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Energy Management and Waste Heat Recovery in the Malaysian Oleochemical Industry

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Abstract

The Malaysian economy heavily relies on the agricultural-based oleochemical industry, which is known for its thermal energy-intensive operation but is considered green due to its use of natural fats and oils. It significantly contributes to the economy and focuses on exports. However, challenges such as stringent global emission regulations and escalating energy costs prompt industrial practitioners to seek approaches to reduce energy consumption, lower carbon footprint, and improve profit margin. While the petrochemical industry has seen significant research in energy management, energy efficiency assessments, tools, and artificial intelligence for big data analysis, a comparable level of attention has not been observed in the oleochemical sector. Despite the potential for fuel savings through reduced consumption without compromising production output or quality, waste heat recovery methods remain underexplored in the oleochemical industry. Existing literature shows that energy management programs have been applied in the oleochemical industry to address challenges related to lower fuel consumption. However, there is a notable gap in the adoption of waste heat recovery practices within oleochemical factories. This study aims to fill this research gap by investigating energy management practices, energy efficiency measures, and approaches to waste heat recovery adoption in the oleochemical industry. Bridging this gap will provide novel insights and practical solutions to enhance energy efficiency, minimize carbon emissions, and improve the overall sustainability of the oleochemical sector.

Keywords

Oleochemical, Energy Management Program, Waste Heat Recovery, Carbon

Footprint Reduction

1. Introduction

The Malaysian manufacturing sector, particularly chemicals and chemical products contributes significantly, comprising 6.1% of Malaysian export-oriented industries [1]. However, the industrial activities supporting Malaysia's economy are closely associated with increased energy consumption, leading to higher waste gas emissions. Research has focused on reducing fuel consumption and implementing energy management practices in factories, including waste energy recovery [2] [3]. Emerging research works are also underway in the Malaysian oleochemical industry to reduce cost and CO_2 emissions [4]-[6]. However, there is a lack of reported research on waste heat recovery in the Malaysian oleochemicals sector, which impacts the industry's sustainability in terms of fuel processing costs and CO_2 emissions.

The Malaysian oleochemical's industry is export orientated, and it faces stricter regulations on waste gasses emissions mandated by statutory agencies, particularly in alignment with the 2015 Paris Agreement and European Union (EU) standards [7]. These regulations have intensified the pressure on Malaysian oleochemical players to strengthen their environmental control measures.

Malaysian researchers have increasingly focused on addressing the challenges posed by global warming from the oleochemical perspective. For instance, mitigation efforts have evolved over time, transitioning from palm oil-based biodiesel production in the 1980s to more recent advancements in algal-based biodiesel production. These developments in biodiesel production have contributed to a reduction in carbon emissions [8]. Seminal work in the field of carbon emission pinch analysis (CEPA) has not only been developed but also applied and expanded, originally from carbon-constrained energy sector planning and subsequently across a range of emission and environmental constraints [9].

The oleochemical industry is recognized for its high energy consumption, with thermal separation unit operations being common. The energy-intensive nature is due to the production process often involving distillation and fractionation processes. Effective energy management, especially concerning fuel and electrical costs, is crucial for business continuity. Efficient fuel cost management has been a key focus for both academic and industrial practitioners. However, there is a lack of research in the literature on recovered waste heat utilization in oleochemical factories, which can also significantly reduce fuel consumption. Addressing this gap could yield substantial benefits for optimizing processing costs in the oleochemical industry.

Nevertheless, it is essential to recognize that waste heat recovery in the oleochemical industry holds promise for the future of Malaysia's oleochemical sector. The exploration of waste heat recovery in oleochemical firms is worth evaluating.

However, the literature review conducted in journals has revealed a limitation in the availability of such information [10].

2. Literature Review

In this study, we aim to explore critical aspects of energy management within the Malaysian oleochemical sector. Firstly, we seek to identify the level of awareness and implementation of energy management practices, particularly focusing on the utilization of free energy sources such as waste heat recovery. Secondly, we will investigate the current obstacles hindering waste heat energy recovery initiatives within the sector. Additionally, we will propose a taxonomy tailored to the manufacturing environment to facilitate the development and implementation of effective heat energy recovery strategies. By addressing these research questions, we aim to provide valuable insights that can inform and enhance energy management practices in the Malaysian oleochemical industry.

In the context of Malaysia, the industrial sector accounts for 26% of the total energy product supply, equivalent to 57,637 kilotonnes of oil equivalent (ktoe), according to data from the MySEEA PSUT Energy 2015 survey [1]. Malaysia's CO_2 emission for 2019 was recorded at 253.27 million tonnes [11]. The energy consumption breakdown is as follows: the industrial sector leads with 49%, followed by the commercial sector at 30%, the residential sector at 21%, and smaller contributions from the agriculture sector at 0.4% and the transportation sector at 0.3% [12]. Despite its high energy intensity, the oleochemical industry, holds significant importance as a contributor to Malaysia's Gross Domestic Product (GDP) and employment. Notably. The palm oil industry alone provides jobs for 437,696 individuals [1]. In 2023, the export of palm oil and oil palm products generated RM 94.95 billion in revenue for Malaysia [13]. Palm oil serves as the primary feedstock for the energy-intensive oleochemical industry, which, in turn, contributes revenue to the Malaysian economy but also results in significant greenhouse gas (GHG) emissions into the environment.

