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A review on techno managerial approaches to energy optimization in chemical process industries

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The chemical process industries, being energy intensive in nature, still struggle to strategically and sustainably consider energy management issues. Energy sustainability depends on a sustainable energy supply, consumption, and waste disposal. This paper analyses current energy management and optimization in industries and also attempts to identify the significance of incorporating energy management into the strategic perspectives of industry through an exhaustive literature review. To ensure the optimization of energy, the paper illustrates the importance of adopting a techno-managerial approach that integrates the technical aspects of energy conservation with relevant management tactics. This is also a preliminary study for proposing a framework for Indian chemical process SMEs to systematically overcome various challenges and seize the opportunity to ensure optimized energy utilization, thereby highlighting the framework's long- and short-term benefits. The suggestions in the paper would help these industries and local- and national-level policymakers to improve their energy footprint and make the world more energy sustainable.

KEYWORDS

energy, energy management, energy conservation, sustainability, energy sustainability, energy optimization

1 Introduction

Energy sustainability depends on a sustainable energy supply, sustainable energy consumption, and sustainable waste disposal. Energy has been considered a support function in industry, with no to low priority in terms of conservation since the main focus of industry is to enhance productivity (Schulze et al. 2016). Chemical process industries, being energy intensive in nature, still struggle to strategically and sustainably consider energy management issues. This situation is changing rapidly due to a decreasing availability in crude oil, gas, and coal, rising energy prices, increasing awareness about their environmental effects, and a concern to alleviate climate change. Chavan and Jain (2014) proposed that energy management and energy efficiency are separate but interconnected concepts. Energy efficiency is vital part of energy management and is attained when energy intensity (energy required per unit of product) in a specific product, process, or area of production or consumption is lowered without affecting production output or consumption. This paper analyses the current energy management and optimization scenario in industry and also attempts to identify the importance of incorporating energy management into the strategic perspectives of these industries through an exhaustive literature review.

2 Methodology

Kannan & Boie (2003) define "energy management" as "…the judicial and effective use of energy, to maximise profits and to enrich [the] company's competitive positions, through organisational measures and optimising energy efficiency in the [sic.] operations,"—thus combining the skills of engineering and management. Energy management, if carried out properly, decreases energy demand, the operational cost of production, and negative environmental and social impacts. This elevates a company's position in the carbon market, customers' willingness to pay, and shareholders' willingness to invest. To utilize available energy effectively and make industrial systems sustainable, industries must optimize energy through energy management and efficient solutions and tools.

According to Schulze et al. (2016), industries have to realize that energy management can be an effective lever for enhancing their production systems and operations toward improved energy efficiency and hence reduce energy use and related energy costs. This is true for process industries as they are major consumers of energy (electricity, oil, gas, and coal) and emitters of greenhouse gases and carbon.

Several factors must be integrated for successful energy optimization; these are investigated in the academic literature through research into topics such as energy management, energy efficiency, the challenges to and drivers of energy management practices, energy efficient methods, energy conservation techniques, and the development of key performance indicators. This paper builds on this previous research by systematically reviewing the literature, as originally outlined by Tranfield et al. (2003) and applied in the area of energy management by Schulze et al. (2016).

Considering advances in technology, the period from 2000 to 2022 has been chosen since many articles, reports, and case studies have been published on energy management practices, energy efficiency, energy management systems, energy efficient technologies, energy performance indicators, and energy performance measurement. The focus when selecting articles was on the following: the time and type of publication; the availability of full-text articles; the sectors considered; the type of studies undertaken (case study, survey, and literature review); and the content of articles, including energy management practices and/or energy efficient methods or technology (Parekh et. al., 2019; Schulze et al., 2016).

The selected articles include peer-reviewed journal articles, and white papers and reports by national agencies to account for continuous improvement and technology diffusion by industries or national agencies. The contents of articles vary, from an emphasis on energy-efficient technology, its application, its analysis, the importance of energy management, case studies of success, benefits of energy management, reports on energy scenarios across the world, energy management practices, and articles that describe successful energy management systems and energy indicators.

