental performance. To validate the results obtained from the analysis, the findings were compared with the previous research. Figure 3.1 shows the methodology employed for this study.

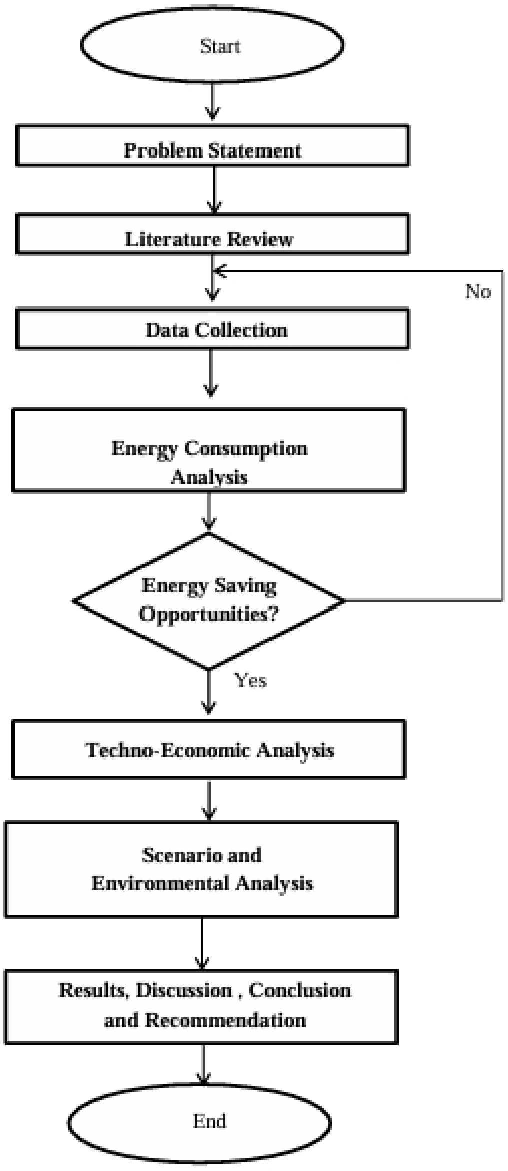


Figure 3. 1: Flowchart showing the steps for conducting the research

3.1 Data Collection

Primary and secondary data were gathered through various channels. Primary information obtained through the energy audit of KMSS. Secondary data taken from previous energy audit reports, annual electricity and diesel consumption reports, and raw milk received reports of KMSS. For the energy audit literature review conducted and based on the Energy Audit Guidelines for Industrial Sectors, the procedure was completed. According to research on minimization of energy consumption and environmental emissions in global dairy production facilities (Xu & Flapper, 2011) thermal energy makeup approximately 80% of total energy consumed and electricity contributing remaining 20% in dairy industries. Accordingly, the research focused on electric and thermal energy consumption in KMSS using energy audit tools like:

- Electrical Power and Energy Analyzer – 3 Phase
- Electrical Clamp-on Power Analyzer – Single phase
- Flue Gas Analyzer
- Infrared Thermometer
- Contact-Type thermometer
- Measuring Tape

3.2 Energy Consumption Analysis

Energy demand in industries can be categorized into electrical and thermal energy. Electric motors, the cooling process, cold storage, and lighting use electrical energy. In contrast, heat energy requirement is supplied by steam generation from the combustion of fuel and biomass in the boiler.

3.2.1 Electrical Energy Consumption

The main source of electrical energy is from Nepal Electricity Authority (NEA). The Balaju Industrial District (BID) provides a reliable power supply to KMSS that is fed through NEA through a 750-kVA distribution transformer installed in the dairy premises. A diesel generator, which uses high-speed Diesel (HSD) installed in the plant to ensure uninterrupted operations during NEA power failure. With the installation of Automatic Power Factor Correction (APFC), KMSS improved its power factor from 0.5 to 0.99 (Sapkota, Shiwakoti, Ghimire, & Lama, 2022). The KMSS operates numerous heavy machines, motors, and sensors, all of which require substantial power. Electrical energy is also used in the raw milk processing process, like homogenizers, cream separators, and filling. Electricity is used for the generation of compressed air, pumps and fans, lighting, and other essential running equipment of offices. Electrical energy consumption is measured with the following electrical parameters.

1 Data Logging: 24-hour data logging using a three-phase data logger, which provides information on power efficiency, overall load (kW and kVA), peak load, potential , current flow and frequency.

2 Load monitoring: power usage is measured using a power analyzer in all induction motors that capture data on kW, kVA, current, and power factor.

3 Diesel Generator: Energy generation rate was determined by calculating kilowatt-hours produced per liter of fuel consumed.

In dairy industries, electricity usage presents a significant opportunity for optimization and cost saving. Reducing electricity consumption mitigates potential airborne emissions and reduces the carbon footprint of milk production. The amount of savings in electrical energy consumption depends on the electricity tariff as well as energy-efficient technologies, which result in substantial financial benefits (Mohsenimanesh, et al., 2021).

The energy tariff is divided into three time zones, termed as T1, T2, and T3 (Peak time, Normal time, and Off-Peak time). Electricity tariff as applicable to the unit as per the NEA tariff structure given in the table below:

Table 3.1: Electricity Tariff Structure: NEA

S.N	Period	NRs./KWh
1.	Peak Time (17:00 to 23:00)	10.50
2.	Normal Time (5:00 to 17:00)	8.55
3.	Off Peak Time (23:00 to 5:00)	5.40
Electrical demand charge per kVA NRs.		@250

The calculation of electrical energy consumption typically uses the basic formula for energy that depends on the power rating of the equipment and the times for which it operates.

Using $E = P * t$

Where,

E: Electrical energy consumed (in kilowatt-hours, kWh or joules)
P: Power rating of the equipment (in kilowatts, kW or watts, W)
T: Time for which the equipment operates (in hours or seconds)

3.2.2 Thermal Energy Consumption

The majority of fuel usage in the dairy plant is used for heat generation and steam production via the boiler system (Prasad, 2022). Steam is used for various processes involved in the operation of pasteurization of milk and others. The biggest share of the fuel is used for direct thermal process and steam production through the boiler plant (Masanet, Brush, & Worrell, 2014).

KMSS consists of two steam boilers for the generation of steam used in various processes like pasteurization of milk, ghee making, and carrying out cleaning in place (CIP) in the milk-processing unit. Presently, only one is in operation. Similarly, in the fresh milk section, a stem is used for curd making, in the incubation room to maintain the temperature of 45 degrees, for sterilization of flavored milk, and to carry out CIP. General specifications of the Steam boiler installed in the plant are given below:

Table 3.2: General Specification of Steam Boiler

Description	**Boiler 1**	**Boiler 2**
Make	Toma, Denmark	Balkrishna Boilers Pvt. Ltd
Model	15669	SJ-20
Type of Boiler	Three-pass, Smoke tube	Three-pass, Smoke tube
Type of Fuel used	HSD	HSD
Rated Capacity	2.0 T	2.0 T
Rated Pressure	10	10.54
Operating Pressure	5-7 kg/cm	5-7 kg/cm

The following parameters are used to measure thermal energy consumption.

- A flue gas analyzer is used to measure flue gas, which maintains ideal flame temperature and monitors carbon monoxide (CO), oxygen, and smoke.
- An Infrared Thermometer is used to measure the exterior temperature of the boiler surface and steam flow lines.
- Incoming and outlet temperatures were measured for further analysis**.**

3.2.3 Specific Energy Consumption

Specific Energy Consumption (SEC), also known as energy usage intensity, is widely used as a benchmark for measuring energy intensity and evaluating the energy efficiency of industrial plants across various sectors (Ramirez, Patel, & Blok, 2006). It is defined as the energy consumption divided by milk products production, which provides energy uses for cooling, electricity, steam, and fuel consumption. SEC is a calculation of the overall production through energy use of a plant adjusted by final liquid-milk production, which is calculated as

$$SEC = \frac{E}{P}$$

Where E is the actual power usage and P is the production quantity

3.3 Techno-Economic Performance Analysis

The techno-economic performance analysis evaluates technical efficiency and economic feasibility to identify optimal solutions that enhance energy efficiency and reduce costs.

3.3.1 Technological Performance Analysis

Efficient energy utilization is crucial for optimizing industrial operations, particularly in energy-intensive sectors like dairy processing. Among the key technological components in dairy industries, refrigeration systems, boilers, and induction motors are vital in maintaining operational efficiency, product quality, and overall sustainability. This study assesses the technological performance within these systems by examining their efficiency, energy used, and potential for energy savings.

A. Refrigeration system

The major electrical energy consumption is in the refrigeration system for the cooling process, for final product storage in a cold store. The refrigeration system for the main process plant consists of three chiller compressors, an ice bank, Fan Coil Units (FCUs), a chilled water circuit, and a condenser water circuit. A heavy-duty, single-stage reciprocating ammonia (R717) compressor having a capacity of 322353 kcal/h with a Variable Frequency Drive (VFD) is used in KMSS. One SMC112L-type compressor has developed cracks in the manifold, leading to the blockage of six valves, and another one has been in operation for approximately 40 years and has undergone multiple overhauls. The aims of the ice bank is to provide ample storage of ice to meet the maximum load demand in the early hours of the morning for milk processing, cooling of raw milk, and chilling of milk in the storage tank. The ice bank temperature is regulated below (-10 to 2 ^{o}C). (Prabhakar, Srivastav, & Murari, 2015)

Performance Assessment of Refrigeration System

The coefficient of performance (COP) acts as a key parameters of the cooling system's performance. The theoretical COP relies on two fundamental system temperatures: the Temperature of the evaporator, T_e and condenser, T_c.

$$COP = \frac{Te}{Tc - Te}$$

COP normally used in industry is calculated as follows:

$$COP = \frac{Cooling\ Effect\ (KW)}{Power\ Input\ to\ compressor\ (KW)}$$

Similarly, other key indicators are

- Refrigerant leakage and environmental impact
- Heat recovery potential

B. Steam Boiler

The boiler refers to a closed system vessel that generates high-pressure steam through water from the burning of fuel. According to the Bureau of Energy Efficiency, boiler thermal efficiency refers to the heat supplied that is effectively converted into steam (Purseth, Dansena, & Desai, 2021). Carbon dioxide emissions arise from energy consumption in boilers, which increase the carbon footprint in the dairy industry (Chauhan, Pinto, Patel, & Bhadania).

Most standards, including IS 8753 and BS 845, are developed for the evaluation of boiler performance with two methods of testing the efficiency of boilers. The research on performance analysis and efficiency improvement of boiler (Purseth, Dansena, & Desai, 2021) used two approaches for boiler performance test.

The direct method or Input-output method is a simple calculation method that is calculated as:

$$Boiler\ Efficiency = \frac{Heat\ Output}{Heat\ Input} \times 100$$

$$Boiler\ Efficiency = \frac{Q \times (hg - hf)}{(q \times GCV)} \times 100$$

Input data are as follows:

- Steam Pressure (kg/cm^2)
- Steam Temperature (^oC)
- Steam discharge (Q) (kg/hr.)
- Fuel Quantity (q) (kg/hr.)
- Inlet water temperature (^oC)
- Calorific value of fuel (kcal/kg)

Where,

h_g - Enthalpy of saturated steam in Kcal/Kg of steam

h_f – Enthalpy of feed water in Kcal/Kg of water

Indirect procedure or Heat loss method: It is used to find boiler efficiency through the calculation of all individual losses.

$$Efficiency\ of\ boiler = 100 - (Total\ \%\ of\ losses).$$

Various losses of the boiler system, according to (Rana & Zala, 2019) are given below.

1. Flue gas losses

   $Loss = \frac{mf*cp(Tf-Ta)}{Gcv\ of\ fuel} \times 100$ Where,

   Loss = % heat loss due to flue gas, M_f = mass flow rate of flue, Cp = Specific heat of flue gas (kcal/kg k), T_f = Flue gas temperature (^oC), Ta = Ambient temperature (^oC)

2. Incomplete combustion of fuel losses

$$loss\% = \frac{\%CO * C}{\%CO + \%CO2} * \frac{5744}{GCV\ of\ fuel} \times 100$$

3. Loss due to the humidity present in the fuel

$$loss = \frac{9H2 * [584 + CP(Tf - Ta)}{GCV\ of\ fuel} \times 100$$

4. Heat loss due to incomplete combustion of fuel in the Bottom Ash

$$loss = \frac{Total\ ash\ collected\ \ kg\ of\ fuel\ burnt * GCV\ of\ bottom\ ash * 100}{GCV\ of\ fuel}$$

5. Heat transfer losses due to radiation, convective, Blowdown, and countless losses

C. Induction Motors

In the Dairy plant, the major high-capacity motors include ammonia compressors with a capacity of 110 kW, which account for significant energy consumption. Therefore, this motor was selected for a detailed performance analysis to evaluate its energy efficiency and potential optimization through real-time power consumption.

3.3.2 Economical Analysis

An economic assessment of this study was performed to evaluate the financial soundness and cost-efficiency of implementing sustainable practices. The assessment examines the return time and cumulative savings of each scenario.

3.4 Description of Scenarios

Scenario analysis evaluates and compares the potential outcomes of different strategies under varying conditions. In the dairy industry, it helps in identifying opportunities to enhance energy effectiveness, minimize working costs, and reduce environmental effects. This study also analyzed the current energy consumption patterns with alternative strategies that prioritize energy efficiency, renewable energy integration, and low-carbon technologies.

3.4.1 Business as Usual (BAU) Scenario

The current scenario serves as a baseline in KMSS to assess the potential impact of implementing renewable energy solutions and energy-efficient practices. KMSS operates under current practices without any substantial intervention of new technologies. It heavily depends on grid electricity and diesel generators, leading to high-energy consumption, inefficiencies in processing, and elevated costs, along with a contribution to high levels of greenhouse gas emissions. Similarly, it uses energy-intensive machinery for different processes without optimization. There is a significant level of energy loss, especially in refrigeration units, due to poor insulation, which contributes to inefficiencies. This scenario provides a clear benchmark for comparing the potential benefits of shifting to a more sustainable and energy-efficient approach, particularly through the adaptation of renewable energy systems. In this case, Energy is assumed to expand at an annual growth rate of 8.52% across the analysis (Joshi & Poudel, 2017).

3.4.2. Efficient Technology Scenario

Efficient Technology Scenario evaluates the potential improvements in energy efficiency through the adoption of modern technologies. This scenario focuses on integrating energy-saving equipment such as highly efficient motors, variable frequency drives for pumps, Replacement of ventilation fans with high efficiency models, and higher efficiency lights. In KMSS, inefficient equipment, motors that have gone through multiple rewinding cycles, and declining efficiency due to losses in the winding insulation result in higher energy consumption and increased operational costs. They can optimize power usage by adjusting speed and torque, reducing unnecessary energy consumption (Ciolkosz, 2023). ABB Drives, in its document, states that VFD pump control helps automate CIP systems, leading to less water and fewer cleaning materials. High-speed bottling lines rely on synchronized conveyor systems. Additionally, in CIP processes, centrifugal wash pumps circulate cleaning solution through pipelines with their speed regulation by VFD (ABB Drives , 2019). From an economic perspective, this scenario evaluates the investment, payback period, and life cycle costs of energy-efficient technologies. It also examines the environmental benefits, which reduce energy use and lower GHG emissions.

3.4.3 Transition of Boiler Fuel scenario

Transition of diesel-based boilers to biomass-based or electric boilers in dairy processing, aiming for energy efficiency, cost savings, and environmental benefits. Presently diesel-based boiler is used in KMSS for generating steam for the thermal process.