Table 1. Energy consumption in petrochemical company [15].

Energy consumption	Units	2019	2020	2021
Natural gas	ktoe	143.78	113.95	165.55
Fuel gas	ktoe	721.96	667.42	681.87
Purchased electricity	ktoe	31.45	32.46	28.67
Total	ktoe	897.17	813.83	876.10
Production	KT	2854	2592	2688
Energy intensity	Ktoe/KT	0.3144	0.3140	0.3259

Oleochemicals encompass a diverse group of chemical components primarily derived from vegetable oils, and fats obtained from plants and animals. However, they can also be synthesized using components produced by the petrochemical industry [14]. It's worth noting that oleochemical companies rarely publish their energy consumption data. However, energy consumption from a similar industry, a petrochemical plant located in southern Malaysia, researcher is provided in **Table 1** illustrates the energy intensity in a petrochemical plant [15]. Oleochemical and petrochemical industries share similar thermal separation processing, and both belong to energy-intensive sectors.

The unit processes involved in basic oleochemical production, which consumed high energy, include vegetable oil hydrolysis, sweet water evaporation, glycerine distillation and bleaching and fatty acid/fatty alcohol fractionation and distillation [16]-[18]. These processes utilize energy sources such as electricity and natural gas for utility generation including steam, and as heating sources for the thermal separation process. Boilers and heaters are commonly used in oleochemical processes for heat energy generation [14], and these activities emit carbon dioxide and other waste gases.

For example, in oil transesterification and fatty acid esterification processes, excess methanol is required for reaction completion, and recycling methanol is energy-extensive. In the USA, the National Biodiesel Board reported an energy of 4.4 MJ for each gallon of biodiesel production [19]. Distillation/fractionation remains the most energy-demanding thermal separation process required by oleochemical industries, accounting for over 50 percent of plant processing costs [20]. Oleochemical industries employ these high-energy consumption processes to produce distilled or fractionate fatty acid/methyl ester/fatty alcohol [5] [21]-[23]. Literature reviews have shown that the adoption of an appropriate energy management program such as energy review, energy audits, employees' knowledge, awareness, and commitment to energy management has led to carbon emissions reductions in both Malaysian and Swedish manufacturing firms [3] [23].

2.1. Energy Management in Industry

Energy management has emerged as a solution to address the energy efficiency gap within the industrial sector [3] [24]. Energy management in a company involves the implementation of energy-efficient technology but also the implementation of processes on how technology and processes are used at the company. Academic experts recommend the use of monitoring and optimization tools to enhance energy efficiency and overcome physical limitations using process integration techniques such as Pinch technology in reducing carbon intensity [25].

Based on author's practical industrial observations, investment in energy-saving projects often receives lower priority compared to investments in yield and production improvement initiatives. Similar findings were reported by Thollander *et al.* (2020) in Swedish and UK companies [26]. However, between 2019 and 2020, an energy-saving initiative at an oleochemical complex in Klang Valley demonstrated significant cost-saving potential. By implementing improved steam management in the tank farm with minimal investment, the facility achieved monetary savings exceeding one million ringgit. One possible root cause for this prioritization is the relatively low fuel cost in the Malaysian context. However, with rising energy cost in Malaysia, for manufacturing companies, energy costs significantly impact the overall cost of the product. Natural gas prices have increased from an average of RM 38/mmbtu in 2020 to RM 65/mmbtu in the first half of 2023, which erodes business profits.

Overcoming firm owners' reluctance to prioritize energy program such as waste heat recovery (WHR) due to cost and potential disruptions, a well-planned approach is key. Firms should consider phased implementation, starting with low-risk, high-impact areas, and integrate WHR installations with planned maintenance shutdowns to minimize downtime. Small-scale pilot projects can also be used to evaluate system performance, build confidence, and address challenges before full deployment. These strategies allow for effective WHR adoption while maintaining operational efficiency and reducing disruptions.

The manufacturing industry sector is one of the highest energy-consuming sectors globally [27]. According to the US Energy Information Agency (EIA), it is projected that the refineries utilization in the United States will remain above 90% over the next two years, similarly to the levels observed in 2022. This increase is to meet the demand for transportation and industrial purposes. Additionally, the EIA forecasts that global energy consumption and energy-related carbon dioxide emissions will continue to rise until 2050 due to population growth, economic expansion, and increasing energy consumption in developing Asian economies. Furthermore, oil and natural gas production are expected to grow, primarily to meet the rising energy demand in these developing Asian economies [28].

