

CHAPTER I

INTRODUCTION

1.1 Background

The industrial sector constitutes the largest energy-consuming domain globally, accounting for 37% of total final energy consumption, with a substantial portion derived from fossil fuel combustion for heat and electricity generation [1]. Within this context, energy-intensive processing industries, particularly the palm oil refinery sector, face mounting pressure to enhance operational efficiencies and reduce their carbon footprint [2]. Global palm oil production, exceeding 75 million tons annually, is predominantly concentrated in Southeast Asia, with Indonesia and Malaysia as the primary producers [3]. Palm oil refineries are characterized by energy-demanding processes including degumming, neutralization, bleaching, deodorization, fractionation, hydrogenation, and texturization, all requiring substantial thermal and electrical energy inputs [4].

Despite this energy intensity, most refinery facilities in developing regions lack systematic energy management practices, typically relying on reactive measures rather than proactive planning strategies, thereby limiting their energy efficiency potential [5]. Moreover, energy efficiency improvements are commonly introduced only during operational audits, frequently overlooking optimization opportunities available during the design phase [6]. The systems approach to energy management, which emphasizes the integration of organizational structures, processes, and technologies to optimize energy performance across interconnected systems [7], has emerged as a critical framework for achieving sustainable energy efficiency in industrial settings [8]. This holistic approach differs from traditional component-based energy management by analyzing energy flows, process interactions, and operational dependencies across the entire facility as an integrated system [9].

A promising solution lies in implementing structured Energy Management Systems (EnMS) following ISO 50001:2018 recommendations, which promote continuous performance improvement through the Plan-Do-Check-Act (PDCA) cycle [10][11][12]. Multiple studies have demonstrated EnMS effectiveness across various industrial sectors. Apriyanti et al. [13] reported energy savings of 47,700 GJ and CO₂ emission reductions of 11,805.75 tons in the pulp and paper industry. Similarly, Custodio et al. [14] documented an 8% reduction in monthly electricity consumption following ISO 50001 implementation in brick manufacturing, translating to annual savings of 522,048 kWh. However, these studies primarily focused on retrofitting existing facilities with available operational data.

Successful EnMS implementation requires top management commitment, clearly designated energy management roles, and cross-functional collaboration through steering and technical committees [15]. Thollander and Palm [16] identified organizational barriers to energy efficiency, emphasizing that effective implementation demands both technical solutions and systematic organizational change. Karcher [17] further highlighted the importance of integrating energy management into corporate strategy and decision-making processes for sustained performance improvement. Best practices emphasize utilizing Energy Performance Indicators (EnPIs), performance baselines, and normalization techniques to enable accurate energy performance tracking across individual, system, and organizational boundaries [18].

Previous research has demonstrated that integrating energy management into early plant design stages enables more effective equipment selection, layout optimization, and energy performance forecasting [19][20]. Elbeltagi et al. [21] showed that prioritizing energy management from the design outset can achieve up to 25% reduction in building energy consumption. Williams and McKane [22] emphasized that the systems approach to industrial energy efficiency requires considering energy flows and interdependencies from the design phase. However, a critical gap exists: while numerous studies address EnMS implementation in operational facilities, limited

research focuses on developing proactive energy management systems using design-phase data and simulation modeling.

The application of Best Available Techniques (BAT) and benchmarking tools such as ISO 50006 strengthens energy-saving opportunity identification in industrial design and operation [23][24][25]. Hehenberger et al. [26] proposed a framework modeling energy-specific properties across various product and process levels, ensuring effective component interaction for energy consumption optimization. Energy Performance Indicators (EnPIs) are crucial for industries to monitor and improve energy efficiency, reduce emissions, and achieve sustainability goals [27][28]. Benchmarking helps identify production process energy inefficiencies, promoting awareness and highlighting potential energy-saving opportunities [29].

In the palm oil industry specifically, existing energy management research reveals significant limitations. Sommart and Pipatmanomai [30] conducted energy audits in operational crude palm oil mills, suggesting boiler retrofitting and heat recovery system enhancement, achieving 7% energy savings. Noraini et al. [31] analyzed electrical energy patterns in palm oil mills, identifying efficiency improvement areas with potential savings of 31.49%. However, these studies were limited to existing operational facilities and focused primarily on individual equipment optimization rather than systematic energy management. Lakshmanan et al. [32] discussed sustainable practices in edible oil refining complexes but provided no structured framework for energy management implementation.