3.4.4 Solar Thermal Scenario

Solar heating scenario evaluates the potential of renewable source to replace fuel-based thermal energy sources in KMSS. The research on Integration and modelling of Solar Thermal system to Dairy operation (Tannous, Masera, Tassou, & Stojceska, 2023) demonstrated significant potential for reduction in fossil fuel and greenhouse gas emissions by the use of solar thermal energy. Various solar thermal technologies like Flat plate collectors (temperature range 60-80 °C), Evacuated tube collectors (80-120°C**),** Concentrate solar thermal technologies like parabolic trough collectors (150–400°C), Linear Fresnel Reflectors (LFR) serve as a cost-effective. A considerable amount of energy is used for warming water that is needed for pasteurization and CIP that met through the use of steam from the steam boiler. Currently, KMSS is relying on diesel or electricity.

3.5 Environmental Impacts Analysis

The Kathmandu Milk Supply Scheme consumes significant amounts of energy that primarily relies on grid electricity and diesel fuel. This assessment focuses on carbon emissions and the potential for renewable energy integration to reduce environmental footprints. The estimation of GHG emissions follows methods aligned with the direction outlined in the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines for National GHG inventories. The general methods for calculating GHG emissions are given below:

$$Emission = \sum_{i=1}^{n} (Ef \times Ac)$$

Where,

EF = emission factor, Ac = activity

Here, EF represents the quantity of GHG emitted for each unit of energy consumption. It refers to the amount of carbon dioxide emitted per unit of fuel burned. Ac represents the activity level measured in the units that align with the emission factor (Shrestha, 2017).

We assumed 0.484 kg of CO_2 per Kilowatt-hour emitted from the NEA grid mix energy (Company, 2021). Similarly, the carbon emission factor for diesel is 2.68 kg CO_2 per liter (Environment, 2015).

CHAPTER 4: RESULTS AND DISCUSSION

This chapter explains the results based on the analysis of the data taken from KMSS.

4.1 Energy Performance Assessment

The study of an energy audit's main results in milk processing focuses on energy diagnosis analysis in electric and thermal energy during milk production (Gonçalves, Rossini, Souza, & Beluco, 2018). Figures show 67% of energy is consumed by thermal sources and the remaining through electrical sources (Utility and Production) in KMSS.

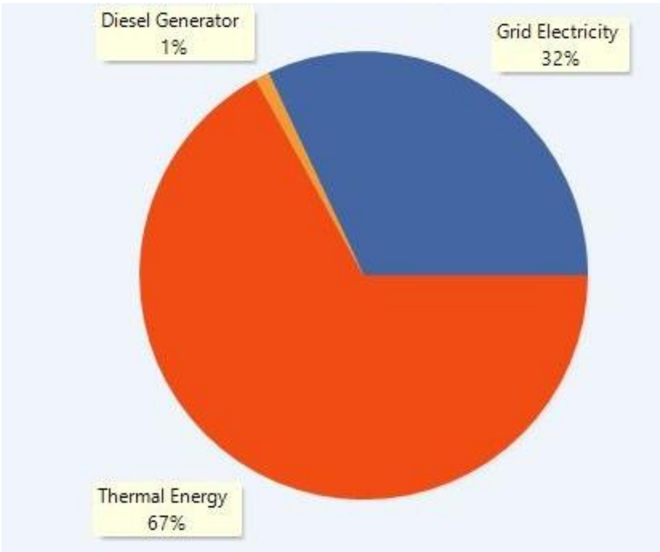


Figure 4.1: Total Energy Consumption

The total cost of grid electricity amounts to NPR 13,851,383, which represents the expenditure on externally supplied power for various dairy processing steps and accounts for 20% of total energy consumption costs. Additionally, DG stands for 5171250, which means 8% of the total costs. Furthermore, the total cost of thermal energy generated from the boiler is significantly higher, reaching NPR 45,946,350, indicating the substantial fuel requirements for heating processes. The figures show the overall cost of energy consumption.

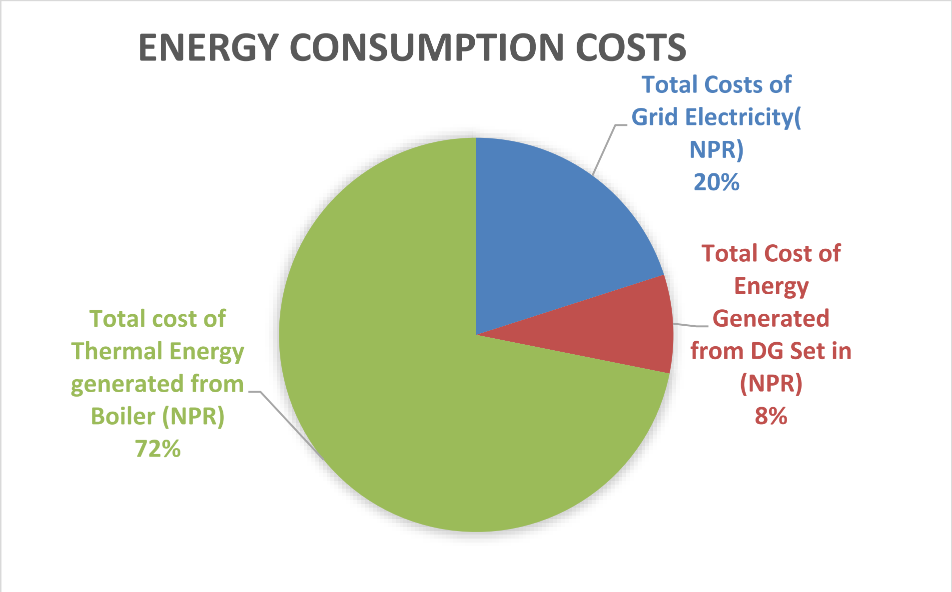


Figure 4.2: Energy consumption costs

The above figure shows that thermal energy from boilers accounts for the largest share. However, grid energy remains the primary source of energy it accounting for a smaller share in KMSS. The use of alternative energy sources and the implementation of energy-efficient technologies could significantly reduce overall costs.

4.1.1 Electrical Energy Performance Assessment

The current electrical energy consumption as per the TOD pattern of NEA Electricity is presented in Figure 4.3.

The various tariffs provide an opportunity to maximize consumption during the lowest billing periods. The analysis for the year 2080/81 reveals the following distribution of energy consumption. The corresponding dataset is presented in Appendix 1.

- At a rate of 10.50/kWh, 26.6 % of energy consumption occurs
- At a rate of 8.55 /kWh, 55.6 % of energy consumption occurs
- At a rate of 5.40/kWh, 17.8% of energy consumption occurs

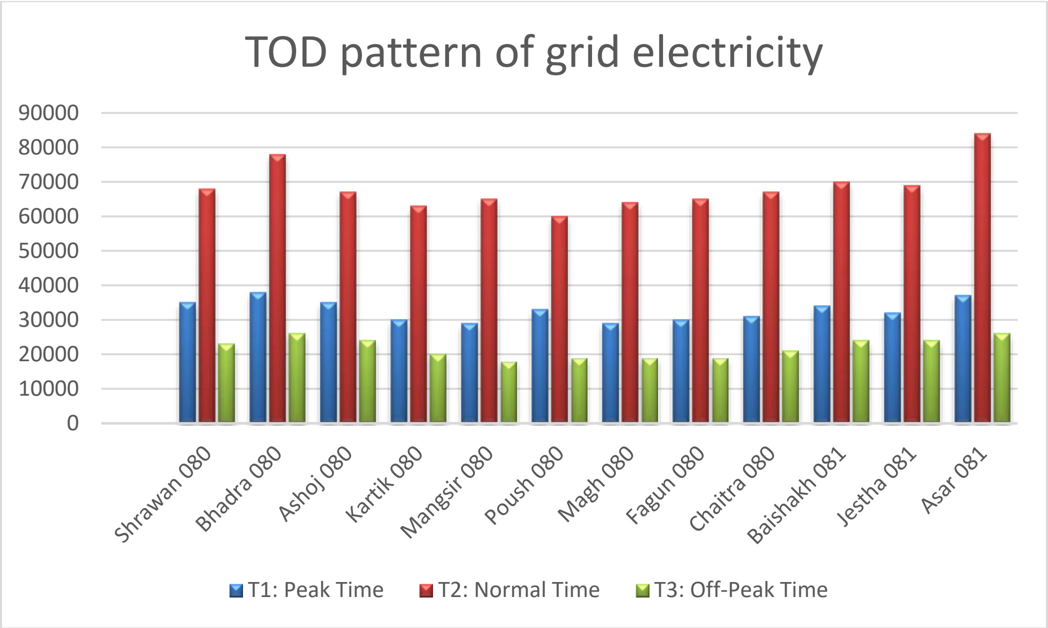


Figure 4.3: Grid electricity consumption in three time zones

Several operations can be scheduled in the dairy industry to utilize the low tariff period (11 PM to 5 AM) to optimize energy costs. The option could include:

- Water Pumping and Storage
- Milk Chilling and Refrigeration
- Ice Bank Storage
- CIP system operation

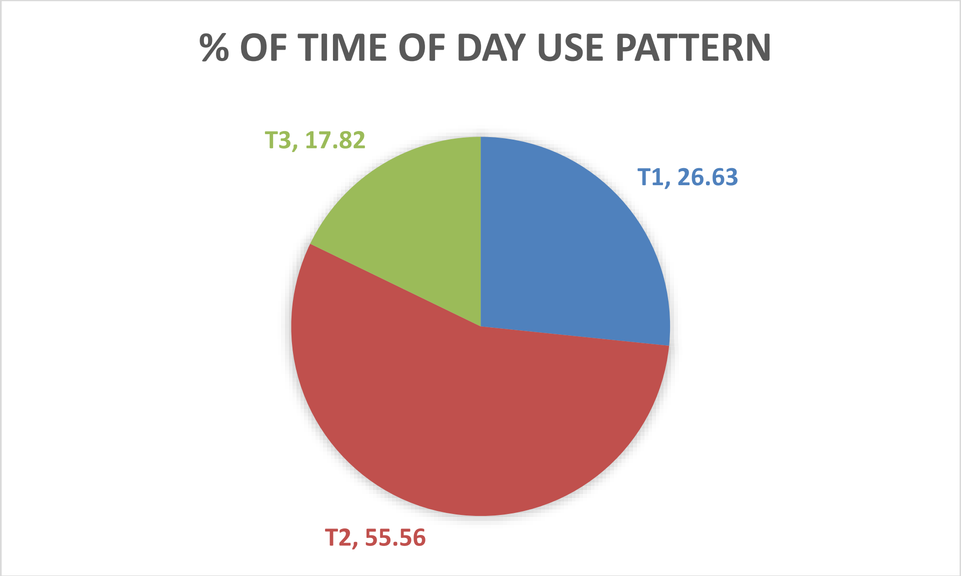


Figure 4.4: Electricity Percentage share in different time zones

The main impact of the time-of-day feature is that it impacts the weighted average energy price of electricity. If the lower tariff periods are not utilized effectively, the weighted average energy price tends to increase. The current weighted average energy price for the 12 months is as follows.

Table 4.1: Weighted average cost of electricity

Electrical Energy	
From NEA Grid in kWh	1476000
Total Costs of Grid Electricity in NPR:	13851383
Cost of grid electricity per kWh in NP	9.4
Aggregate Energy Consumption (NEA+DG) in KWh	1510475
Total Cost of Electrical Energy Consumption	19436333
Weighted average cost of Electrical Energy, NPR/kWh	12.9

The Recorded Demand is the value measured by the TOD meter that NEA is using to calculate the Demand Charge that is part of the electricity bill. This data represents the maximum power that has been demanded by the plant during the month, even for a few seconds. This value is generally reached when the plant is working at its full capacity and all the machines are in operation. The corresponding dataset is presented in appendix 1.

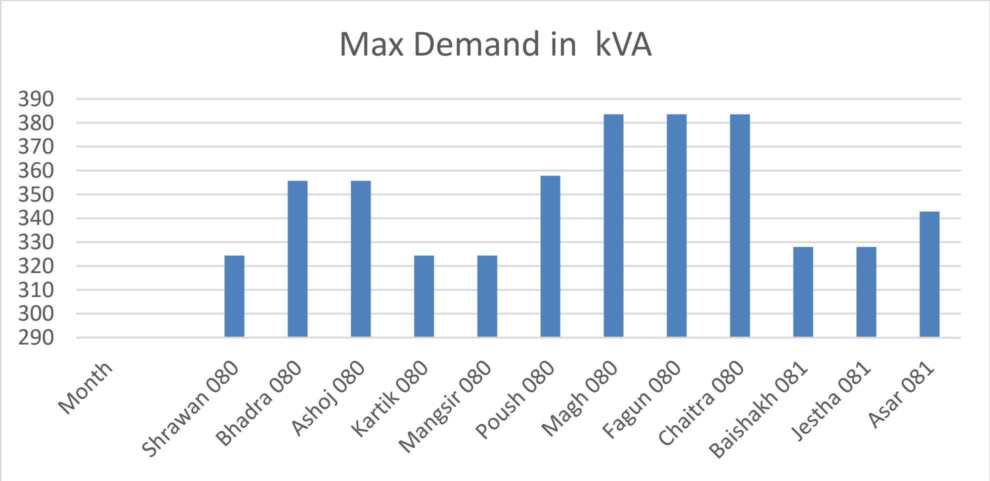


Figure 4.5: Recorded Demand found in NEA Electricity Bills

The approved demand of the plant is 750 kVA, and the extreme billing demand rate is Rs. 250. As per the recorded data analysis, the power factor varied from 0.76 to 0.96, from 62.53 to 243.25 kVA loading. The maximum demand from the past energy bill was 383.6 kVA during the months of Magh, Fagun, and Chaitra.

Similarly, Automatic Power Factor Correction (APFC) is installed at the service entrance, where the power factor is attuned by adequate amounts of capacitance. The following summary table presents the measured three-phase electrical parameters at peak load which is presented in appendix 4.

Table 4.2: Summary of measured three-phase parameters

S.N	Measured Parameters	Value
1	Voltage (V)	244.1
2	Current (A)	251.2
3	Apparent Power (KVA)	243.25
4	Active Power (KW)	233.37
5	Power Factor (Cos Φ)	0.96

Electrical Parameters during Monitoring

The electrical parameters observed during the monitoring period namely active power (kW), apparent power (kVA), and power factor (PF) are presented graphically in figures 4.6, 4.7, and 4.8 respectively. These figures illustrate the variations in load at the main incomers over monitoring duration. The corresponding dataset is presented in the appendix 4.