For manufacturing companies, one of the most promising means of reducing energy consumption and related energy costs is implementing energy management within an organization [23] [26] [29]. The pursuit of energy efficiency in the manufacturing industry has been ongoing for the past two decades [30], with extensive literature provided by researchers on energy management for Swedish companies [26]. However, there is limited journal coverage regarding energy management specifically for the oleochemical industry, except for emerging studies [4]-[6]. Additionally, some kinds of research on waste heat recovery have been conducted by researchers [2] [3] [10].

2.2. Energy Management Framework

The energy management framework and standards provide a structure for conducting energy reviews and audits. These processes allow for the analysis of energy consumption, assessment of heat recovery potential, and identification of opportunities for energy savings [3]. Some of the background searches related to the energy management framework are listed below.

The State Government of Victoria [31], has introduced Module 4 in the Energy and Greenhouse Management Toolkit, providing comprehensive guidance for energy management systems. This module outlines a systematic approach to energy management: In the initial step, organize resources and appoint an energy manager, establish an implementation team, and deploy a corporate energy management policy with reduction targets. In the following phase, create a detailed action plan, allocate budgets, implement awareness and training programs, and oversee the execution of energy-saving projects. Lastly, regular reviews should be conducted, and progress should be assessed. By following this approach, organizations can efficiently manage energy consumption and work towards achieving their goals reduction [32].

EN 16001, an energy management system standard published in 2009 by the European Union, is in alignment with ISO 14001 and is based on the plan-do-check-act cycle. It assists organizations in establishing comprehensive energy management systems and continually improving energy utilization performance, which leads to lower energy costs and reduced greenhouse gas emissions [33].

ISO 50001 standard serves as the global benchmark for energy management systems and was first published in June 2011. This standard was developed by integrating elements from ISO 9001 Quality Management System (QMS) and ISO 14,001 Environmental Management System (EMS). Organizations have widely adopted ISO 50001 as a roadmap for energy management, and it has been implemented [34]. It comprises five phases that emphasize continuous improvement: policy, planning, implementation, checking and corrective action and management review. It follows a plan-do-check-act cycle, designed based on the Deming quality management system.

Energy management, at its core, aims to reduce energy wastage without compromising production quantity or product quality while simultaneously minimizing a company's environmental impact [35]. Applied ISO 50001 in a study to optimize energy consumption in the operations of an Irish dairy plant [34]. It has strategically assisted companies in implementing programs [26] [36].

Malaysia has implemented several policies and initiatives to promote energy efficiency, environmental protection, and industrial sustainability. These include the Energy Efficiency and Conservation Act (2024) [37], which regulates energy consumption and conservation. The EECA aims to enhance energy efficiency across various sectors, reduce energy waste, and support Malaysia's goal of achieving carbon neutrality by 2050. Additionally, the Circular Economy Policy Framework by MITI [38] seeks to redefine traditional industrial models. This framework encourages the transition towards green growth by promoting resource efficiency and waste minimization throughout the manufacturing value chain. The adoption of waste heat recovery practices aligns well with these objectives, contributing to overall energy efficiency and sustainability goals.

2.3. Energy Management in Manufacturing Sector

Research conducted within Malaysian manufacturing firms has shed light on energy management practices aimed at mitigating thermal energy issues, albeit with minor findings reported in journal articles. For instance, Fernando *et al.* (2017) [23] discuss the implementation of energy efficiency measures, while case studies on the heat integration of boilers and the optimization of heat exchanger networks have also been documented [4] [5].

However, research on mitigating thermal energy issues within Malaysia remains limited. To supplement these findings, studies conducted outside Malaysia, particularly in Swedish and German firms, as well as the USA, provide valuable insights. For example, Lou, Y. (2016) [2] focuses on the recovery of waste heat energy within manufacturing facilities.

Notably, studies have highlighted the significant impact of energy management programs in reducing energy costs, with potential savings ranging from 4 to 40% [39]. Furthermore, comprehensive assessments conducted within Swedish firms have identified key elements crucial for effective energy management, including barriers to implementation, evaluation methodologies, and top management leadership [40]-[42] as shown in **Table 2**. A comprehensive assessment focusing on characterization has also been conducted within Sweden's medium and large-sized energy-intensive firms [43]. The essential elements captured in this characterization are summarized in **Table 3**.

Table 2. Summary of energy management research works undertaken in manufacturing sector's.