Based on the aforementioned criteria, 95 articles, including 81 peer reviewed articles and 14 reports, were studied to discover the best practices available across the world, and their application to chemical process industries. There are 44 articles that showcase the energy-saving opportunities in manufacturing sectors, followed by 26 articles on the chemical process sector, including chemical manufacturing, the petroleum, pharmaceutical, iron and steel, and paper and pulp industries, cement manufacturing, and water treatment plants.

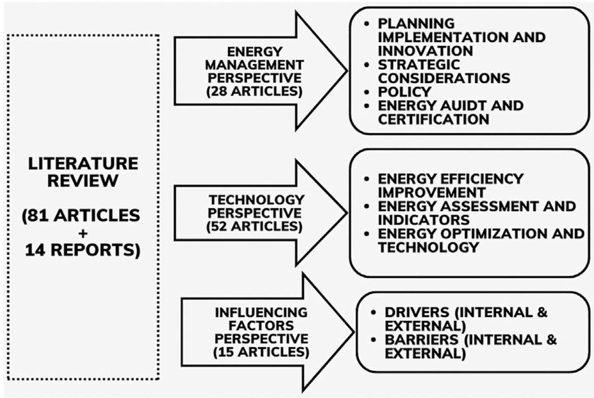

FIGURE 1
Analysis of selected articles.

After identifying the relevant articles, the data were categorised based on their orientation: energy management perspective, energy efficient technology perspective, and positive and negative influencing factors.

3 Categorization of reviewed articles

Many articles are published on energy management practices, but they are fragmented in terms of concepts, industry, country, and policies. Learning from these will help cultivate further research, developments, and innovation unique to relevant sectors, industry types, and countries.

This section analyses and categorises the literature on three major categories: management, technology, and influencing factors. The articles analysed were broadly categorised by their focus of study, highlighting the perspectives of energy management, technology, influencing factors, and energy efficiency (Figure 1).

3.1 Energy management perspective

"Energy management" is planned, monitored, controlled, and executed actions to ensure maximum energy output using minimum energy resources for a predetermined performance by an organization to gain competitive advantage, serve national interests, and adhere to stringent environment standards. Energy management is thus the strategic approach of a company toward its energy usage. The academic literature indicates that energy-intensive organizations that adopt a strategic approach to energy management may reduce energy usage as much as 40%. According to Sivill et al. (2013) and Mulder and Hagens (2008), energy management is below raw materials optimization and production commitment as a priority in energy-intensive industries. Cooremans and Schönenberger (2019) and Schulze et al. (2016) confirm this and argue that considering energy in strategic planning, implementation, and the control, organization, and culture of an organization can exploit a company's energy efficiency potential. Without long-term strategy and the allocation of energy costs, companies will not realise the benefits of energy management. Thollander and Ottosson (2010)

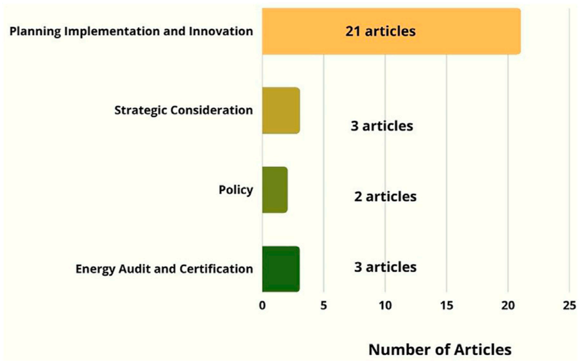

FIGURE 2
Classification of articles with a management perspective.

suggest senior management be involved in developing their company's energy policy, in managing energy-saving projects, and in creating an environment that thus motivates and trains their employees. Schulze et. al. (2016) demonstrated a comprehensive framework for incorporating strategic planning, implementation, control of energy use, reorganizing the organization structure, and modifying an organization's culture to effectively tap its energy efficiency potential. Gopalakrishnan et al. (2014) also suggested a framework of energy management to effectively implement ISO 50001 to reduce the energy costs and losses from minimizing greenhouse gas emissions.

Some 21 articles investigated planning, implementation, and innovation through qualitative and quantitative studies, or a combination of both. Three studies elaborated the process, requirements, and benefits of energy audits and certifications. As illustrated in Figure 2, only three studies investigated the importance of using energy management as a strategic objective; just one article examined the impact of policies on energy management.