- **Active Power (kW) Variation**

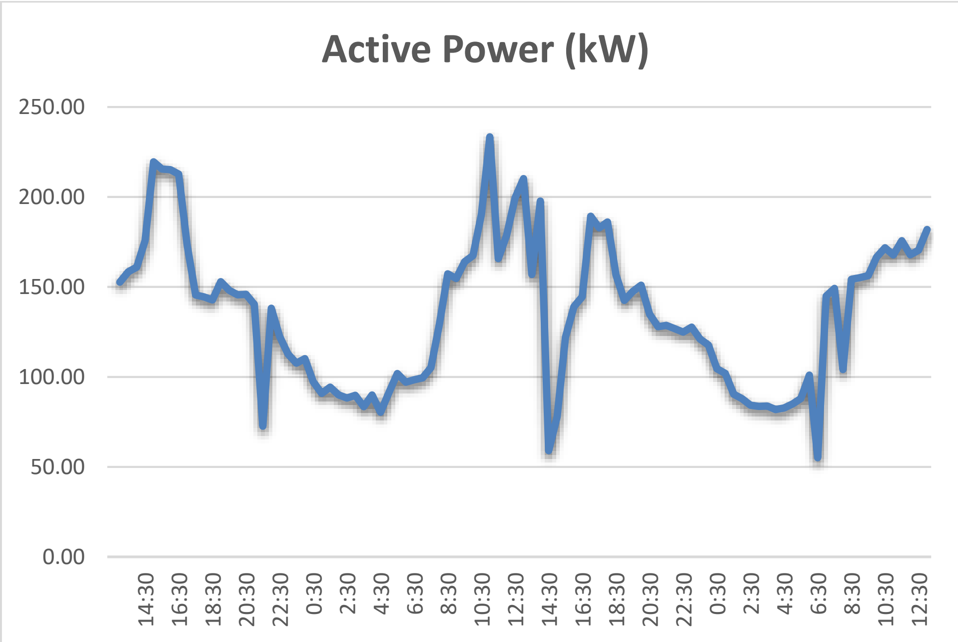


Figure 4.6: Graphical representation of kW load of main incomer

- **Apparent Power (kVA) Variation**

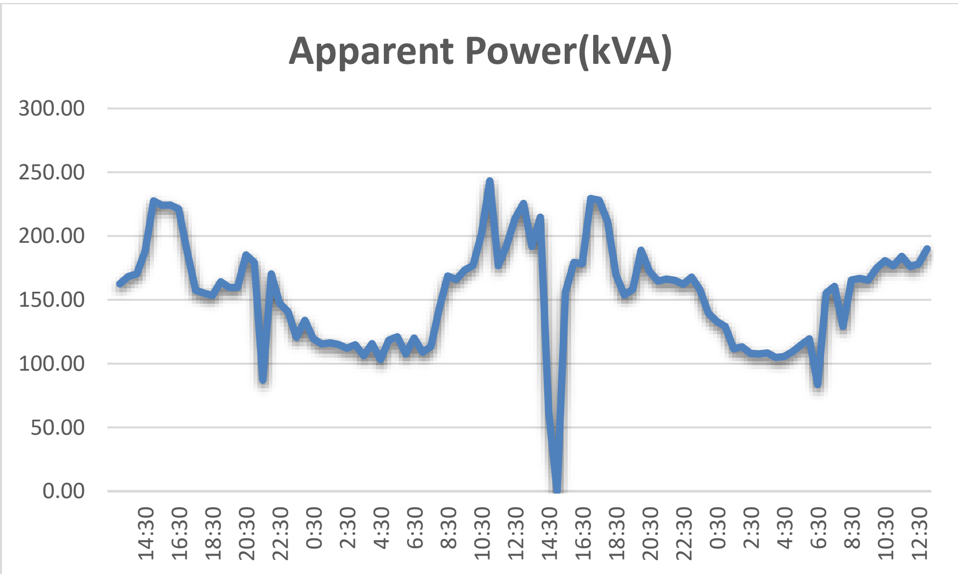


Figure 4.7: Graphical representation of kVA load of main incomer

- **Power Factor Variation**

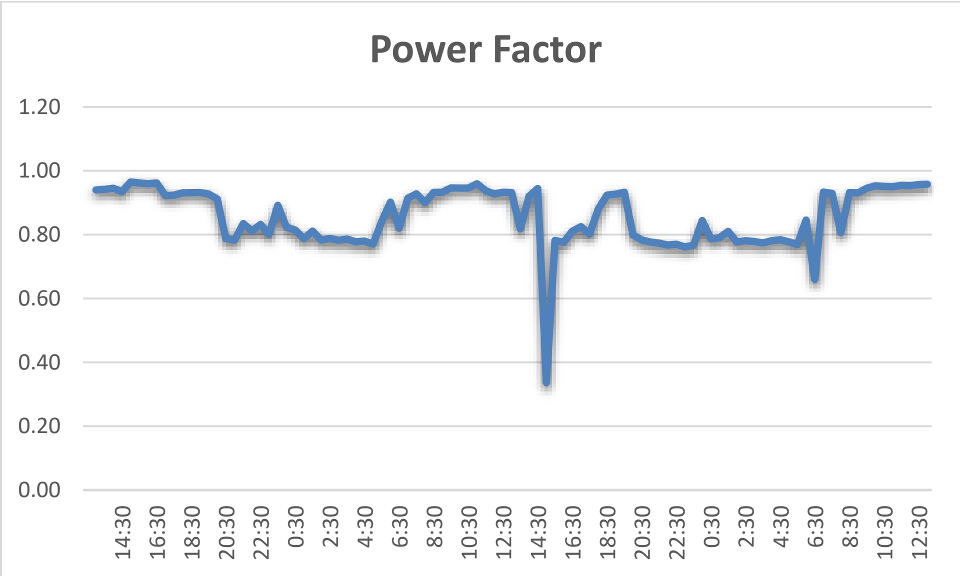


Figure 4.8: Graphical representation of PF variation of main incomer

4.1.2. Thermal Energy Performance Assessment

The primary source of thermal energy is diesel based boiler. During our study, we carried out the Performances of the Balkrishna Boiler that influence thermal energy consumption. Boiler efficiency is a key determinant, as a more efficient boiler reduces fuel consumption and operational costs. The total diesel consumption of the fiscal year 2080/81 was found to be 306309 liters. The boiler's overall thermal was found to be 80.47%, which shows opportunities to enhance efficiency. Implementing energy efficiency measures like Waste heat recovery systems, improved boiler efficiency, and optimized heating processes can significantly reduce energy costs and carbon emissions. Integrating renewable energy sources further enhances sustainability by minimizing reliance on fuels. Total consumption of diesel to produce steam is shown in the figure.

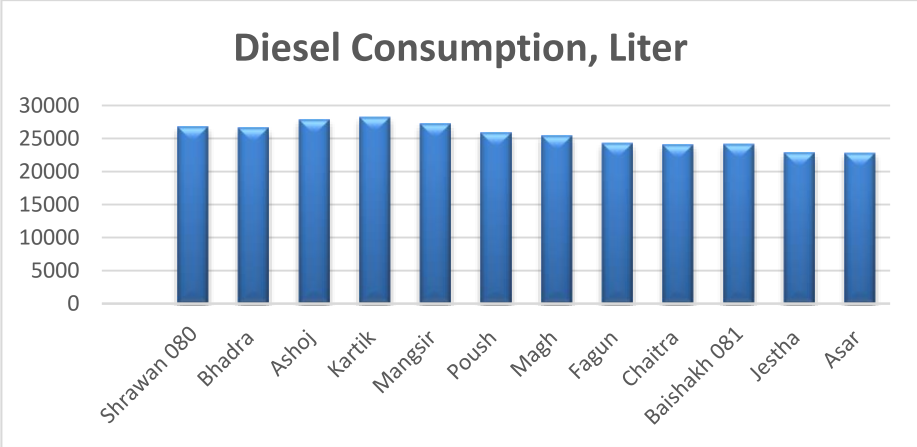


Figure 4.9: Diesel consumption of the year 80/81

4.1.3 Specific Energy Performance Assessment

Total electricity and diesel consumption by the plant for raw milk processing to form products was 74.75 kWh per 1000 liters of raw milk and 149.24 kWh per 1000 liters of raw milk, which is shown in the below table.

Table 4.3: Specific Energy Consumption

Sources	Unit	Value
Total electricity Consumption	kWh	1510475
Total Diesel Consumption	Liter	306309
	kWh	3015905.54
Total Milk Processed	kL	20207.25
Specific electrical energy consumption per 1000 liters of raw milk processed. (1KWh=860kCal, 3.6 MJ)	kWh/kL	74.75
	MJ/kL	269.1
Specific diesel consumption per 1000 liters of raw milk processed @density 0.83 kg/lit @10200 kcal/kg diesel	lit/KL	15.16
	kWh/KL	149.24
	MJ/kL	646.9

4.2 Techno-Economic Assessment

The existing techno-economic analysis addresses the current performance of KMSS based on the findings from energy audit, consumption analysis, and Cost evaluation.

4.2.1 Refrigeration System

The coefficient of performance of the refrigeration system was found to be 4.05, which means the system has better efficiency and can remove more heat using less energy. Detailed calculation is shown in the Appendix. If the system consumes 1 kWh of electricity, it will produce 4.05 kWh of cooling effect. The temperature of the superheated state was found to be 110 °C, which shows opportunity for energy optimization through the Installation of a desuperheater that produces hot water at 65 °C for process needs (CIP, Crate washing). Similarly, it reduces the cooling load in the condenser and reduces the consumption power of the compressor by around 5 %. Superheated devices extract excess heat from Refrigerant or steam and transfer it to water, which improves refrigeration system efficiency by lowering compressor discharge temperatures.

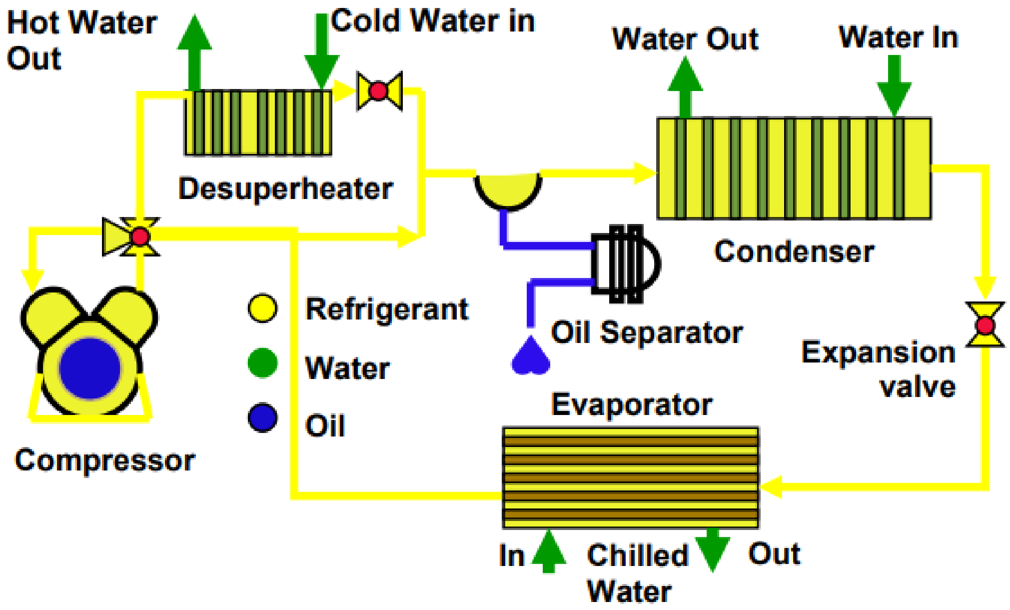


Figure 4.10: Illustrative layout for de-super heater installation

Source: Energy audit report of KMSS.

The cost-benefit analysis of the system, which is given below, showed the annual cost saving of fuel at the present price is nearly 1.5 crores with a simple payback period of 2.5 months.

Table 4.4: De SuperHeater Cost Analysis

Description	Value
Compressor discharge temperature in ^{0}C	110
Condensing Temperature in ^{o}C	40
Compressor Power Consumption in KW	92.5
Recoverable heat per kW (kCal/hr per kW)	1525
Total heat recovered in kcal per day, assuming 20 hours of operation and 50 % heat recovery effectiveness.	1410625
Equivalent fuel savings per day in lit considering @10,200 kcal/kg of HSD and 80.47 % boiler efficiency: 1410625/(10200*0.83*0.8047)	207
Hot water generated in liters over 20 hours working per day (from 25 ^{0}C to 65 ^{o} C) ((1410625*20)/(1*40))*0.5	≈36000 liters/day
Annual fuel oil savings @ 365-day working, in lit (207*365)	75577
Annual cost savings @ NPR.162 per liter of HSD	12243545
Estimated cost of implementation in NPR for the de-superheated piping and storage system	2500000
Simple payback period (Months)	2.5

During the study, the atmospheric condenser was found to scale that resulting in poor cooling of the refrigerant inside the condenser. The temperature of the refrigerant after condensation is found at 40 ^{o}C. The expected temperature range after condensation is 30-32^{o} °C, which indicates that there is scope for a reduction of temperature by at least 8 ^{o}C by regular cleaning of the atmospheric condenser.

Table 4.5: Cleaning of Condenser Cost Analysis

Description	Values
Measured the KW load of the Compressor	92.5
Annual Energy consumption (kWh/year)	810300
Energy Saving due to regular cleaning of the condenser by 4 % in kWh (810300 * 0.04)	32412
Annual Cost Saving in NPR, @NPR 9.4 /kWh	304672.8

Similarly insulation of the pipelines of the refrigeration system avoids losses.

Table 4.6: Energy Efficiency Options in Refrigeration System

S.N	Energy Efficiency Option	Annual Saving			Investment (NPR)	Payback Period (Months)
		Electrical Energy kWh	Thermal Energy (Lit per annum)	Cost (NPR)		
1	Installation of De-superheater at ammonia Compressor discharge		75577	12243545	2500000	2.5 ≈3
2	Regular cleaning of the atmospheric condenser to reduce the condensing temperature	32412		304673	Nominal	
3	Insulation of Refrigeration pipelines				Nominal	

The use of condensate returns for heating the feed water of the boiler would lower the consumption of energy by boiler by 8% as found in the study done on Lithuanian dairy plant (Makaliunas, 1998). Similarly, the systems designed for process cooling, final product cooling, and pipeline insulation were evaluated, showing potential to lower electricity consumption by 3% and 5 %, respectively. In both cases, the calculated pay-back period is less than one year (Mladen, Sustersic, & Gordic, 2020). Installation of de super heaters in the dairy industry saves 186624 Rs/month (Mane, 2013).

4.2.2 Steam Boiler System

The efficiency of the Balkrishna boiler was found to be 80.47%. Required data and calculations are taken from Appendix.. Presently, there is no monitoring system to assess the combustion efficiency of the boiler. Observation of flue gas parameters shows a high level of excess air that highly affects the efficiency of the Boiler. The main reason for low efficiency is the high excess air level indicated by high oxygen content (14.10%) in the flue gases. Proper monitoring of oxygen percentage increases the efficiency of the boiler. Installation of an oxygen analyzer provides real-time O_2 reading for combustion optimization. The key observation and associated cost optimization calculation from data assuming O_2 and CO_2 for complete combustion, ambient temperature 22.30 degrees, and consistent boiler load are shown in Table 4.5**.** The below adjustment shows a reduction of 65.24% in excess air. The cost optimization of the excess air control system shows an annual saving of around 12 thousand liters of fuel with a 15-month payback period.

The relationship between excess air and boiler efficiency is influenced by oxygen levels and stack temperatures. For optimal combustion, fuel oil systems typically operate at 15%. A general rule suggests that every 100% increase in excess air leads to a 5% drop in boiler efficiency. Conversely, reducing excess air by 15% can improve efficiency by approximately 1% (Bhatia, 2022).

Table 4.7: Combustion Cost Optimization

Particulars	**Unit**	**Present Scenario**	**After Adjustment**
O_2	%	14.10	12
Flue gases Temperature	oC	177.30	177.30
Ambient Temperature	oC	22.30	22.30
Excess Air Measured	%	204.35	133.33
Boiler Efficiency	%	80.47	84.38
Percentage Fuel Saving	%	3.91	
Annual fuel consumption	Lit	306309	
Annual fuel saving	Lit	11977	
Annual Cost Saving	NPR	1940222.4	
Estimated Investment	NPR	1600000	
Simple Payback Period	Months	15	

Similarly, another energy-saving opportunity is a waste heat recovery system, which is not installed in the plant. The process of capturing and reusing the heat generated through different processes is waste heat recovery. This heat can be utilized for preheating of boiler feed water that lessens fuel consumption and lowers greenhouse gas emissions. The exhaust gases are at high temperature, around 150 to 250 ^{0}C. Hence, by retrofitting the economizer that exact heat from flue gases can preheat the boiler feed water. In this case, we assumed continuous availability of heat energy.