Year	Author	Research work
1995 [39]	Caffal	Found energy management program conducted within the factories could reduce energy costs by 4 to 40%.
2016 [2]	Luo, Y.	Doctorate Dissertation in Waste Heat Recovery in Manufacturing sector, at United Kingdom
2018 [26]	Mechaussie, E.M.	Methodology for efficient use of thermal energy in the chemical and petrochemical Industry.
2020 [36]	Halo, N. *et al.*,	Barrier gap of energy efficiency network to energy efficiency?
2020 [37]	Kanchiralla, F.M. *et al.*,	Energy end-use characterization and performance indicators for Energy management in the Engineering industry
2020 [38]	Konig, W *et al.*,	Establishing Energy Efficiency-Drivers for energy efficiency in German manufacturing Small-and Medium-Sized Enterprises.
2021 [36]	Jalo, N *et al.*,	Barriers to and Drivers of Energy management in Swedish SMEs

Table 3. Characterization of Energy Management practices [40].

	Attribute studied
1	Type of energy management practices
2	Type of energy efficiency improvement
3	Target of energy management practice
4	Position in the industrial energy management setting
5	Development stage
6	Method of adoption
7	Extend of adoption
8	Organization involvement

By synthesizing findings from both Malaysian and overseas research, a more comprehensive understanding of energy management practices and their effectiveness in mitigating thermal energy issues can be attained.

2.4. Energy Management for Oleochemical and Petrochemical

2.4.1. Oleochemical

Even though limited literature exists on oleochemical's energy management [5] [10], an overview write-up on oleochemical distillation and fractionation processes has been provided [13]. Zarlie pointed out that due to the heat sensitivity of fatty acids, the design of distillation units for thermolabile fatty acids requires a careful approach, involving high vacuum and lower temperature conditions to prevent cracking or polymerization. Short residence time at the column bottom is essential. Distillation processes utilize deaerators, thermal oil, or high-pressure steam as heat sources, along with condensing and vacuum making them intensive-energy.

Emerging literature revealed in Malaysian oleochemical sector has been revealed [4]-[6], as shown in **Table 4**. However, existing research works have not yet provided a comprehensive framework for assessing waste heat recovery (WHR). This gap is worth exploring extensively within the oleochemical industry.

Table 4. Emerging energy management research works undertaken for Malaysian oleochemical firms.

Year	Author	Research work undertaken	Impact of study
2019	Koh, K.S *et al.*,	Utilization of waste gas recovery case studies, focusing on reduction of fuel consumption and greenhouse gas emission in Malaysian oleochemical firm.	a saving of 17.29% of fuel consumption and approximated 149.49 tonnes per annum of carbon dioxide gas (CO_2)
2021	Trisha, V. *et al.*,	Applied Aspen Energy Analyser V 10 to retrofit heat exchanger network of an oleochemical plant	save over 80% in annual costs and reducing energy consumption by 1,882,711 gigajoules per year (GJ/year).
2022	Lee, T. S. *et al.*,	Steam Network Optimization and CO_2 reduction in an oleochemical production complex.	29.56% - 50.82% cost saving and reduction of CO_2 emissions of 95,222 tonne carbon per year

2.4.2. Petrochemical

Energy management has garnered significant attention in China and Russia's petrochemical industry. It has been reported that the Russian petrochemical has the highest energy consumption [44]. Specifically, for ethylene production, China's plants have shown considerably lower energy efficiency compared to international counterparts [27] [45] [46]. According to the International Energy Agency (IEA) [27], the energy used for ethylene production is substantial, amounting to 1700 TWh annually. Petrochemical process is known for their high energy consumption, over 50 percent of operating costs in ethylene plants are attributed to energy cost [47] [48]. Similarly, oleochemical exhibit a comparable pattern, as observed by the author's industrial experience.

Research attention in the petrochemical industry surpasses that in the oleochemical industry. Research conducted in the petrochemical sector is summarized in Table 5.

Table 5. Energy management reported in the petrochemical industry.

Petrochemical		
Year	Author	Research undertaking
2018 [3]	Mechaussie, E.M.	A proposal was made for the efficient utilization of thermal energy in the chemical and petrochemical industry
2020 [45]	Han, YM *et al.*,	Review-Energy efficiency evaluation of complex petrochemical industries
2019 [49]	Gong, S.X *et al.*,	An energy efficiency integration optimization scheme for ethylene production with respect to multiple working conditions was undertaken.
2021 [47]	Cronshaw, M *et al.*,	Petrochemical in energy perspective
2020 [50]	Kramer, A *et al.*	Artificial intelligence in process control applications and energy saving: a review and outlook
2020 [44]	Sinkevich, A. I. *et al.*,	Modelling of energy efficiency factors of petrochemical industry was studied.
2021 [51]	Han, YM *et al.*,	Resource optimization model using novel extreme learning machine with t-distributed stochastic neighbor embedding: Application to complex industrial processes
2021 [46]	Han, YM *et al.*,	Energy analysis and resources optimization of complex chemical processes: Evidence based on novel DEA cross-model
2023 [48]	Chanin Panjapornpon *et al.*,	Improving energy efficiency prediction under aberrant measurement using deep compensation networks is reported for A case study of petrochemical process
2023 [49]	Shixin Gong *et al.*,	Multi-scale energy efficiency recognition and diagnosis scheme for ethylene production based on a hierarchical multi-indicator system
2023 [52]	Hu, Jianqing *et al.*,	Optimization and assessment method for total energy system retrofit in the petrochemical industry considering clean energy substitution for fossil fuel