Several critical gaps emerge from the literature review. First, existing palm oil refinery energy management studies predominantly focus on operational facilities with available historical data, creating a significant gap in design-phase energy management approaches [30][31][32]. Second, while the systems approach to energy management has been widely advocated in manufacturing industries [7][8][9], its specific application to palm oil refineries using integrated organizational and technical frameworks remains underexplored. Third, the development of EnMS using

simulation-based modeling and design data, particularly for ISO 50001 compliance, has not been adequately addressed in palm oil sector literature.

This study aims to develop a proactive Energy Management System (EnMS) for palm oil refineries using a systems approach applied during the plant design phase. The research investigates how engineering design data can estimate energy baselines, structure an ISO 50001-compliant framework, and define Energy Performance Indicators (EnPIs) without relying on historical operational data. By addressing these aspects, this research fills a critical gap in energy management literature—specifically, the absence of system-based methodologies tailored to new industrial facilities before operational commencement.

The study focuses on developing a design-stage energy management system for a large-scale palm and lauric oil refinery in the Sei Mangkei Special Economic Zone (SEZ), North Sumatra, with projected annual capacity exceeding 450,000 metric tons. The facility encompasses multiple processing lines—refining, fractionation, hydrogenation, and texturization—primarily targeting international export markets. In the absence of operational data, the study utilizes engineering design information and simulation-based modeling to estimate energy consumption and structure an ISO 50001-compliant EnMS prior to plant commissioning.

The primary contribution of this research is developing a novel, proactive energy management framework that addresses the critical gap in design-phase energy planning for industrial facilities. Unlike existing approaches relying on post-commissioning operational data, this study presents the first comprehensive methodology for developing an ISO 50001-compliant EnMS using design specifications and simulation modeling specifically for the palm oil refinery sector. The systems approach integrates organizational structures, technical specifications, and performance monitoring systems into a unified framework replicable across energy-intensive manufacturing domains. Furthermore, this research demonstrates the feasibility of using simulation-based EnPI modeling as a performance-planning tool without real-time data, offering

a novel and replicable framework for energy-intensive industries pursuing sustainability from inception.

1.2 Objective

The objective of this study is to:

1. Develop a comprehensive, proactive energy management system for palm oil refinery, utilizing plant design data and equipment specifications in the absence of historical operational data.
2. Create a framework for continuous improvement in energy efficiency, including strategies for data collection, analysis, and system optimization.
3. Establish a set of relevant and measurable Energy Performance Indicators (EnPIs) tailored to the specific processes of palm oil refinery, enabling effective monitoring and improvement of energy performance during operations.

1.3 Scope of Study

The scope of this study is as follows:

1. This research focuses on the development and implementation of an Energy Management System (EnMS) within a palm oil refinery, with a specific emphasis on defining and applying Energy Performance Indicators (EnPIs) to measure and enhance energy efficiency.
2. The study is limited to the major processes within the refinery, specifically fractionation, refinery, hydrogenation, and texturization. Other processes, such as utilities and ancillary operations, are only considered where they directly impact the energy performance of these core processes.
3. The illustrative examples and analysis are based on a hypothetical dataset representing a single month of operation. Long-term trends, seasonal variations, and external factors influencing energy performance are acknowledged but not deeply explored within this study.

4. The research is confined to the technical and operational aspects of energy management within the refinery. Broader economic, environmental, or social implications of energy management practices are beyond the scope of this thesis.

1.4 Paper Framework

The framework of this study is as follows:

Chapter I: Introduction

This chapter introduces the background of the study, highlighting the importance of energy management in palm oil refineries. It defines the research problem, formulates key questions, and sets clear objectives. Additionally, it explains the benefits of this study in terms of energy efficiency and operational cost reduction.

Chapter II: Literature Review

The literature review establishes the theoretical foundation for the study by discussing key concepts related to energy management systems, international standards (such as ISO 50001), and best practices in the palm oil industry.

Chapter III: Methodology

This chapter details the research methodology, outlining the step-by-step process of designing the EnMS framework. It describes the data collection methods, including plant design references and energy consumption modeling, and explains the analytical tools used. A structured flowchart is presented to illustrate the sequence of research activities, ensuring clarity in methodology execution.

Chapter IV: Energy Management Framework Validation

This chapter presents the proposed energy management framework, detailing its structure, key components, and implementation strategy. The framework is then validated by an experienced Energy Management Committee to assess its practicality and alignment with operational requirements.

Chapter V: Conclusion

The final chapter summarizes the research findings, highlighting the feasibility and benefits of the proposed EnMS framework. It provides a critical evaluation

of the study's limitations and suggests future research directions to further improve energy management practices in palm oil refineries.