The cost optimization of the adding a waste heat recovery system showed an annual saving of around 1 lakh liters of fuel with a 5-year simple payback period.

Table 4.8: Waste Heat Recovery Cost Optimization

Description	Unit	Value
A/F ratio		14
Excess air	%	204.35
Boiler efficiency	%	80.47
Fuel consumption	lit/month	25525
	lit/Hr	35.45
Mass of fuel rate @ density 0.83 kg/lit	kg/hr	29.42
Mass of air rate	kg/hr	535.5
GCV of fuel	kcal/kg	10200
Specific heat of air (Cp)	KJ/kg ^{o}C	1.005
Specific heat of water (Cp)	KJ/kg ^{o}C	4.18
Flue gas temperature	oC	177.30
Ambient Temperature	oC	22.30
waste heat recovered from flue gas(Q)	KJ/hr	80192.74
Mass of fuel saved	kg/hr	9.706
	kg/month	6988.5
	lit/month	8419.8
Annual fuel saving	Lit/year	101037.6 (around 1 lakh)
Annual cost saving	NRP	16368091.2 (around 1.5 crores)
Estimated Investment	NPR	3500000
Simple payback period		Around 5 years

The research by Swapnil Ratnakar Mane (Mane, 2013) showed saving in fuel consumption through waste heat recovery that saves Rs. 96870 per month, assuming an A/F ratio of 14, excess air of 13\% %, GCV 10300, and exhaust gases are at high temperature (250^{0} c). Similarly, the research in Waste Heat Recovery Technologies and Applications by Jouhar (Jouhara, 2018) illustrated that recovering heat from flue gas presents one of the effective methods for reclaiming the heat in the steam systems. Further, that recovered heat can be utilized to preheat boiler feed water in an economizer. Additionally, the research on Energy Efficiency and Renewable Energy demonstrated that improved economizers, like condensing economizer, have the capability to recover even greater amounts of heat from outgoing flue gas, which improves steam system efficiency and heat recovery by up to 10% (Department of Energy, 2007). Similarly, a feed water economizer lowers the fuel requirements of steam boiler by allowing the transfer of heat to feed water from the flue gas. Boiler flue gases are frequently discharged into the stack at temperatures more than 37.7°C to 65.56°C higher than the temperature of the generated steam. Generally, reducing the flue gas temperature by 4.44°C can increase boiler efficiency by 1%. Utilizing waste heat through economizers often results in a 5 to 10% decrease in fuel consumption and typically recovers its cost within 2 years (Department of Energy, US, 2012).

Another energy opportunity is blow-down steam recovery. In this process, pressure reduction often generates substantial amounts of steam when water is released from a high-pressure boiler tank. This low-grade steam can be utilized for preheating the feed and heating the space. The Blowdown steam recovery mechanism can save approximately 1% of fuel used in small boilers (Galitsky, 2005).

Table 4.9: Energy Efficiency Options in Thermal System

S.N	**Energy Efficiency Option**	**Annual Saving**			**Investment (NPR)**	**Payback Period (Months)**
		Electrical Energy kWh	**Thermal Energy (Lit per annum)**	**Cost (NPR)**		
1	Improving the combustion efficiency of a steam boiler through excess air control to achieve fuel savings.		11977	1940222	1600000	15
2	Waste heat recovery system through economizer	32412	101038	16368091	3500000	60
3	Blow down steam recovery				Nominal	

4.2.3 Induction Motors System

The recorded data of the induction motor running the ammonia compressor shows the following conditions.

Table 4.10: Measured Ammonia Motor Parameters

Description	**Value**
Measured Peak kW load	17.72
Measured Peak kVA load	22.8
Power Factor	0.7874
Voltage	420.82
Current	98.8

Based on the measured data, the power factor ranges between 0.76-0.78, which shows reactive power losses. Similarly, apparent power (kVA) is higher than true power (kW), which confirms significant reactive power consumption affecting the efficiency. Since the central capacitor bank and VFD are already installed, further improvement can be made through the installation of the decentralized capacitor at the motor terminals, which can help in improving PF. Installation of a 20 KVAR capacitor in parallel to the motor terminal increases p.f. from 0.78 to 0.9. The cost-benefit optimization showed an annual saving of NPR 145184 with a 5-month payback period.

Table 4.11: Decentralized PF Correction Cost Optimization

Description	**Value**
Existing Power Factor	0.78
Proposed Power Factor	0.9
Existing kVA	22.8
Existing Active power kW	17.72
KVAR requirement , kW*(TAN(ACOS(old p.f))-TAN(ACOS(new p.f))	14.21
New KVA after power factor correction	19.7
Demand Reduction (Saving)	22.8-19.7
	3.1 KVA/month
Annual cost saving due to demand reduction	9300
Estimated energy saving per year	14456
Annual Cost Saving due to energy saving @NPR 9.4/kWh	135884
Total Annual cost-saving	145184
Estimated investment	60000
Simple payback period (months)	5.0

4.3 Final Energy Demand and Carbon Emission

4.3.1 Business As-Usual Analysis

The final energy consumption is estimated to grow at an average annual rate of 8.52% between 2025 and 2040. As a result, Energy used was found to increase from 4526 MWh in 2025 to 5785 MWh. In the base year, the energy supplied from electricity is 1511 MWh, and that from fuel is 3016 MWh. The fuel share in 2040 would be 1930 MWh from electricity and 3854 MWh from diesel that as shown in Figure 4.11

Similarly, the GHG emission was found to be 731 tons of CO_2 per kWh from electrical energy consumption and 821 tons of CO_2 per liter from diesel consumption. The carbon emissions in 2040 would be in increasing order. This shows the need for cleaner energy in KMSS to reduce carbon footprints. The overall emission is shown in Figure 4.12

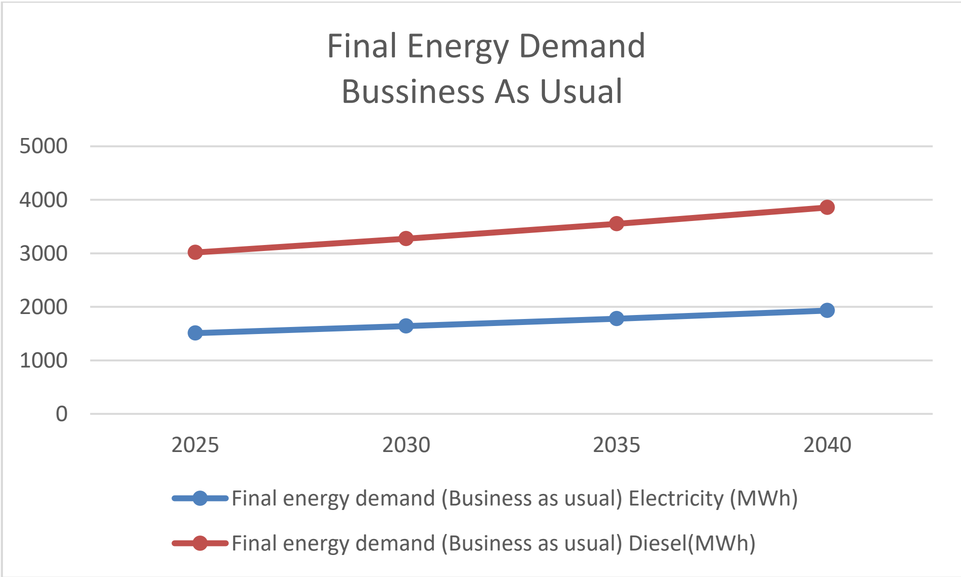


Figure 4.11: Final Energy Demand in BAU Scenario

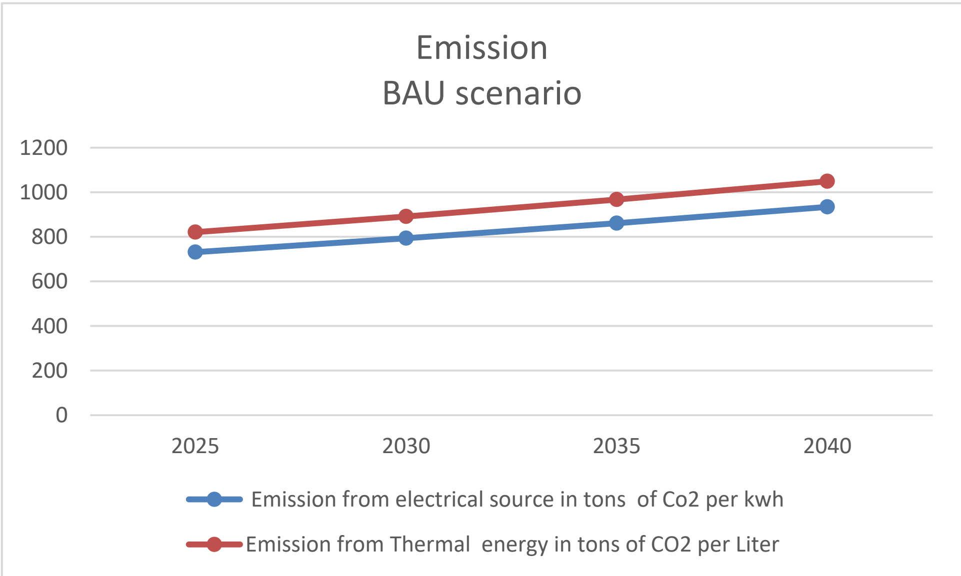


Figure 4.12: Carbon Emissions in BAU Scenario

4.3.2 Efficient Technology Scenario

Upgrading to modern, high-efficiency motors, Variable Frequency Drives (VFDs), and implementing smart control technologies, the system can achieve energy savings, low electricity costs, and reduced carbon emissions. In dairy, almost 62 pumps and motors of different sizes fitted for a different operation show a huge amount of savings in cost and reduced emissions. Key Assumptions are given below:

Table 4.12: Assumptions for Motor

Assumption	**Values**
Constant Operating Hours	4000 hours per year
Fixed power rating	5.5 kW
	No changes in load demand
Constant Efficiency value	Existing 82% throughout their lifetime
	New 95% without degradation
Annual Energy Consumption	Increases by 8.5% every year uniformly.
Energy saving	Only from highly efficient motors
External Factors	Not included
Independent Motor Operation	Operate Independently

Overall cost saving and reduction in carbon emission from a single motor is shown below:

Table 4.13: Cost Optimization of Efficient Motor

Description	**Unit**	**Values**
Old Motors		
Power rating	kW	5.5
Operating Hours	hr per year per motor	4000
Efficiency	%	82
New efficient Motors		
Efficiency	%	95
Energy saving	kWh per year per motor	3011
Annual cost saving @9.4	NPR per motor	28299
Estimated Investment	NPR per motor	150000
Simple Payback period	Years	5
Total Carbon Emission reduced	Tons per motor	1.5

The scenario assumed that the share of efficient technologies reaches 33% by 2030, 66% by 2035, and 100% by 2030. In this case, it is assumed that the existing motors will be replaced with energy-efficient models. Energy consumption in 2025 is 27 MWh per motor and goes up to 34 MWh in 2040. With efficient motors, its range is from 28 MWh to 30 MWh. Figure 4.13 shows energy consumption by motors.

Carbon emissions from old motors are found to be 14 tons of CO_2 per kWh in 2030. Similarly, Efficient motors produce 13.45 tons of CO_2 per kWh. 100% efficient motors produce 14.32 tons of CO_2 per kWh of carbon emission in 2040, while old motors produce 17 tons of CO_2 per kWh of carbon emission in 2040. Figure 4.14 shows carbon emissions from motors.

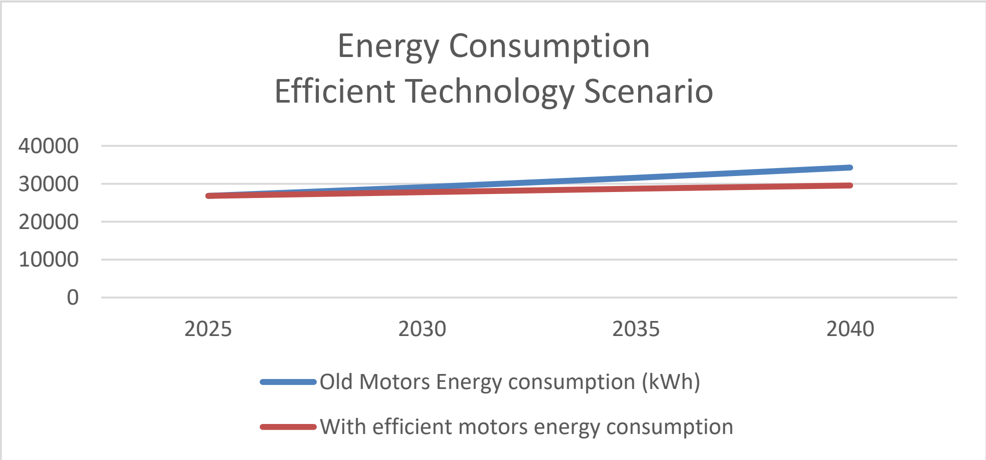


Figure 4.13: Energy consumption by Motors

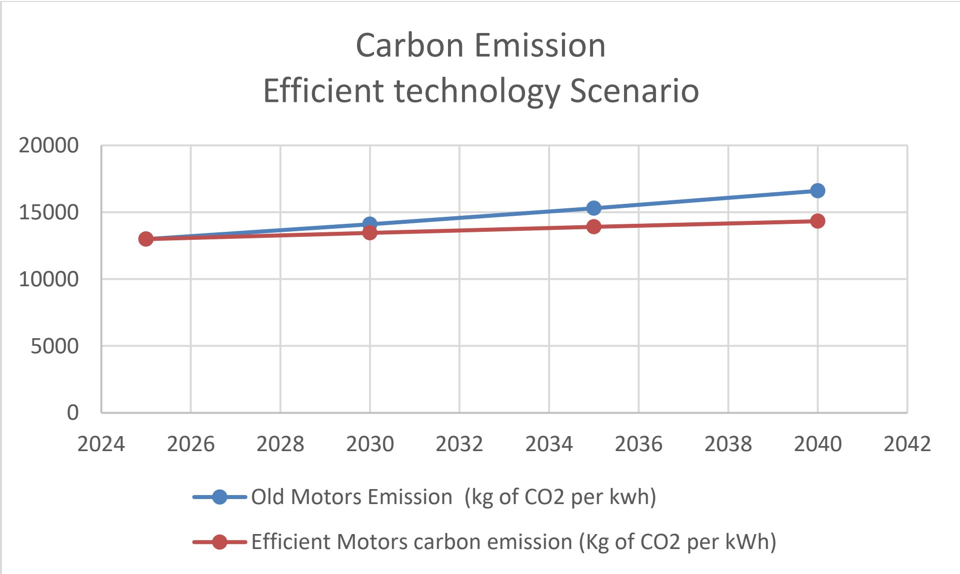


Figure 4.14: Carbon emission (Efficient technology Scenario)

Research into energy efficiency enhancement options for the EU food industry showed that implementing high-efficiency motors can lead to significant energy savings of up to 5%.

(Kaminski & Leduc, 2010). Similarly, investment in highly efficient motors, i.e., medium investment, can return within 1-2 years. (Galitsky, 2005).

4.3.3 Transition of Boiler Fuel scenario

The main source of energy is grid supplied in KMSS, which accounts for few share of the total consumption. In this scenario, the use of boiler-producing thermal energy is a key factor contributing to low efficiency and a high carbon footprint. It is recommended to transition of fuel of the boiler to biomass or an electric boiler that not only reduces emissions but also enhances energy efficiency by utilizing cleaner electricity sources.