Planning and implementation are core to energy management and require a gradual and structured approach that starts from the unit process to the factory facility and multi-facility units, incorporating entire supply chain in the process if possible (Duflou et al. 2012). Alternately, Sivill et al. (2013) focused on incorporating proper change management tools and rewards to make energy management successful. There are many ways to effectively implement energy management in an organization which may differ based on geographic locations, sectors, or the scale of operations. Backlund et al. (2012), using the multiple case study model for Sweden, found energy-intensive firms to be more enthusiastic and successful in adopting energy management.

3.2 Technology perspective

Energy optimization can be achieved through the appropriate channelling of technological interventions and processes by upgrading existing systems or replacing existing systems to achieve energy-efficient systems, depending on the situation. The chemical process industry has a natural scope of energy optimization as it can consume and create energy through various means or can integrate the available energy to achieve higher potential or reduce energy consumption. Lipiäinen et al. (2022) suggest use of bio-alternatives to replace fossil fuels, thus decreasing the carbon intensity of processes.

Exothermic processes release energy into the environment; this can be efficiently trapped for useful energy on-site. Pinch technology and heat exchanger networks (HENs) to integrate process streams are used frequently. Geldermann et al. (2006) took the automobile industry as a case study to demonstrate that blending process integration engineering with operations research can provide economic and environmentally friendly solutions. Waste heat recovery is a big challenge for process industries as it entirely depends on amount, quality, and source of waste heat. Many studies exploit this challenging area of design for recovering low-grade waste heat in the process industry; Law et al. (2016) demonstrated this through a case study, using knowledge-based programs and available plant data. The case study of Oluleye et al. (2016) also investigates different models of on-site waste heat utilization by recording the temperature and duties at the heat source. In a literature review, Chan et al. (2013) illustrated the possibility of recovering low-grade heat using technologies like "Chemical heat pumps, organic Rankine cycles, [and] thermal energy storage. . .". Ammar et al. (2012) evaluated the technical and economic feasibility of extracting low-grade thermal energy using CFD (computational fluid dynamics) for process industries in the United Kingdom, provided that strong government regulations and policies are in place; similar approaches may be applied in other countries.

Even some economical modifications to existing equipment or replacing the energy-intensive with energy-efficient parts can help reduce the energy requirement of the plant. Enhancing awareness and identifying action areas to improve the energy use of processes can be effective if energy analysis is conducted at manufacturing level (Andrei et al.,2022). Saidur et al. (2010) reviewed and further identified energy-saving techniques—such as variable speed drives, energy efficient motors, recovery of waste heat, leakage avoidance, and pressure-drop reduction—for energy-intensive motor-driven process industry equipment. The speed and scale at which technology develops and diffuses across industries, the cost of technology, energy prices, the intensity of chemical industrial activities, and national and international policies will determine the potential effects of mitigation on climate change (Worrell et al., 2009). Xuezhi et al. (2011) emphasised the need for energy saving as a low-cost option with a high potential to benefit the present scenario. Outsourcing energy optimization activities to energy service companies (ESCOs), with the latest know-how required for energy efficiency, and funds to operationalise it, is seen as the latest trend by Benedetti et al. (2015).

According to Lindberg et al. (2015), key performance indicators, used for monitoring operations in industries, need to be benchmarked to similar processes or equipment to classify areas of improvement and necessary actions to be developed and implemented to bridge gaps. Worrell et al. (2003) illustrated the importance of incorporating the productivity benefits associated with energy efficient technologies in terms of cost savings related to conserved energy.

3.3 Influencing factor perspective

Drivers of energy management, as defined by Cagno and Trianni (2013), are ". . .factors facilitating the adoption of both energy-efficient technologies and practices, thus going beyond the view of investments and including the promotion of an energy-efficient culture and awareness." Stringent environment requirement, government regulations, incentives, and awareness have driven Sweden's iron and steel industries to adopting energy management (Brunke et al.,2014). Trianni et al. (2016) and Singh et al. (2008) listed organizations' policies, long-term strategies, top management commitment, and realizing low-energy benefits as positive influencers for SMEs in the manufacturing industry. Rudberg et al. (2013) described the recognition of non-energy benefits for process industries.