The implementation of energy-saving programs has led to a reduction in energy intensity, decreasing from 129.62 kg of conventional fuel per 10 thousand rubles to 104.72 kg in petrochemical enterprises [44]. The steam system optimization program was implemented across 220 Japanese plants, including 48 refineries and petrochemical plants, over 16 years, resulting in a significant reduction of 562,000 tons of CO_2 emissions and a decrease in steam generation by 3.85 million tons [49]. Efficient energy management in petrochemicals not only brings economic benefits but also contributes to environmental preservation [45] [49]. The implementation of Artificial Neural Network (ANN) systems in oil and gas reported savings of 14.2% and 19.4% compared to the control case [50].

Han *et al.* (2021) offered a comprehensive review of energy efficiency evaluation methods for the petrochemical industry [45]. They identified three types of methods, including traditional transport mechanism, data-driven artificial intelligent (AI), and hybrid methods. While the traditional method is precise, it is labor-intensive and suitable for simple processes. Data-driven AI can handle complexity, and hybrid methods combine both approaches. For instance, prediction modeling integrated with data-driven methods has been highlighted in journals as a means to bridge the energy efficiency gap [48]. Carbon emissions from ethylene plants are reduced by approximately 2.87% using the extreme learning machine (ELM) method based on t-distributed stochastic neighbor embedding (t-SNE) to optimize energy and reduce carbon emissions [51]. Artificial intelligence is widely used in oil and gas for plant optimization and Production Dynamic Prediction of Oilfield [53].

The petrochemical industry is continually evolving, and emerging research approaches in the petrochemical industry are gaining attention. For instance, the adoption of additive manufacturing (AM) has resulted in a reported 70% reduction in costs in the oil and gas sector [50] and 25% - 55% less power consumption [51]. Positive benefits have been noted [48] [50]. However, the full exploration of Additive manufacturing (AM) in energy management within the oil and gas industry remains an area of ongoing research [50]. Additionally, a multi-objective optimization approach was reported to enhance both thermal efficiency for energy-saving and reduce the NOx Emission Index (EINOx) in gas turbines operation. This approach utilized a global optimization algorithm known as the Genetic Algorithm (GA) [52]. Furthermore, dynamic models have been applied at various levels (system, process, and equipment) for ethylene production, particularly under varying working conditions [49]. A Mix-integer Non-linear programing (MINLP) optimization with GAMS software was used to reduce total exergy consumption by 3200 KW in the retrofit of the petrochemical complex [52].

Top of Form

Lotte Chemical Titan Holding Berhad (LCT), a prominent petrochemical player located in southern Malaysia, has implemented an energy management program to address energy efficiency matters. Their approach includes replacing obsolete systems, optimizing energy usage in plant operations, and developing action plans to execute energy-saving opportunities with Key Performance Indicators (KPI), such as a 0.5% energy reduction target. They have also undertaken initiatives like installing solar photovoltaic (PV) panels, retrofitting inefficient motors, and conducting internal energy audits [15].

Based on the authors' industrial observations, an oleochemical complex in Klang Valley has implemented a fundamental energy management system in its tank farm and unit operations since 2000. The initiatives include retrofitting the condensate recovery system, upgrading the least energy-efficient equipment, establishing short-term and mid-term energy-saving programs, and conducting various energy optimization initiatives. These programs are led by the in-house process engineering team using tools such as commercial simulation software package. However, the application of big data analysis or Artificial Neural Network (ANN) systems has not yet been observed in the factory environment.

2.5. Energy Efficiency in Industry

Maximizing energy efficiency has become increasingly significant for managing energy costs, reducing reliance on external sources, promoting energy sustainability, and safeguarding the environment and natural resources [54], energy efficiency involves using energy without compromising life standards, needs, and product quality by prioritizing high efficiency and savings. It entails reducing energy consumption per unit of service or product quantity without compromising living standards and service quality in buildings, production, and quality industrial enterprises. The application of energy efficiency typically involves stages such as implementing an energy management system, identifying potential savings through energy audits, preparing action plans, and utilizing the best available technologies [3] [54].

The energy efficiency and energy management gap as the difference between the potential for energy efficiency and what is actually implemented. Continuous energy management practices in companies contribute to further improvements in energy efficiency, rather than solely relying on new technology. Similar gaps have been observed in oleochemical firms [26] as shown in **Figure 1(a)** and **Figure 1(b)**.