A biomass (wood-based) boiler with an economizer was used in the Curd and fresh milk section, and its performance assessment showed the efficiency of 67.3%. Based on the energy produced from wood, equivalent diesel consumption was calculated. A comparison was done between a wood-fired boiler and a diesel-fired boiler, assuming an efficiency of 80.74%. The analysis revealed that to produce the same energy level, wood-fired boilers seem to be advantageous, with a cost saving of 4.74 million annually.

The cost optimization of the transition of a diesel boiler to a wood boiler is given below:

Table 4.14: Diesel to Wood-based Boiler Cost Optimization

Description	**Value**
Total wood used (Kg)	76495.92
Wood calorific value (kCal/kg)	4500
Wood Boiler efficiency (%)	67.3
GCV Diesel (kCal/kg)	10200
Diesel Boiler Efficiency (%)	80.47
Useful energy from Wood (kCal)	231667894
Equivalent Diesel Consumption (Kg)	28225
Wood cost per kg (Rs/Kg)	10
Diesel per kg @0.83 kg/lit@162	195
Total Cost of wood	764959
Total Cost of diesel	5508947
Cost Saving (NPR)	4743988
Switching to wood saves approximately NPR 4.74 million annually.	

The final energy demand of diesel and wood boilers is shown below.

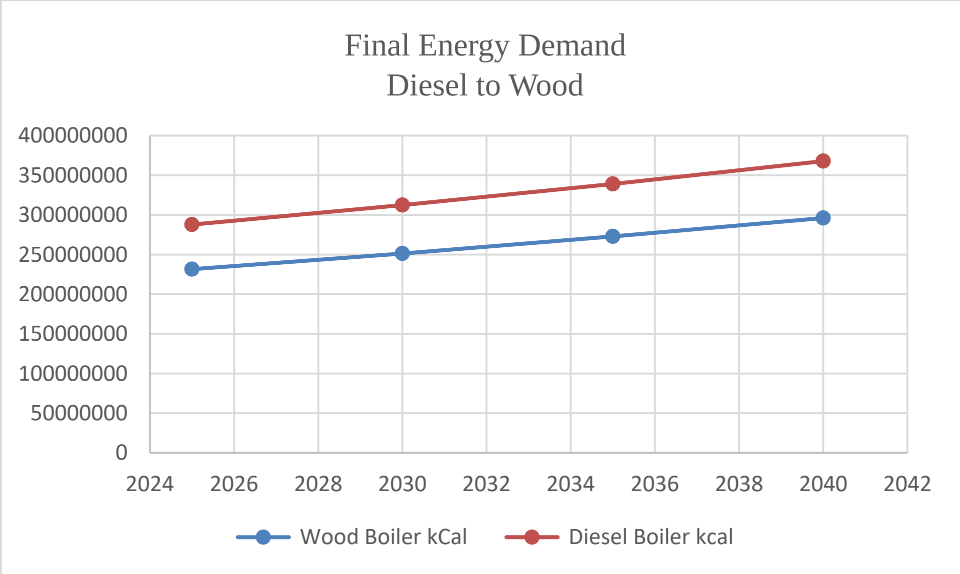


Figure 4.15: Final energy demand (Diesel to Wood)

Carbon emission from wood-based boilers and diesel-based boilers is given below. This shows higher emissions from the wood boiler than the diesel boiler. Carbon emission found to be 122 tons from the wood boiler in 2025, whereas 91 tons per CO_2 per liter from the diesel boiler in 2025. It is projected to be 156 tons from wood and 119 tons from diesel in 2040. Although wood produces higher CO_2 emissions, it is considered carbon-neutral over time because trees absorb CO_2 during growth. Diesel, on the other hand, releases fossil carbon, contributing directly to climate change.

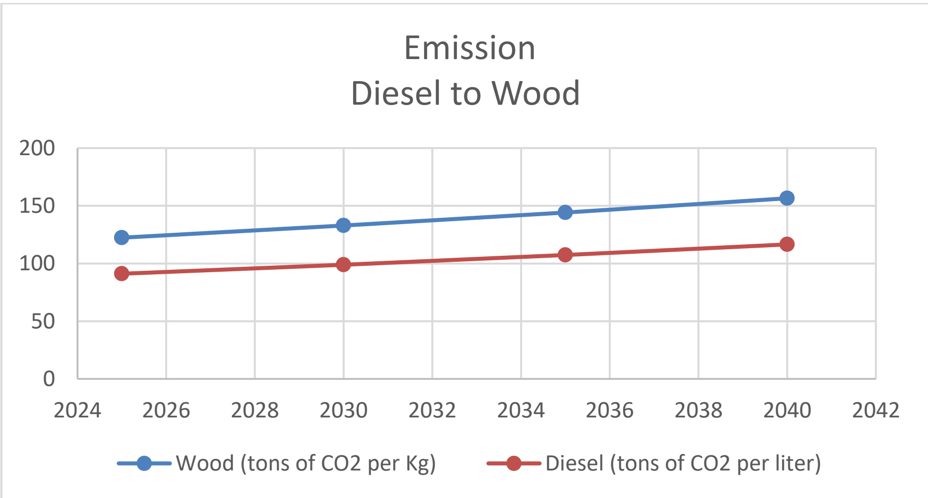


Figure 4.16: Emission (Diesel to Wood)

Similarly, per unit production cost was found to be NPR 3 per kg from wood and NPR 18 per kg from diesel.

Table 4.15: Per unit Production Cost

Description	**Value**
Total production of curd+ fresh milk (kg)	256040
Wood	
useful energy kCal	231667894
Total fuel cost	764959.2
Cost per unit production	3.0
Diesel	
Diesel Required liters	28225
Total cost of diesel @162 per liter	4572426
Cost per unit production (Rs per liter)	18

Studies on the environment performance of utility boiler energy conversion systems have motivated the power industry to innovate and advance efficient, dependable renewable energy solutions. A major advantage of renewable fuel boilers is their almost negligible CO_2 emission. Recently, there has been swift progress globally in the development of boilers that utilize renewable fuel like solar energy and biomass. From the result of the sustainability (Li, Gillum, Toupin, Park, & Donaldson, 2016). The transition from a diesel-fired boiler to an electric boiler reveals an energy consumption pattern of 3015906 kWh in 2025, and that of electric boilers is 2549697 kWh, assuming the following data.

Table 4.16: Assumptions for Electric Boiler

Assumption	**Values**
Electric Boiler efficiency	96%
Thermal Energy output	Remain constant
Electric boiler Capacity	Heat output of the Diesel system
Efficiency	Do not consider efficiency degradation over a period.
Electricity grid reliability	Stable power supply
Maintenance	Regular basis (not considering losses)
Electric tariff	Constant

The table below shows the cost optimization of the electric Boiler.

Table 4.17: Diesel to Electric Boiler Cost Optimization

Description	**Unit**	**Value**
Diesel Boiler		
Annual Diesel Consumption	Liter	306309
Total consumption@0.83kg/lit density, GCV of diesel =10200 kCal/kg	kcal/year	2593211994
	kWh/year	3015905.549
Efficiency of the boiler	%	80.47
Energy Output	kWh/year	2426899.20
Annual fuel cost @162	NPR	49622058
Electric Boiler		
Assume efficiency	%	96
Energy Required	kWh/year	2528020
Annual Energy Saving	kWh/year	487886
Annual electricity cost@9.4	NPR	23763388
Annual saving	NPR	25858670
Estimated Investment	NPR	15000000
Simple payback period	Year	0.58
	Months	7
Total carbon emission reduced.	Tons	236

The final energy demand of diesel and electric boilers is shown below.

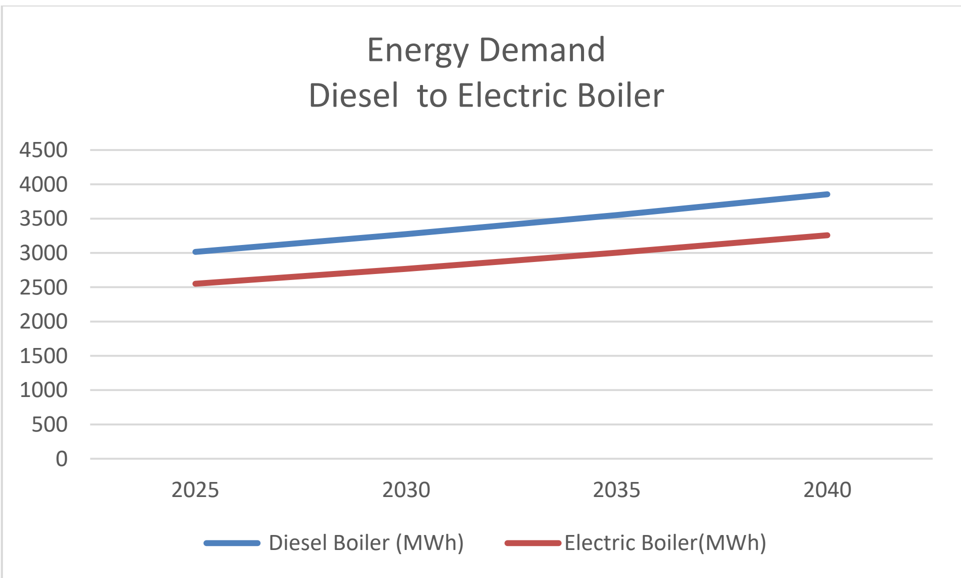


Figure 4.17: Energy Consumption Diesel Boiler Vs Electric Boiler

Diesel boilers produce 821 tons of CO_2 per kWh in the year 2025, and Electric boilers produce 1234 tons of CO_2 per kWh. The figures show the carbon emissions from boilers.

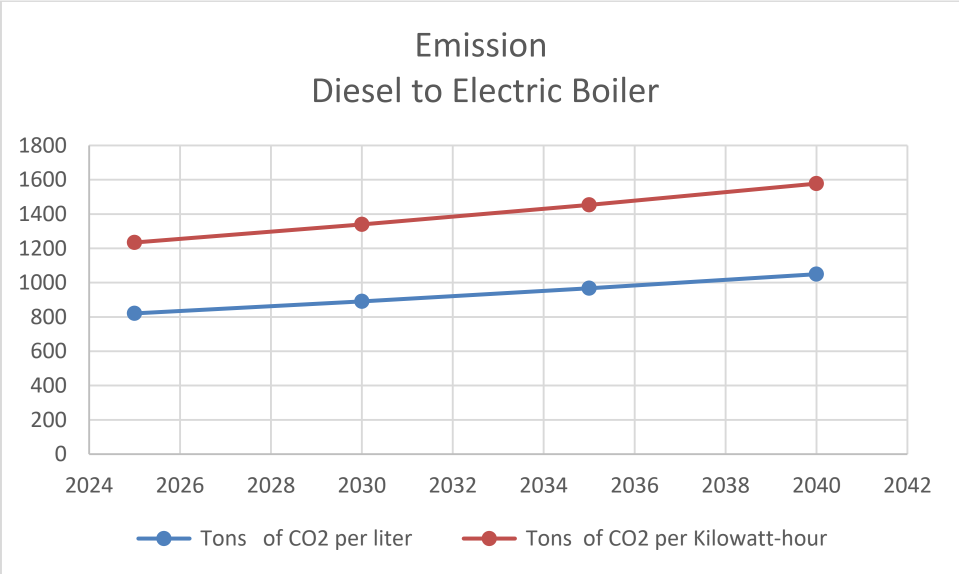


Figure 4.18: Emissions from Boilers

On comparison of the electrification scenario with the results obtained by various researchers, it was found that the electrification of boilers aligns with prior literature results. As per (Zuber, Hasanbeigi, & Morrow, 2021) electrification of industrial boilers reduces energy demand with a potential saving of 16-20 percent. Initial electrification may slightly increase CO_2 emissions, but in the long term benefit from lower emissions. Similarly, Marc Marsidi in his technology factsheet states that an electric boiler has an efficiency of up to 95-99 %, which produces superheated steam with a temperature of up to 350 °C and a capacity of up to 70MWe.

A study on the Design and Development of Electric boilers focuses on generating steam using heaters or electrodes to enhance boiler efficiency, minimize pollution, and reduce generation time. Boilers play an important role in thermal power plants. Electrifying industrial processes provides a solution to lower carbon emissions and improve energy efficiency. As industrial fuel demand increases while availability declines, transitioning to electric boilers offers a sustainable and efficient solution that experiences minimal heat loss and offers higher efficiency as compared to fire and water tube boilers (Deshmukh, Patil, Rane, & Kotwal, 2020).

Another option would be a pellet boiler. The research on the Analysis and Comparison of Biomass Pellets with Various Fuels aims to analyze pellets as an alternative fuel. Pellet fuel can be an effective alternative to diesel fuels. 2.38 kg of pellets is needed to produce the same energy as 1 liter of diesel. The cost of pellets required for this energy output is Rs. 34, leading to a cost saving of Rs. 30 per liter of diesel replaced, which means a 46.87% saving (Ganvir, Tulankar, Bawankar, Rahimkar, & Singh, 2017). Another report on a wood pellet-fired biomass boiler at the Ketchikan federal building showed reliable and efficient results. Performance specification showed 85%-90% efficiency at full load and 85.6% at partial (45%) load. Results support that biomass boilers are viable alternatives since they are most cost-effective where natural gas is unavailable (GSA's GPG Program, 2014).

4.3.4 Solar Thermal Scenario

This scenario installs a solar hot water system to generate hot water for use in CIP. Installing a 5000-liter per day solar hot water system can reduce the demand for hot water that is generated through fuel-based boilers. The system can produce temperatures around 50 to 70 degrees, capturing 250000 kcal of thermal energy per day. It will save 6014 liters of HSD annually, saving a cost of 974341 per year. The initial investment would be 1500000 with a payback period of 8 months. There will be zero emissions from renewable energy.

Table 4.18: Solar Thermal Cost Optimization Scenario

Description	**Unit**	**Value**
Recommended capacity of Solar Water Heater	Liters per day	5000
Expected temperature rise in o C from the ambient temperature (25 oC to 75 oC)	oC	50
Thermal energy potential per day	kCal	250000
Fuel savings potential in Kg/day @ @boiler efficiency of 81 % and HSD calorific value of 10200 kcal/kg @ @0.83 density	Liters	16.5
Annual fuel oil (HSD) savings @365 day working	Liter	6014
Cost savings in NPR @ NPR 162 lit of HSD	NPR	974341
Estimated investment for a 5000 LPD solar hot water collector	NPR	1500000
Simple Pay Back Period	Months	8

The research on Utilization of Solar Heated Water in Shell and Tube Heat Exchanger for Pasteurization of Milk develops a system using solar heated water, using parameters like heat exchanger effectiveness, and convective heat transfer coefficient. The results show that pasteurization using conventional heating costs Rs. 2.75 per unit, whereas solar water heating reduced costs to Rs. 1.90 per unit (Bisen & Agrawal, 2015).

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

This section presents the conclusion of the research along with further recommendations.

5.1 Conclusion

This study evaluated the technological, economic, and environmental performance of the dairy industry. Energy consumption patterns were assessed to identify inefficiencies. The current techno-economic performance was analyzed to understand whether the dairy plant functions effectively. Finally, cost-saving opportunities and carbon emission reductions were explored under various scenarios.

A. Energy Consumption Analysis

- The total energy consumption from the national grid is 32%, Diesel generation is 1%, and thermal energy is 67%.
- The electrical energy monitoring showed a peak load of 233.37 kW with 0.96 p.f, which showed energy opportunities through the schedule of peak time load to normal time or off time.
- There is significant potential to minimize energy costs and emission through integration of renewable energy resources as study reveals that boiler efficiency of 80.47% and annual diesel consumption of 306309 liters.