Sorrell et al. (2011) defined a barrier to energy efficiency as a hypothesised mechanism that deters an energy-efficient and cost-effective decision or behaviour. They also suggested that barriers to energy efficiency are multidimensional, varied, and diverse, and are specific to the industry type and the technologies they used. Smith et al. (2022) and Lee KH (2015), emphasised that understanding the barriers and drivers to energy conservation and optimization from frontline workers is also important. As found by Singh et al. (2008) for Indian SMEs, the challenge lies in cost, quality, deliverables, and human resources development. Minciuc et al. (2017) considered limited access to capital and knowledge about energy-efficient technologies alongside poor awareness amongst employees and top management as essential barriers for energy conservation and optimization. These are internal factors within organizations that prevent them shifting toward energy-efficient management. Various myths that are negative influencers were identified by Ammar et al. (2012) and Thollander and Ottosson (2010): perceptions that energy-efficient technologies require higher investment and have a negative impact on production. Factors outside the organization can also hinder their effective energy management, such as support from financial institutions for promoting energy-efficient technologies (Worrell et al.,2009), absence of incentives, limited availability of public information, and lower energy prices in developing countries (Bhattacharya and Cropper, 2010; Alcorta et al.,2014). It is imperative to weaken the barriers to and strengthen the drivers for successfully implementing energy management and mitigate climate change. Parekh et al. (2022) categorize drivers and barriers to energy optimization in the Indian context, using literature and a preliminary survey, into internal and external factors and further analysed them using PESTEL analysis for external factors and SWOT analysis for internal factors. The conclusion from the analysis is the importance to designing energy optimum solutions of evaluating internal and external factors based on the situation and industry type.

4 Discussion and conclusion

Energy optimization is the pressing need to mitigate the impact of energy use on climate change on a macro scale. The extensive use of fossil fuels in industrial operations, rising fuel prices, and its fluctuating availability is driving the global movement to conserve energy, increase energy efficiency, and manage operations with minimal energy resources. The literature focuses on improving energy efficiency, the means to conserving energy, and the importance of managing these within organizations. It also focuses on the barriers to and drivers of energy management practices in industry. We have identified three essential gaps in the available sample of the literature: a lack of integration of management and technology perspectives, lack of policy intervention and implementation, and failure by organizations to consider energy as a strategic objective on par with productivity.

The aforementioned review reveals that the integration of technology and management approaches to energy optimization is still nascent. Such an integrated approach may be termed a "techno managerial approach" which combines the benefits of managerial and technological perspectives, detailed analysis of positive and negative influencing factors, and the local and national energy policies; such an approach would serve as a useful tool for industry.

This review further identifies a gap in the studies related to energy management policy implementation in various industrial sectors across different locations. Energy efficiency policies and initiatives devised by governments do exist, but research shows they are rarely implemented by industry.

Energy cost is normally second to raw material costs in the energy-intensive chemical process industry, thereby making considerable attention on energy conservation and optimization there imperative. To effectively achieve this ambition, energy must be adopted as a strategic objective by business. The strategic importance of optimising energy use percolates from top to bottom in an organization's management, necessitating responsibility and accountability for the wastage of energy resources. Very few articles have considered giving strategic importance, to energy consumption and utilization in chemical process industries. This also helps determine the non-energy benefits of energy-efficient systems and energy management practices, including possibility of generating alternate revenue (Rudberg et al., 2013).

The findings of this paper suggest the relevance and timing of studies which combine energy efficiency and energy management perspectives, thus developing appropriate frameworks for industries is necessary. Ambitious energy efficiency improvement targets need to be set by governments with strategies for implementing them on the ground. The future scope is enormous in the area of energy optimization and realising the revenue benefits of making energy a strategic agenda, which can motivate the industries, academics, and policymakers in a positive direction for future research.

Author contributions

NP: conceptualization and writing—original draft. JK: supervision and editing. RP: supervision and editing. RG: critical reviewing. The authors read and approved the final manuscript.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The handling editor VK shares second affiliation with authors NP, JK, and RP.

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