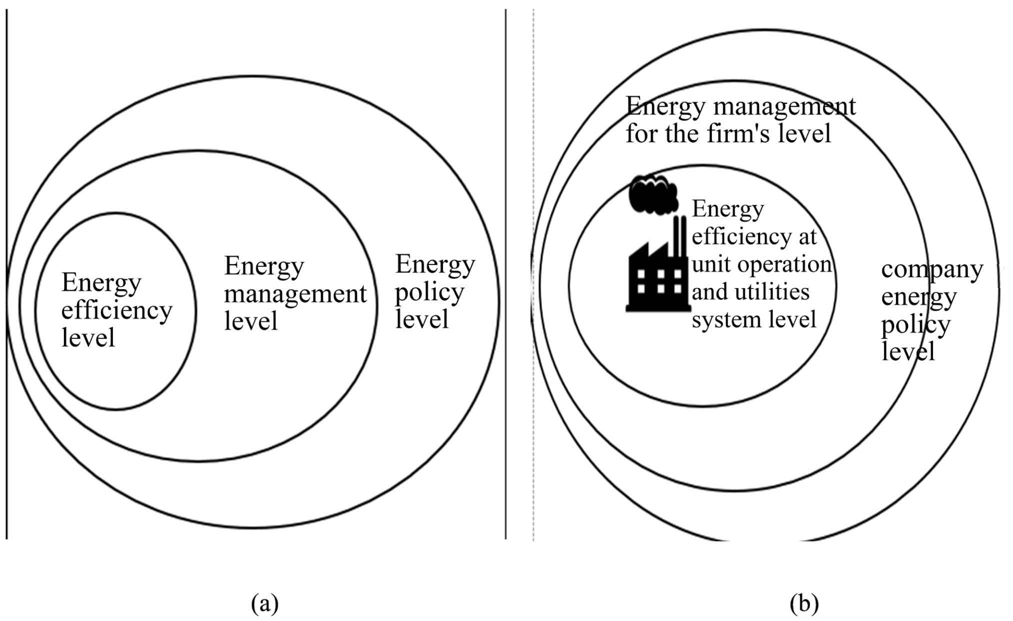

Figure 1. (a) Typical Energy Efficiency Gap derived from Thollander, P. *et al.*, (2020); (b) Energy Efficiency Gap in Malaysian oleochemical firms.

Energy management practices in Malaysian manufacturing firms are in the early stages of development, resulting in marginal improvements in energy efficiency [26]. Swedish research also indicates obstacles to the adoption of energy efficiency measures in industries, including limited organizational and managerial commitment to innovation and investment, primarily due to economic and technical barriers [26] [55].

Implementing an energy efficiency improvement program is a complex and challenging endeavor, often starting with energy audits and mapping energy consumption and identifying possible measures for improving energy efficiency. Key elements for successful implementation include management commitment, organizational culture, employee behavior towards energy wastage, knowledge of the system, and leadership by experts [3] [54] [56]. Utilizing energy more efficiently is a cost-effective approach that reduces CO_2 emissions, improves productivity, and reduces dependence on imported energy sources [2].

Research on improving energy efficiency has expanded [30]. A systematic literature review was conducted to address gaps in energy assessment. Total 1758 papers were screened and studies. The study aimed to provide a comprehensive overview of energy management in manufacturing for academia, industry, and policymakers [30].

Industrial improvements in energy efficiency have been observed, particularly in energy management, integrated with pinch analysis, which has been applied in petrochemical plant [2] [3]. Energy efficiency implementation observed Extensive use of electric motor systems also observed in energy efficiency implementation which 70% - 96% of energy could be saved in motor electric systems [54] [57].

Artificial intelligence technology was employed for energy-saving management in industrial buildings [58]. The research encompassed the evaluation of circuit architectural design, workflow processes, and the functionality of the electrical equipment control interface. Additionally, it examined the specific hardware design of the energy consumption acquisition module and intelligent gateway. The study revealed that the implementation of intelligent energy-saving management effectively reduced energy consumption in industrial buildings [58].

The Data Envelopment Analysis (DEA) method evaluated total factor energy efficiency and its determinants across 31 industrial sectors in Beijing spanning from 2002 to 2018. The findings indicated that the industrial sectors in Beijing exhibit low energy efficiency, which is primarily attributed to inefficiencies in management practices. Furthermore, heavy industries demonstrated higher energy efficiency levels in comparison to light industries [59].

The adoption of motor systems utilizing Industrial 4.0 (I4.0) aims to enhance industrial energy efficiency through the integration of Artificial Intelligence (AI) [60].

A Study conducted in China's 30 provinces from 1997 - 2016 utilized the Meta frontier method combined with the stochastic frontier to analyze energy efficiency performance, focusing on technological gaps [61].