B. Existing Techno-Economic Performance Analysis

- The coefficient of performance of the refrigeration system was found to be 4.05, with a superheated state temperature was found to be 110 °C, which shows an opportunity for energy optimization through the Installation of a desuperheater that increases efficiency and reduces consumption costs.
- Performance assessment of thermal energy source (steam boiler) has the efficiency of 80.47%, which can be increased through control of excess air and reuse of flue gas heat.
- The ammonia induction motors run with p.f. ranges from 0.76-0.78. The concept of decentralization of the capacitor bank increases the efficiency of the motor and reduces energy consumption costs.

C. Cost Saving Opportunities and Carbon Emission under Different Scenario

- Implementation of highly efficient motors can reduce energy consumption from 34 MWh to 30 MWh and carbon emissions.

- Transitioning from boiler fuel to wood or pellet, or an electric boiler saves energy consumption with a reduction in carbon emissions. Similarly, per unit production cost was found to be NPR 3 per kg from wood and NPR 18 per kg from diesel. Replacement of diesel boiler with wood boiler is more feasible.
- Installation of a solar hot water system saves up to 6014 liters of fuel per year.

In conclusion, an energy audit shows energy opportunities that help in reduction of energy consumption and carbon emission.

5.2 Recommendation

The following recommendation can be provided:

- Performance assessment can be carried out in different dairy industries in Nepal.
- Individual milk processing energy consumption can be analyzed.
- Further, a study can be carried out by adopting different energy-efficient technologies in the dairy industries of Nepal.

REFERENCE

Bisen , P., & Agrawal, D. (2015). Utilization of Solar Heated Water in Shell and Tube Heat Exchanger for Pasteurization of Milk (Milk Pasteurization by using Solar Energy). *International Journal of Engineering Research & Technology (IJERT), 3*.

Bojovic, M., & McGregor, A. (2023). A review of megatrends in the global dairy sector: what are the socioecological implications? *Agriculture and Human Values*, 373-394. Retrieved from https://doi.org/10.1007/s10460-022-10338-x

Deshmukh, R. G., Patil, P. R., Rane, V. S., & Kotwal, A. U. (2020). Design and Development of Electric Boiler . *International Research Journal of Engineering and Technology (IRJET), 7*, 1119-1121.

Fiorillo , V., & Amico , B. M. (2024). Milk Quality and Economic Sustainability in Dairy Farming:A Systematic Review of Performance Indicators. *Dairy, 5*, 384-402. doi:https://doi.org/10.3390/dairy5030031

Fiorillo, V., & Amico , B. M. (2024). Milk Quality and Economic Sustainability in Dairy Farming: A Systematic Review of Performance Indicators. *Dairy*. Retrieved from https://doi.org/10.3390/dairy5030031

Janzekovic, M., Mursec, B., Vindis, P., & Cus, F. (2009). Energy saving in milk processing. *Journal of Achievements in Material and Manufacturing Engineering*.

Kuchibhatla, S., Banu, M., Taskeen, S., begum, S., Sultana, S., & Karli, G. (2024). Dairy Farming – a Case Study. *International Research Journal on Advanced Engineering and Management, 02*(01 January 2024), 16-19.

Lei, Y., Cheng, M., McCarl , B., & Cessna, J. (2024). A Review of Options and Costs for Mitigating GHG Emissions from the U.S. Dairy Sector. *Atmosphere*. Retrieved from https://doi.org/10.3390/atmos15080926

Renewable Thermal Collaborative. (2024). *Decarbonizing Process Heat at California Dairies, Inc.with Skyven Technologies.* http://www.renewablethermal.org/.

ZHAO, R., XU, Y., WEN, X., ZHANG, N., & CAI, J. (2017). Carbon footprint assessment for a local branded pure milk product: a lifecycle based approach. *Food Science and Technology*. Retrieved from http://dx.doi.org/10.1590/1678-457X.02717

ABB Drives . (2019). *Dairy production Boosting productivity, reliability and energy efficiency.* Retrieved from https://search-ext.abb.com/.

About Us: Dairy Development Corporation. (2024, Nov 30). Retrieved from Dairy Development Corporation: https://ddc.gov.np/

Arunachalam, P. (1982). *A M.Tech Thesis on Energy accounting in Dairy Plants* . Agricultural Engineering Department, IIT Kharagpur.

Barma, M. C., Saidur, R., & Rahman, S. M. (2017). A review on boilers energy use, energy savings, and emissions reductions. *Renewable and Sustainable Energy Reviews*.

Bhatia, A. (2022). *Improving Energy Efficiency of Boiler Systems.* CEDengineering.com.

Brien, D. O., Hennessy, T., Moran, B., & Shalloo, L. (2015). Relating the carbon footprint of milk from Irish dairy farms to economic performance. *Journal of Dairy Science*.

Brush, A., Masanet, E., & Worrell, E. (2011). *Energy Efficiency Improvement and Cost Saving Opportunities for the Dairy Processing Industry.* Ernest Orlando Lawrence Berkeley National Laboratory .

Chauhan, R. R., Pinto, S. V., Patel, S., & Bhadania, A. G. (n.d.). Carbon Footprint and Dairy Industry. *National Seminar on "Indian Dairy Industry - Opportunities and Challenges*.

Choyal, D. S. (2019). Economic analysis of Impact of Technological Advancements on Indian Dairy Industry. *JETIR*.

Ciolkosz, D. (2023, 03 09). *How a Dairy Farmer Can Improve Energy Efficiency.* Retrieved from https://extension.psu.edu/.

Company, V. (2021). *Report on Projection of Emission Associated With Electricity Trading as Part Of Nepal's Long Term Strategy to Achieve Netzero Emission Status By 2050.* NEPAL RENEWABLE ENERGY PROGRAMME.

de Lima, L. P., de Deus Ribeiro, G. B., & Perez, R. (2018). The energy mix and energy efficiency analysis for Brazilian dairy industry. *Journal of Cleaner Production*.

Department of Energy. (2007). Energy Efficiency and Renewable Energy. *ADVANCED MANUFACTURING PROGRAM*.

Department of Energy, US. (2012). Energy Efficiency and Renewable Energy. *ADVANCED MANUFACTURING PROGRAM*.

Egas, D., Ponsá, S., Llenas, L., & Colón, J. (2021). *Towards energy-efficient small dairy production systems: An environmental and economic assessment.* Retrieved from http://www.elsevier.com/locate/spc

Environment, T. M. (2015). *Summary of Emissions Factors for the Guidance or Voluntary Corporate Greenhouse Gas Reporting - 2015.* The Ministry for the Environment.

ETSAP, I. (2010). *Industrial Combustion Boilers* .

Florindo, T. J., Rosa, A. P., Santos, L. C., & Renato, N. d. (2022). Life Cycle Assessment of Dairy Products: A Case Study of a Dairy Factory in Brazil. *Sustainability*. doi:https://doi.org/10.3390/su14159646

Galitsky, C. C. (2005). Energy Efficiency Improvement and Cost Saving Opportunities: An ENERGY STAR Guide for Energy and Plant Managers. . *Lawrence Berkeley National Laboratory, Berkeley, California*.

Ganvir, K. D., Tulankar, P. G., Bawankar, P. P., Rahimkar, K. T., & Singh, S. L. (2017). Analysis and Comparison of Biomass Pellets with Various Fuels . *International Journal for Scientific Research & Development*.

Gerber, P., Vellinga, T., & Dietze, K. (2010). *Greenhouse Gas Emissions from the Dairy Sector: A Life Cycle Assessment.*

Gonçalves, R. G., Rossini, E. G., Souza, J. d., & Beluco, A. (2018). Main Results of an Energy Audit in a Milk Processing Industry in Taquara,Southern Brazil. *Journal of Power and Energy Engineering*, 21-32. doi:https://doi.org/10.4236/jpee.2018.61003

Gradhoc World. (2024, 04 30). *Gradhoc*. Retrieved from Smart Refrigeration in the Dairy Sector: https://gradhoc.com/eBook/smart-refrigeration-predictive-maintenance-dairy-sector/

GSA's GPG Program. (2014). *WOOD-PELLET BIOMASS BOILER.* gpg@gsa.gov.

Heifer International Nepal. (2022). Climate-Smart Dairy Farming in Nepal . Retrieved from https://heifernepal.org/climate-smart-dairy-farming-in-nepal/

Hillsdon, M. (2024, June 17). 'Blindspot' over methane emissions puts dairy and beef sectors at risk, say investors. *Reuters*. Retrieved from https://www.reuters.com/sustainability/decarbonizing-industries/blindspot-over-methane-emissions-put-dairy-beef-sectors-risk-say-investors-2024-06-17

IRENA. (2020). *Renewable Energy and Climate Pledges: Five yaer after the Paris Agreement.* International Renewable Energy Agency. Retrieved from https://www.irena.org/

Joshi, S. B., & Poudel, L. (2017). Energy Efficiency Improvement Potential of Dairy Development Corporation: Kathmandu Valley Milk Supply Scheme. *Proceedings of IOE Graduate Conference, 2017, 5*, 497-504.

Jouhara, H. (2018). Waste Heat Recovery Technologies and Applications. *Thermal Science and Engineering Progress*.

Kaminski, J., & Leduc, G. (2010). Energy efficiency improvement options for the EU food industry. *ResearchGate*.

Kedia, S. (2013). *Energy Audit in the Dairy Industry - Sitaram Gokul Dairy Nepal.*

Kerr, D., & Blair, A. (2011). Thermal Power Plant Performance Analysis. *Physiotherapy (United Kingdom),*. doi:https://doi.org/10.1016/j.physio.2011.04.002

Kraatz, S., Berg, W., & Brunsch, R. (2009). Factors influencing energy demand in dairy farming. *South African Journal of Animal Science* .

Li, C., Gillum, C., Toupin, K., Park, Y. H., & Donaldson, B. (2016). Environmental performance assessment of utility boiler energy conversion systems. *Energy Conversion and Management*.

Lukuyu, J. M., Blanchard, R. E., & Rowley, P. N. (2018). A risk-adjusted techno-economic analysis for renewable-based milk cooling in remote dairy farming communities in East Africa. *Renewable Energy*.

Makaliunas, S. a. (1998). Process Integration and Waste Heat Recovery in Lithuanian and Danish Industry Case Study: Dairy "AB Kupiskio pienas". *Danish Ministry of Energy -EFP-95 Programme.* .

Mane, S. R. (2013). Energy Management in a Dairy Industry . *Proceedings of IRAJ International Conference*.

Masanet, E., Brush, A., & Worrell, E. (2014). Energy Efficiency Opportunities in the U.S. Dairy Processing Industry. *Energy Engineering*.

Mech, A., Devi, G. L., Sivaram, M., Sirohi, S., Dhali, A., Kolte, A. P., . . . Bhatta, R. (2023). Assessment of carbon footprint of milk production and identification of its major determinants in smallholder dairy farms in Karnataka, India. *Journal of Dairy Science, 106*.

Mickiewicz, B., & Volkava, K. (2022). Global consumer trends for sustainable milk and dairy production. *VUZF Review*. doi: 10.38188/2534-9228.22.2.1

Mladen, J. M., Sustersic, V. M., & Gordic, D. R. (2020). Ranking Energy Performance Opportunities Obtained With Energy Audit in Dairies . *Thermal Science* .

Mohsenimanesh, A., LeRiche, E. L., Gordon, R., Clarke, S., MacDonald, R. D., MacKinnon, I., & VanderZaag, A. C. (2021). Review: Dairy Farm Electricity Use, Conservation and Renewable Production-A Global Perspective . *Applied Engineering in Agriculture*, 977-990.

Mojica, C. D., García, C. E., & Silva-Rodríguez, R. (2021). A review of the different boiler efficiency calculation and modeling methodologies. *Informador Técnico*.

Muhamad, N. A., Phing, L. Y., & Arief, Y. Z. (2014). Pre-study on potential electrical energy savings in Malaysia dairy manufacturing industry of medium enterprises . *2nd International Conference on Sustainable Energy Engineering and Application*.

Organization Profile. (n.d.). Retrieved December 2024, from Dairy Development Cooperation: https://www.ddc.gov.np/page/about-us/1

Pandya, A. (1998). Energy Economics of Indigenous dairy products, A compendium of short\ term training course on energy conservation in dairy processing operations. *SMC College of dairy science, Gujarat Agricultural University, Anand.*

Prabhakar, P., Srivastav, P., & Murari, K. (2015). Energy consumption during manufacturing of different dairy products in a commercial dairy plant: A case study. *Asian J. Dairy & Food Res.*, 98-103.

Prasad, S. (2022). THERMAL ENERGY CONSUMPTION DURING MILK PROCESSING IN A COMMERCIAL DAIRY PLANT: A CASE STUDY. *International Journal of Engineering Applied Sciences and Technology,*.

Prasad, S. (2022). Thermal Energy Consumption During Milk Processing in a Commercial Dairy Plant: A Case Study . *International Journal of Engineering Applied Sciences and Technology*, 160-165.

Purseth, S., Dansena, J., & Desai, M. S. (2021). Performance Analysis and Efficiency Improvement of Boiler- A Review. *International Journal of Engineering Applied Sciences and Technology*, 326-331.

Ramirez, C., Patel, M., & Blok, K. (2006). From fluid milk to milk powder: energy use and energy efficiency in the European . *Energy–The International Journal*.

Rana, A. H., & Zala, S. H. (2019). Performance Analysis of Industrial Boiler. *IJSRD - International Journal for Scientific Research & Development*.

Sapkota, D. B., Shiwakoti, B., Ghimire, B., & Lama, A. (2022). *Case Study at the Kathmandu Milk Supply Scheme (KMSS) DDC, Balaju Industrial District.*

Savchenko, A., & Mikhieieva, K. S. (2018). ANALYSIS AND AUDIT OF KEY ECONOMIC INDICATORS OF ECONOMIC ENTITIES (A CASE STUDY OF THE DAIRY INDUSTRY). *Baltic Journal of Economic Studies*.

Schleich, J., & Fleiter, T. (2019). Effectiveness of Energy Audits in Small Business Organizations. *Resource and Energy Economics*.

Schreiber, D., Feil, A. A., & Haetinger, C. (2020, june 21). Sustainability in the dairy industry: a systematic literature review. *Environment Science and Pollution Research, 27*, 33527-33542.

Sharma, H., Singh, P. K., Kaur, I., & Singh, R. (2024). Water Footprints of Dairy Milk Processing Industry: A Case Study of Punjab (India). *Water*. Retrieved from https://doi.org/10.3390/w16030435

Shine , P., Upton, J., Sefeedpari, P., & Murphy, M. D. (2020). Energy Consumption on Dairy Farms: A Review of Monitoring, Prediction Modelling, and Analyses. *Energies*(13), 1288. doi:http://dx.doi.org/10.3390/en13051288

Shingh, S., Kalwar, C. S., Poudel, S., Tiwari, P., & Jha, S. (2020). A Study on Growth and Performance of Dairy Sector in Nepal. *International Journal of Environment, Agriculture and Biotechnology*. doi:https://dx.doi.org/10.22161/ijeab.54.36

Shrestha, A. (2017). A Comparative Study of Environmental Aspect in Dairy Industries of Kathmandu Valley. *Journal of Environment Science*.

Shrestha, D. (2017). *Nepal's GHG Inventory :For Third National Communication to the UNFCCC.* Third National Communication Project, Ministry of Population and Environment, Government of Nepal, Singh Durbar, Kathmandu.

Singh, A. B., Bhakar, V., Gaurav, G., Khandelwal, C., Sarkar, P., Singh, H., & Dangayach, G. S. (2024). Environmental Sustainability of Milk Production : A comparative Environmental Impact Analysis and Sustainability Evaluation. *Frontiers in Sustainability*. doi:DOI 10.3389/frsus.2024.1352572

Singh, G., Singh, P., Tyagi, V., & Pandey, A. (2019). Thermal and Exergoeconomic Analysis of a Dairy Food Processing Plant. *Journal of Thermal Analysis and Calorimetry*.

Slyke, B. V., Mirkouei, A., & McKellar, M. (2021). Techno-Economic and Environmental Assessment of Dairy Products: A case study in Southeast Idaho, USA . *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*.

Smith, C. (1981). Energy Management Principles: Applications, Benefits, Savings. *Pergamon Press, New York*.

Tamilselvan, G., & Tyagi, N. (2024). Life Cycle Assessment as an evaluation tool- A critical review on carbon footprint in dairy sector. *Letters in Animal Biology*.

Taner, O. O. (2023). Energy and production analysis of a dairy milk factory: A case of study. *Journal of Thermal Engineering*.

Tannous, H., Masera, K., Tassou, S., & Stojceska, V. (2023). Integration and Simulation of Solar Thermal Energy to Diary Processes. *AIP Conference Proceedings*.

TEAM, C. N. (2020). *Dairy Sector Strategy - Nepal.* Commercial Agriculture for Smallholders and Agribussiness.

Upadhyay, N., Khanal, B., Acharya, Y., & Timsina, K. P. (2021). Nepalese legal standard of milk and common milk products and its implications. *Journal of Agriculture and Natural Resources*, 284-294.

UPME, REES, & TEP Energy. (2019). Primer balance de energia util para Colombia. *Resumen ejecutivo BEU sector Industrial* .

Vergé ,, X. P., Maxime, D., Dyer, J. A., Desjardins, R. L., Arcand, Y., & .Vanderzaag, A. (2013). Carbon footprint of Canadian dairy products: Calculations and issues . *Journal of Dairy Science*.

WECS, T. W. (2017). *Energy Audit Guidelines for Industrial Sectors.* GIEF Consultancy Pvt. Ltd. Retrieved from http://www.giefnepal.com/

Wojdalski, J., Ligenza, P., Postuła, M., Dróżdż, B., & Niżnikowsk, R. (2023). Determinants of Energy Consumption in the Dairy Industry: A Case Study in Poland. *Environmental Protection and Natural Resources, 34,* 69-91.

Woolery , S., Osei, E., Yu, M., Guney, S., Lovell, A., & Jafri, H. (2003). The Carbon Footprint of a 5000-Milking-Head Dairy Operation in Central Texas. *Agriculture*.

World Bank Group. (2024, October). *Nepal Development Update*. Retrieved from https://www.worldbank.org/en/country/nepal/publication/nepaldevelopmentupdate: https://www.worldbank.org/en/country/nepal/publication/nepaldevelopmentupdate

Xu, G., Huang, S., Yang, Y., Wu, Y., Zhang, K., & Xu, C. (2013). Techno-economic analysis and optimization of the heat recovery of utility boiler flue gas. *Applied Energy*.

Xu, T., & Flapper, J. (2011). Reduce energy use and. *Energy Policy*.

Zuber, M. J., Hasanbeigi, A., & Morrow, W. R. (2021). *Electrification of Boilers in U.S. Manufacturing.* Sustainable Energy & Environmental Systems Department Energy Analysis & Environmental Impacts Division Lawrence Berkeley National Laborator.

APPENDIX

Appendix 1: Electricity consumption of the reference year 2080-81

Month	Consumed Unit: kWh				kWh costs, NPR	Max Demand: kVA	Demand Cost, NPR	Total Cost, NPR
	T1: Peak Time	T2: Normal Time	T3: Off-Peak Time	Total				
Shrawan 080	35000	68000	23000	126000	1073100	324.38	81095	1154194
Bhadra 080	38000	78000	26000	142000	1206300	355.7	88925	1295225
Ashoj 080	35000	67000	24000	126000	1069950	355.7	88925	1158875
Kartik 080	30000	63000	20000	113000	961650	324.38	81095	1042744
Mangsir 080	29000	65000	18000	112000	957450	324.38	81095	1038545
Poush 080	33000	60000	19000	112000	962100	357.8	89450	1111400
Magh 080	29000	64000	19000	112000	954300	383.6	95900	1110050
Fagun 080	30000	65000	19000	114000	973350	383.6	95900	1129100
Chaitra 080	31000	67000	21000	119000	1011750	383.6	95900	1173800
Baishakh 081	34000	70000	24000	128000	1085100	328	82000	1167100
Jestha 081	32000	69000	24000	125000	1055550	328	82000	1137550
Asar 081	37000	84000	26000	147000	1247100	342.8	85700	1332800
Total	**393000**	**820000**	**263000**	**1476000**	**12557700**		**1047985**	**13851383**

Appendix 2: Production of the Reference year 2080-81

Month/Year	Standard Milk (L)	Whole Milk (L)	Cow Milk (L)	Tea Milk (L)	Flavored Milk (L)	Yoghurt (L)	Raw Milk Receipt (L)
Shrawan 080	1624510	289750	262508	78850	3285	20895	20207250
Bhadra 080	1570090	280767	282278	56360	2500	24290	
Ashoj 080	1508627	272570	240093	54510	2700	21080	
Kartik 080	1356570	245690	235923	34550	1050	16600	
Mangsir	1509740	262850	222273	43150	0	7950	
Poush	1488600	256760	212483	40720	0	6260	
Magh	1509390	254900	209738	35350	1050	8030	
Fagun	1574380	262930	219373	36000	0	9100	
Chaitra	1528840	257940	215273	32540	1365	20300	
Baishakh 081	1534650	262195	236353	31190	1890	25965	
Jestha 081	1581480	268610	222633	31590	1530	32475	
Asar 081	1520420	254990	211573	31230	720	31165	
Total	**18307297**	**3169952**	**2770501**	**506040**	**16090**	**224110**	**20207250**

Appendix 3: Diesel Consumption for the reference year 2080-81

Month/Year	Diesel Consumption, Liter		
	Boiler: Milk Processing	**Diesel Generator**	**Total**
Shrawan 080	26754	765	27519
Bhadra	26607	1909	28516
Ashoj	27881	780	28661
Kartik	28257	1092	29349
Mangsir	27244	988	28232
Poush	25921	312	26233
Magh	25427	104	25531
Fagun	24285	260	24545
Chaitra	24108	416	24524
Baishakh 081	24157	260	24417
Jestha	22883	624	23507
Asar	22785	2340	25125
Total	**306309**	**9850**	**316159**

Appendix 4: Measured Three-Phase Electrical Parameters

Date	Time	Line Voltage in Volts			Line Current in Amps				True Power (kW)	Apparent Power(kVA)	P.F
		AN	BN	CN	A	B	C	N			
12/3/2025	13:06	237.36	235.42	236.77	236.24	211.3	238.29	8.08	152.69	162.47	0.94
12/3/2025	13:30	236.66	234.74	235.94	240.29	217.83	253.79	11.5	158.46	168.24	0.94
12/3/2025	14:00	236.69	234.92	235.83	238.02	220.45	261.76	13.1	161.04	170.34	0.95
12/3/2025	14:30	235.3	233.61	234.87	282.29	246.31	272.07	8.59	175.74	188.13	0.93
12/3/2025	15:00	238.39	236.79	238.05	335	296.54	324.2	9.84	219.52	227.54	0.96
12/3/2025	15:30	238.04	236.36	237.6	332.83	293.62	316.4	8.18	215.54	224.08	0.96
12/3/2025	16:00	239.56	237.77	239.01	331.65	291.96	314.23	7.83	215.17	224.26	0.96
12/3/2025	16:30	239.81	237.97	239.32	327	295.04	302.32	5.99	212.72	221.18	0.96
12/3/2025	17:00	242.16	240.34	241.77	273.64	246.27	257.05	5.99	173.19	187.74	0.92
12/3/2025	17:30	246.1	244.11	245.54	217.26	199.39	224.76	9.13	145.51	157.54	0.92
12/3/2025	18:00	245.75	243.54	244.99	217.42	200.75	215.71	6.12	144.49	155.26	0.93
12/3/2025	18:30	242.12	239.5	240.84	220.75	201.53	214.05	5.69	142.81	153.36	0.93
12/3/2025	19:00	243.84	241.31	242.63	234.79	210.6	230.1	8.19	152.91	164.08	0.93
12/3/2025	19:30	247.13	244.84	246.42	228.77	203.86	215.38	5.66	148.11	159.69	0.93
12/3/2025	20:00	248.82	246.65	248.27	221.4	204.57	217.92	6.24	145.65	159.74	0.91
12/3/2025	20:30	250.65	248.85	250.1	243.76	244.8	252.66	7.33	145.92	185.25	0.79
12/3/2025	21:00	250.35	248.8	250.06	235.69	240.33	241.29	6.44	140.31	179.17	0.78
12/3/2025	21:30	182.1	180.66	181.74	164.72	157.35	157.19	4.07	72.62	87.01	0.83
12/3/2025	22:00	250.05	248.18	249.63	229.92	228.13	224.96	6.21	138.17	170.29	0.81
12/3/2025	22:30	249.42	247.74	249.15	195.92	202.9	192.78	7.48	122.52	147.24	0.83
12/3/2025	23:00	248.97	247.59	248.92	184.76	193.13	187.56	6.05	112.62	140.56	0.8
12/3/2025	23:30	248.84	247.3	248.84	155.48	171.64	158.24	9.22	107.63	120.71	0.89
12/3/2025	0:00	249.11	247.67	249.19	174.66	186.33	177.03	8.34	110.19	133.88	0.82
12/3/2025	0:30	249.3	247.93	249.36	152.34	165.6	161.81	7.35	97.36	119.5	0.81
12/3/2025	1:00	250.04	248.74	250.16	147.14	161.72	152.72	7.07	90.83	115.36	0.79
12/3/2025	1:30	250.1	248.77	250.28	149.92	161.05	154.52	6.22	94.34	116.32	0.81
12/3/2025	2:00	250.13	248.77	250.27	147.44	156.19	156.81	6.01	90.07	115.05	0.78
12/3/2025	2:30	251.43	250.05	251.48	141.89	151.45	152.63	6.16	88.28	112.02	0.79

Date	Time	Line Voltage In Volts			Line Currents in Amps				True Power	Apparent Power	P.F
		AN	BN	CN	A	B	C	N			
12/3/2025	3:00	251.41	250.04	251.51	145.5	154.51	156.88	6.22	89.77	114.76	0.78
12/3/2025	3:30	251.45	250.14	251.63	134.15	143.5	145.22	6.15	83.5	106.26	0.79
12/3/2025	4:00	252.44	251.04	252.5	146.76	155.39	156.66	5.94	89.93	115.69	0.78
12/3/2025	4:30	252.55	251.09	252.45	131.88	140.82	135.95	5.51	80.4	103.05	0.78
12/3/2025	5:00	251.57	250	251.17	152.08	159.86	159.48	6.07	91.18	118.34	0.77
12/3/2025	5:30	249.79	248.08	249.16	157.43	167.16	160.96	6.41	101.88	120.97	0.84
12/3/2025	6:00	249.39	247.47	248.72	144.67	134.52	153.07	9.4	97.1	107.65	0.9
12/3/2025	6:30	249.68	247.59	248.72	149.52	154.06	177.07	12.9	98.41	119.98	0.82
12/3/2025	7:00	248.55	246.19	247.56	139.01	133.81	164.86	13.9	99.52	108.92	0.91
12/3/2025	7:30	247.5	245.31	246.36	156.21	137.91	164.35	8.84	105.14	113.32	0.93
12/3/2025	8:00	244.99	242.59	243.55	201.58	180.73	206.37	10.5	129.38	143.75	0.9
12/3/2025	8:30	243.53	241.12	242.1	240.59	206.38	246.89	12.6	157.26	168.65	0.93
12/3/2025	9:00	243.93	241.65	242.77	239.06	207.73	235.09	8.37	154.72	165.86	0.93
12/3/2025	9:30	243.44	241.27	242.36	243.62	226.54	244.38	7.83	164.03	173.31	0.95
12/3/2025	10:00	243.35	241.28	242.28	246.63	222.42	259.49	14	167.4	176.97	0.95
12/3/2025	10:30	244.39	242.37	243.56	282.93	251.47	291.37	14.4	190.55	201.49	0.95
12/3/2025	11:00	244.89	243.04	244.39	349.37	311.63	334.31	9.49	233.37	243.25	0.96
12/3/2025	11:30	246.82	244.84	246.26	247.1	224.72	246.21	9.24	165.76	176.8	0.94
13/3/2025	12:00	247.62	245.81	247.25	273.23	240.87	264.86	8.67	178.63	192.61	0.93
13/3/2025	12:30	248.21	246.59	248.15	304.42	268.43	288.95	8.44	199.39	213.73	0.93
13/3/2025	13:00	248.7	247.08	248.59	319.16	282.1	306.4	8.95	210.21	225.53	0.93
13/3/2025	13:30	249.14	247.51	248.75	256.34	247.69	267.44	6.84	156.88	191.79	0.82
13/3/2025	14:00	248.38	246.82	248.24	298.53	268.92	298.22	11.1	197.71	214.79	0.92
13/3/2025	14:30	134.86	133.98	134.84	160.88	145.09	158.2	5.51	59.05	62.53	0.94
13/3/2025	15:00	170.78	169.75	170.36	43.08	43.2	49.46	3.21	77.9	231.84	0.34
13/3/2025	15:30	249.36	247.74	248.79	199.41	204.33	222.81	8.22	122.01	156	0.78
13/3/2025	16:00	249.38	247.75	248.98	237.37	233.7	249.4	5.86	139.06	179.27	0.78
13/3/2025	16:30	248.98	247.11	248.53	245.79	228.45	243.97	5.67	144.57	178.36	0.81
13/3/2025	17:00	248.79	246.98	248.42	320.81	290.63	312.62	8.29	189.26	229.45	0.82
13/3/2025	17:30	248.69	246.85	248.33	321.2	291.99	305.25	5.34	182.78	227.91	0.8
13/3/2025	18:00	249.11	247.02	248.6	299.87	265.29	285.7	7.19	186.11	211.5	0.88