In Malaysia, the government supports energy efficiency measures to reduce greenhouse gas emissions through initiatives such as the Malaysia Energy Efficiency Action Plan and the development of Intended Nationally Determined Contributions (INDC). This commitment is further outlined in the 12th Malaysia Economy Plan, which charts Malaysia's path to achieving net-zero emissions, including the goal of carbon neutrality by 2050 [62].

2.6. Waste Heat Recovery

Waste heat is commonly released in oleochemical industry, often in the form of waste gas, waste steam and waste condensate, which is released without recovered. The author opined such wasteful phenomenon may be due to a lack of alignment between business strategies and energy management by the firm's owner. Based on actual billing data for Natural Gas (NG) in Malaysia, gathered from the author's industrial experience, the cost of fuel has increased significantly. For instance, one unit of MMBtu of Natural Gas was traded at an average of RM 28/MMBtu in 2018 compared to RM 68/MMBtu in 2023 (Q1). In plants, waste heat can significantly enhance combustion efficiency by heating the combustion air for boilers or furnaces. Each 28˚C increase in air temperature correlates with a 1% rise in combustion efficiency. Waste heat recovery from combustion air is very applicable [54]. It is estimated that around 17% of the UK industrial energy consumption ends up as waste heat that is not utilized [63].

Waste heat source that can be considered for recovery are available widely including high-temperature source (620 - 1700˚C), medium-temperature source (160 - 815˚C), and low-temperature (32 - 232˚C) [2]. The best practices for utilizing high-temperature waste heat for power generation is through heat recovery steam generators [64].

In the case of medium temperature, a commonly implemented waste heat recovery method in oleochemical firms involves heat exchange with the flue gas from furnace or boilers to heat up fresh combustion air or a liquid medium. Industrial practitioners often rely on rules of thumb to estimate the boiler efficiency [63] [64].

For lower temperature level, heat recovery technology is known as Organic Rankine Cycle (ORC), which utilizes low boiling temperature organic agents. A comprehensive review paper on ORC, steam Rankine cycle (SRC), turbo compound (TC), and thermoelectric generators (TEG) [10]. The organic Rankine cycle (ORC) is commonly selected for waste heat recovery due to its versatility in operating with low, medium, and high-temperature heat sources. This flexibility makes it highly compatible with various waste heat sources, making it a preferred choice in waste heat recovery technologies, waste heat recovery enables to generates electricity [63]. For low temperature grade waste heat recovery, reported comprehensive literature review conducted in harnessing industrial waste heat recovery for district heating purpose [65] and using long-term dynamic simulations integrated with borehole thermal energy storage [66].

Research on waste heat recovery has been undertaken. [2] studied waste heat recovery in manufacturing in United State of America and developed a software tool for waste heat recovery optimization. Additionally, [10] conducted a study in Malaysian oleochemical industry. They aimed to recover waste heat for reducing fuel costs and CO_2 emission through the reuse of thermal oil heater's flue gas.

A recent study conducted examined global publication trends in Waste Heat Recovery (WHR) research from 1991 to 2020 [10]. The study utilized bibliometric analysis on 5649 publications extracted from the Web of Science (WoS) database. The findings highlighted that WHR research mainly focused on technologies such as Organic Rankine Cycle (ORC), Steam Rankine Cycle (SRC), Turbo Compound (TC), and Thermoelectric Generators (TEG) [10].

Waste heat recovery has been widely utilized for power generation, including the utilization of low-grade waste heat in roots power machines [67]. However, the adoption of low-grade waste heat recovery in oleochemical firms is currently limited, indicating a gap in WHR implementation within the oleochemical industry.

The Onion diagram, originally invented by Linnhoff in 1982 [68], was modified by Mechaussie, E. M. (2018) [3] to identify the potential waste heat recovery in petrochemical plants. In Mechaussie's study, technologies for recovering waste heat were evaluated using a bottom-up approach, which is linked to the modified Onion diagram and Pinch Analysis. In Mechaussie's modified onion's diagram, it consists of several layers, progressing from inner layer to outer layers involving the following steps (1) Process technology: Modifying chemical process technology at the process level (2) Process operating parameters: Modifying operating conditions (e.g., temperature, pressure, reflux ratio) for higher energy efficiency. (3) Process heat integration: Redesigning the heat exchanger network using pinch analysis (4) Heat pumping: Identifying heat pumping opportunities based on the shape of the grand composite curve (5). Energy conversion: Utility system supplying the remaining process heating and cooling as needed (6) Operation and maintenance: Associating with determining optimal operation set points and the establishing proper maintenance, especially at the level of the steam distribution network.

Table 6. Illustrates some of the emerging technologies in the waste heat recovery market.