Date	Time	Line Voltage in Volts			Line Currents in Amps				True Power	Apparent Power	P.F
		AN	BN	CN	A	B	C	N			
13/3/2025	18:30	246.51	244.06	245.39	235.43	219.05	236.37	9.19	156.69	169.59	0.92
13/3/2025	19:00	246.68	244.12	245.52	219.33	195.42	210.78	7.14	142.51	153.73	0.93
13/3/2025	19:30	248.33	245.96	247.44	221.35	203.27	214.7	6.64	147.53	158.19	0.93
13/3/2025	20:00	249.39	247.47	248.78	260.76	246.21	252.67	5.43	151.01	188.85	0.8
13/3/2025	20:30	250.18	248.35	249.51	227.85	228.25	234.07	6.09	134.88	172.12	0.78
13/3/2025	21:00	250.96	249.22	250.39	217.29	219.48	221.21	5.38	127.9	164.64	0.78
13/3/2025	21:30	251.27	249.68	250.77	218.82	221.01	223.76	5.54	128.66	166.3	0.77
13/3/2025	22:00	252.96	251.5	252.67	216.11	219.45	219.38	4.85	126.83	165.3	0.77
13/3/2025	22:30	253.49	252.12	253.27	210.12	215.71	215.2	4.96	124.88	162.18	0.77
13/3/2025	23:00	253.44	252.14	253.3	216.27	223.55	223.07	5.44	127.68	167.71	0.76
13/3/2025	23:30	253.4	252.14	253.28	203.55	210.75	209.93	5.17	121.08	157.92	0.77
13/3/2025	0:00	254.19	252.82	254.07	172.56	191.53	184.88	7.21	117.72	139.43	0.84
13/3/2025	0:30	253.77	252.5	253.61	168.25	176.33	179.99	5.59	104.52	132.94	0.79
13/3/2025	1:00	254.32	253.08	254.25	163.09	174.18	170.53	5.65	101.96	128.99	0.79
13/3/2025	1:30	254.54	253.34	254.49	142.79	147.64	148.83	4.79	90.45	111.66	0.81
13/3/2025	2:00	254.73	253.52	254.71	143.5	151.27	150.08	5	87.92	113.18	0.78
13/3/2025	2:30	255.29	254	255.28	136.36	143.78	143.2	5.02	84.3	107.94	0.78
13/3/2025	3:00	255.64	254.29	255.61	136.09	143.23	141.83	4.92	83.69	107.51	0.78
13/3/2025	3:30	256.18	254.83	256.05	136.76	144.46	142.32	4.95	83.85	108.34	0.77
13/3/2025	4:00	256.07	254.68	255.96	132.54	139.51	137.9	4.89	81.87	104.82	0.78
13/3/2025	4:30	255.53	254.07	255.41	132.66	139.45	141.49	5.58	82.73	105.54	0.78
13/3/2025	5:00	254.13	252.6	254	136.79	143.03	150.91	6.81	84.99	109.35	0.78
13/3/2025	5:30	254.83	253.15	254.55	145.45	151.57	153.45	5.67	88.05	114.55	0.77
13/3/2025	6:00	251.74	249.72	251.09	147.87	159.38	167.83	8.8	100.96	119.39	0.85
13/3/2025	6:30	248.59	246.53	247.67	106.59	104.59	124.75	9.33	55.1	83.54	0.66
13/3/2025	7:00	245.29	242.64	244.26	214.71	185.08	232.95	15.4	144.91	155.24	0.93
13/3/2025	7:30	243.09	240.7	242	227.24	196.49	237.67	11.9	149.17	160.55	0.93
13/3/2025	8:00	242.76	240.59	241.78	182.18	162.47	188.75	8.71	104.14	129.23	0.81
13/3/2025	8:30	242.25	240.11	241.52	240.48	202.82	240.41	9.97	154.25	165.51	0.93
13/3/2025	9:00	242.2	240.06	241.62	241.93	209.82	237.93	7.45	155.18	166.73	0.93
13/3/2025	9:30	241.62	239.43	241.06	235.97	208.61	240.93	9.45	156.33	165.37	0.95

Date	Time	Line Voltage in Volts			Line Currents in Amps				True Power	Apparent Power	P.F
		AN	BN	CN	A	B	C	N			
13/3/2025	10:00	242.29	240.19	241.61	240.61	228.1	254.58	8.59	166.52	174.79	0.95
13/3/2025	10:30	242.58	240.62	242.21	264.77	221.69	258.29	9.61	171.8	180.65	0.95
13/3/2025	11:00	243.57	241.74	243.36	252.81	225.54	248	6.31	167.76	176.65	0.95
13/3/2025	11:30	243.87	242.24	243.87	261.57	231.46	262.05	8.84	175.69	184.06	0.95
13/3/2025	12:00	242.73	240.99	242.56	250.02	227.64	248.95	7.41	167.88	176.09	0.95
13/3/2025	12:30	242.89	241.23	242.67	244.72	235.07	255.02	7.93	170.45	178.14	0.96
13/3/2025	13:00	242.91	241.25	242.92	271.65	243.16	267.91	7.02	181.94	189.94	0.96

Appendix 5: COP Refrigeration

Description	Unit	Value
Evaporation Temperature OC	oC	-10
Condenser Temperature OC	oC	40
Evaporator Pressure @-10oC	kPa	427.3
Condenser Pressure @40oC	kPa	1557.8
Enthalpy of Saturated Vapour (h1)	kJ/kg	1427
Enthalpy of Saturated liquid (h4)	kJ/kg	293.3
Enthalpy of Saturated Vapour (h2)	kJ/kg	1707
Enthalpy of Saturated liquid (h3)	kJ/kg	293.3
Work Done by Compressor	kJ/kg	280
Refrigeration Effect	kJ/kg	1133.7
COP		4.05

Appendix 6: Performance Assessment of Steam Boiler

Indirect Method		
Parameter	Experiment -1	Source
Ultimate fuel analysis		
Carbon percentage (%)	87.30	Source: GIZ audit report
Hydrogen percentage (%)	12.60	
Oxygen percentage (%)	0.04	
Sulphur percentage (%)	0.22	
Theoretical air required (kg/kg)	14.52	
Excess air supplied		
Oxygen percentage (%)	14.10	Flue gas reading
Excess air supplied (%)	204.35	
Actual mass of air supplied (kg/kg)	30.67	
Heat loss due to dry flue gas		
Temperature of flue gas (°C)	177.30	Flue gas reading
Ambient air temperature (°C)	22.30	
Specific heat capacity of flue gas (kJ/kg·°C)	1.005	
Excess air (%)	204.35	
Gross calorific value of fuel (kJ/kg)	42,800	Source: WECS synopsis report 2024
Heat loss due to dry flue gas (%)	11.53	
Heat loss due to hydrogen in fuel		
kg of hydrogen on a 1kg basis (kg/kg)	0.13	
Specific heat capacity of superheated steam (kJ/kg·°C)	2.10	
Latent heat (kJ/kg)	584	
Heat loss due to hydrogen in fuel (%)	2.41	
Heat loss due moisture present in the fuel		
kg of moisture in fuel on a 1 kg basis (kg/kg)	1.00	Source: GIZ audit report
Heat loss due to moisture present in fuel (%)	2.13	
Heat loss due to the moisture present in the air		
Humidity factor (kg/kg)	0.02	
Heat loss due to moisture present in air (%)	0.47	
Heat loss due to incomplete combustion		
Volume of CO in flue gas (%)	0.0006	Flue gas reading
Volume of CO2 percent in flue gas (%)	5.10	
Carbon content per kg of fuel (kg/kg)	0.87	
Heat loss due to partial combustion (kJ/kg)	5,744	
Heat loss due to incomplete combustion (%)	0.0014	
Unaccounted losses		
Radiation, convection, and miscellaneous (%)	3	
Efficiency (%)	80.47	

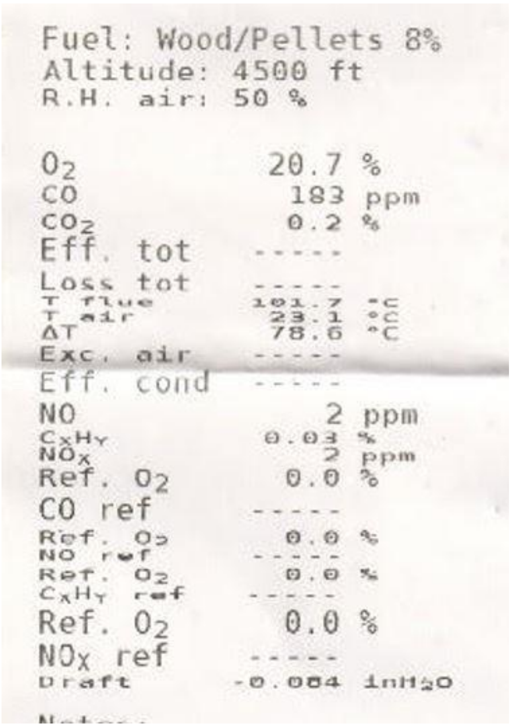
After Adjustment

Indirect Method	
Parameter	Experiment -1
Ultimate fuel analysis	
Carbon percentage (%)	87.30
Hydrogen percentage (%)	12.60
Oxygen percentage (%)	0.04
Sulphur percentage (%)	0.22
Theoretical air required (kg/kg)	14.52
Excess air supplied	
Oxygen percentage (%)	12.00
Excess air supplied (%)	133.33
Actual mass of air supplied (kg/kg)	20.36
Heat loss due to dry flue gas	
Temperature of flue gas (℃)	177.30
Ambient air temperature (℃)	22.30
Specific heat capacity of flue gas (kJ/kg·℃)	1.005
Excess air (%)	133.33
Gross calorific value of fuel (kJ/kg)	42,800
Heat loss due to dry flue gas (%)	7.77
Heat loss due to hydrogen in fuel	
kg of hydrogen on a 1kg basis (kg/kg)	0.13
Specific heat capacity of superheated steam (kJ/kg·℃)	2.10
Latent heat (kJ/kg)	584
Heat loss due to hydrogen in fuel (%)	2.41
Heat loss due moisture present in the fuel	
kg of moisture in fuel on a 1 kg basis (kg/kg)	1.00
Heat loss due to moisture present in fuel (%)	2.13
Heat loss due to the moisture present in the air	
Humidity factor (kg/kg)	0.02
Heat loss due to moisture present in air (%)	0.31
Heat loss due to incomplete combustion	
Volume of CO in flue gas (%)	0.0006
Volume of CO2 percent in flue gas (%)	5.10
Carbon content per kg of fuel (kg/kg)	0.87
Heat loss due to partial combustion (kJ/kg)	5,744
Heat loss due to incomplete combustion (%)	0.0014
Unaccounted losses	
Radiation, convection, and miscellaneous (%)	3
Efficiency (%)	84.38

Oper.: Operator 1
Sign.:
E4500-C
Serial: 2363
Date: 00/04/25
Time: 09:26 PM
Draft -0.084 inH2O
Notes:

Oper.: Operator 1
Sign.:
E4500-C
Serial: 2363
Date: 00/04/25
Time: 09:26 PM
Fuel: Diesel
Draft -0.088 inH2O
Notes:

A. Diesel Boiler Flue gas Analyzer



Fuel: Wood/Pellets 8%
Altitude: 4500 ft
R.H. air: 50 %

O_2	20.7	%
CO	183	ppm
CO_2	0.2	%
Eff. tot	-----	
Loss tot	-----	
T flue	101.7	°C
T air	23.1	°C
ΔT	78.6	°C
Exc. air	-----	
Eff. cond	-----	
NO	2	ppm
C_xH_Y	0.03	%
NO_x	2	ppm
Ref. O_2	0.0	%
CO ref	-----	
Ref. O_2	0.0	%
NO ref	-----	
Ref. O_2	0.0	%
C_xH_Y ref	-----	
Ref. O_2	0.0	%
NO_X ref	-----	
Draft	-0.084	inH_2O

B. Wood boiler Flue gas Analyzer

Appendix 7: Ammonia Induction Motor

Time	Line Voltage			Line Current				True Power	Apparent Power	Power Factor
	AB	BC	CA	A	B	C	N			
12:30	416.62	416.93	418.66	96.61	92.35	93.94	9.14	17.63	22.72	0.77
12:35	418.49	419.18	420.80	95.95	91.72	94.68	8.49	17.71	22.79	0.78
12:40	418.50	419.15	420.82	95.80	92.12	94.53	9.30	17.72	22.80	0.78
12:45	419.70	420.47	422.40	95.81	92.12	95.45	7.79	17.70	22.95	0.77
12:50	419.80	420.10	422.25	95.72	92.49	94.34	6.85	17.57	22.87	0.76
12:55	419.96	420.29	422.72	95.43	91.40	94.22	5.58	17.55	22.77	0.77
13:00	419.72	419.96	422.26	95.15	91.68	93.76	4.69	17.50	22.71	0.77
13:05	419.77	419.83	422.26	95.29	91.41	93.65	4.80	17.45	22.69	0.76
13:10	421.12	420.99	424.19	96.06	92.04	92.33	4.76	17.56	22.78	0.77
13:15	419.62	419.26	421.59	94.74	92.83	92.47	5.43	17.59	22.64	0.77
13:20	417.81	417.91	421.27	95.88	92.24	93.08	5.71	17.45	22.67	0.76
13:25	418.85	418.98	421.74	93.88	91.16	92.83	5.76	17.28	22.45	0.76
13:30	417.60	417.78	420.30	94.66	91.79	93.25	5.02	17.40	22.53	0.77

Appendix 8: Carbon Emission calculation

Description	**Value**
Diesel CO_2 emission factor (kg CO_2 per liter)	2.68
Diesel Consumption in Liters	34006
Total CO_2 emission from diesel (kg CO2 per liter)	91136
Wood CO_2 emission factor (kg CO_2 per kg of wood)	1.6
Total wood consumption	76496
Total emission from wood (kg CO_2 per kg of wood)	122393
Although wood produces higher CO_2 emissions, it is considered carbon-neutral over time because trees absorb CO_2 during growth. Diesel, on the other hand, releases fossil carbon, contributing directly to climate change.	

Appendix 9: Tools Used

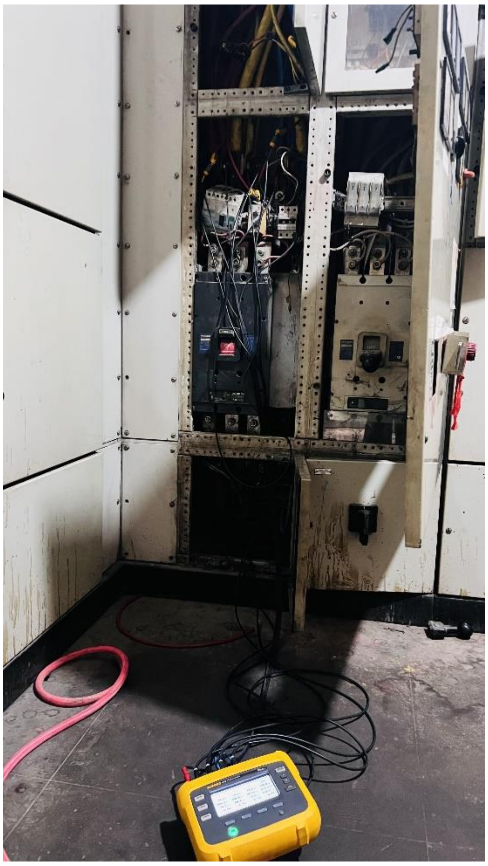
A. Gun Thermmeter   B. Clamp on meter   C. Power Analyzer

Appendix 10: Pictures of the Plant KMSS

Kathmandu Milk Supply Scheme (DDC)

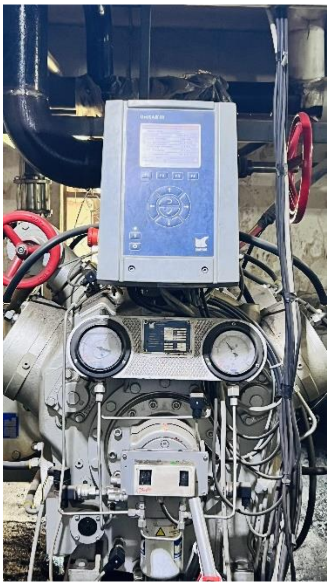
A. Boiler

B. Boiler Feed water



C. Power analyzer setup

D. Flue gas analyzer setup



E. Compressor

F. Capacitor Bank

G. Scaled Condenser

F. Refrigeration Pipelines

G. Flue gas System

[IOEGC16] Editor Decision

2025-03-24 10:32 AM

Anita Rijal, Co-author:

We are pleased to inform you that your manuscript titled "The Techno Economic and Environmental Analysis of Dairy Industry : " A case study of Dairy Development Cooperation" submitted to 16th IOE Graduate Conference is **Accepted** for presentation in the Conference as well as inclusion in the Peer-Reviewed Proceedings. Please note that inclusion in hard copy proceedings is contingent upon your timely response to further edits, if any, during the publication process.

With Warm Regards,
IOEGC-16 Editorial Team

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