No	Medium temperature (600˚ to 1200˚ F or 315˚ to 650˚ C)	Low temperature (250˚ to 600˚ F or 120˚ to 315˚ C)	Ultralow temperature (< 250˚ F or 120˚ C)
1	Recuperators with innovative heat transfer surface geometries	Convection recuperator (metallic) of many different designs	For corrosion resistant heat exchangers, with phase change material *i.e.*, Non-metallic (polymer or plastic)
2	Advanced design of metallic heat wheel-type regenerators	Advanced heat pumps	Absorption systems for latent heat recovery from moisture-laden gases using desiccant.
3	Self-recuperative burners Systems with phase change material	Membrane type systems for latent heat recovery from water vapor	Membrane-type systems for latent heat recovery from water vapor
4	Advanced design of metallic heat wheel	Low temperature power generation (*i.e.*, ORC, Kalina cycle, etc.)	Condensing water heaters or heat exchangers

Some obstacles to waste heat recovery have been identified, including reluctance to prioritize modifications to thermal and electrical energy-saving processes within unit operations by firm owners, who prioritize meeting customer requirements in manufacturing. Additionally, frequent startups lead to unnecessary energy wastage [54]. Another challenge lies in the absence of a justified strategy and a reliable methodology for analyzing waste heat recovery, compounded by insufficient data to accurately characterize waste heat sources. These factors collectively hinder the effective implementation of waste heat recovery initiatives in the industrial sector [64].

Table 6 shows emerging technologies excerption at the development market of waste heat recovery, which is sourced from [64].

2.7. Novelty of Energy Management in Oleochemical Industry

An extensive literature review has been undertaken in the field of energy management for various industries, including the manufacturing and building heating sector (see **Table 7**). The research covers topics such as waste heat recovery and utilization, energy efficiency tools and assessment methods, as well as the drivers and barriers to the implementation of energy management programs, among others. However, it is worth noting that there has been a gap in the development of decision framework for utilization of energy management and waste heat recovery specifically in the oleochemical industry. This report aims to explore and address these untapped opportunities.

Table 7. Summary of academic review undertaken for various topics.

No	Author	Year	No of articles under studied	Area of search
1	Kuah, C.T. *et al.*, (2022) [10]	1991 - 2020	5682 articles from Web of Science, using bibliometric method	Waste heat recovery, Waste heat utilization, Energy efficiency
2	Andrei, M. *et al.*, (2022) [69]	2010 - 2020	157 articles (final) from Scopus and Web of Science	Knowledge management, Energy management
3	Kawtar I.B. *et al.*, (2023) [62]	2016 - 2022	1758 articles from Scopus	Energy efficiency, Manufacturing industry
3	Menghia, R. *et al.*, (2019) [38]	2012 - 2018	1367 articles, zoom down to 64, from Web of Science, Scopus and ScienceDirect	Tools and methods for energy efficiency assessment
4	Lee, D.S *et al.*, (2016) [70]	1976 - 2014	305 cases (final) from Science Direct	Building energy management system
5	May, G. *et al.*, (2016) [53]	1995 - 2015	365 articles (final) Scopus and Web of Science	drivers and barriers, energy management
6	Schulze, M *et al.*, (2015) [29]	1979 - 2014	931 articles, zoom down to 44, from Web of Science, EBSCO (including Business Source Complete and EconLit) and ScienceDirect	Energy management for industry, Energy management system, Energy efficiency

3. Outlook and Perspective

The Malaysian oleochemical industry, which took root in the 1980s, has experienced significant growth over the past four decades. However, it is noteworthy that there is a lack of research in energy management specifically focused on reducing energy consumption through the use of waste heat recovery systems. Drawing from the author's practical experiences within the industry, it becomes evident that energy management implementation in the oleochemical sector has predominantly centered on investment priority, with minimal integration into broader business strategies. Given the industry's export-oriented nature and the global emphasis on stricter CO_2 emission control, there arises an increasingly pressing need for a more proactive approach to energy management within Malaysian oleochemical production.

In recent years, energy management practices within the Malaysian oleochemical production sector have gained increasing attention from researchers, primarily due to its substantial thermal energy consumption. Current research endeavors have been centered on various areas, including waste gas recovery, steam network optimization, and heat exchanger retrofitting [4]-[6]. These initiatives and efforts are aimed at achieving energy efficiency gains and reducing the industry's carbon footprint.

However, there remains a notable gap in comprehending the processes regarding waste heat recovery implementation in oleochemical facilities. This gap presents a compelling avenue for further investigation.

4. Conclusion

Waste heat recovery in the Malaysian oleochemical industry remains largely untapped. However, literature reviews have shown that bridging this gap and harnessing waste heat in oleochemical firms are not only possible but also feasible. Through the implementation of energy management practices and the utilization of waste heat recovery, higher energy efficiency can be achieved, ensuring the sustainability of the Malaysian oleochemical business. Furthermore, the reuse of waste heat can play a pivotal role in reducing CO_2 emissions and addressing the challenge of lower energy consumption within the oleochemical industry. In summary, a promising and bright future awaits in the field of energy management within the oleochemical industry.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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