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Optimizing Energy Efficiency and Environmental Sustainability in Industrial Processes: Case Studies and Best Practices

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ABSTRACT

Energy measurement is generally acknowledged as a low-cost strategy to increase efficiency, which in turn reduces environmental impact and promotes energy sustainability. An emphasis on renewable energy generation would also prioritize cleaner energy carriers, particularly electricity, and potentially hydrogen, which would yield advantages for urban air quality. Methods for evaluating industrial processes' energy efficiency and sustainability have not yet been extensively documented in the literature. Energy management and energy efficiency in industrial facilities are the foci of this article. The current state of energy management and energy management systems in industrial facilities, as well as the correlation between energy conversion and consumption processes and energy efficiency, are explored in detail. Additionally, several aspects of energy efficiency are also discussed. The substantial potential of industries to improve energy efficiency, thereby directly contributing to climate change mitigation and sustainable development, is emphasized.

1. INTRODUCTION

Energy is the most important factor in any country's ability to eradicate poverty, advance economically, and maintain security. Today, uninterrupted energy supply is a crucial concern for any nation (Oyedepo, 2012). Energy has a significant role in every area of the economy of any nation (Ramchandra & Boucar, 2011). In addition to their non-renewability, the usage of fossil fuels as an energy source that is not environmentally benign has continued to provide significant environmental issues (Adeolu A Awoyale & Lokhat, 2021). The per capita energy consumption of a nation can be closely correlated with its standard of living. Two factors are to blame for the current global energy crisis: the world's population is growing at an accelerated rate, and entire societies' standards of living are rising. Per capita energy consumption serves as a gauge for both national prosperity and per capita income (Rai & Rai, 1992). These days, the lack of energy and resources is placing a heavy load on industry and government, while environmental disruption, climate change, air pollution, and water contamination are all having an increasing negative impact on people's lives and health. Because traditional manufacturing damages the environment and uses resources that will be used by future generations, it cannot comply with present environmental regulations. As a result, sustainable manufacturing has emerged as a response to the growing recognition of the significance of

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sustainability. Sustainable business practices are providing significant financial and environmental benefits to a wide and increasing number of industrial enterprises (Dincer & Acar, 2015).

When it comes to manufacturing, sustainability is the process of producing goods using financially sound methods that reduce their adverse effects on the environment while preserving energy and natural resources. Sustainable manufacturing improves worker, community, and product safety in addition to benefiting future generations (Meng, Yang, Chung, Lee, & Shao, 2018). These criteria provide a concise summary of what constitutes sustainable production. nil or minimal harm to society and the environment, and no decline in the ability of natural resources to meet present-day and future energy needs high efficiency, no harmful emissions to the land, air, or water, little or no emissions of greenhouse gases, and no strain on future generations. In certain energy-intensive industries, such the pulp and paper and cement sectors, measurements of energy efficiency based on plant-level data demonstrate that local conditions should be taken into account when attempting to increase energy efficiency (Tanaka & Managi, 2021). furthermore, reaching clean and low carbon targets as well as lowering energy usage depend heavily on creative ways to increase energy efficiency. Effectively, the most important factors are constant energy management, industrial symbiosis related procedures, increasing eco-efficiency, and using alternative fuels made from renewable resources (Branca et al., 2021), (Adeolu A. Awoyale, Lokhat, Eloka-Eboka, & Adeniyi, 2023). The European Union (EU) views energy efficiency as a critical component in achieving its 2030 climate targets and becoming the first continent to achieve climate neutrality by 2050. The Energy Efficiency Directive of the European Union sets a challenging objective for efficiency, aiming for a decrease of 39% and 36% in primary and final energy consumption, respectively, compared to the projected levels for 2020 (Gennitsaris et al., 2023). Enhancing energy efficiency is a significant strategy in mitigating climate change and is also essential for individual enterprises to uphold and enhance their competitiveness. Significant enhancements in energy efficiency can be readily accomplished through the utilization of energy services (Southernwood, Papagiannis, Güemes, & Sileni, 2021). This review paper seeks to explore different methods used in optimizing energy efficiency and maintaining a sustainable environment in Industrial Processes.

1.2. Global outlook of the current energy system

The energy system of a country or region encompasses the conversion of energy from its original source (such as extracting and utilizing natural energy resources like crude oil, natural gas, wind, and solar power) to its final useful form (used by energy-consuming units in various sectors like industry, transportation, and buildings) (Kanellakis, Martinopoulos, & Zachariadis, 2013). The initial stage in the evaluation of an energy-related system is to appraise its energy usage. Figure 1 illustrates the changes in global primary energy consumption from 1965 to 2020.

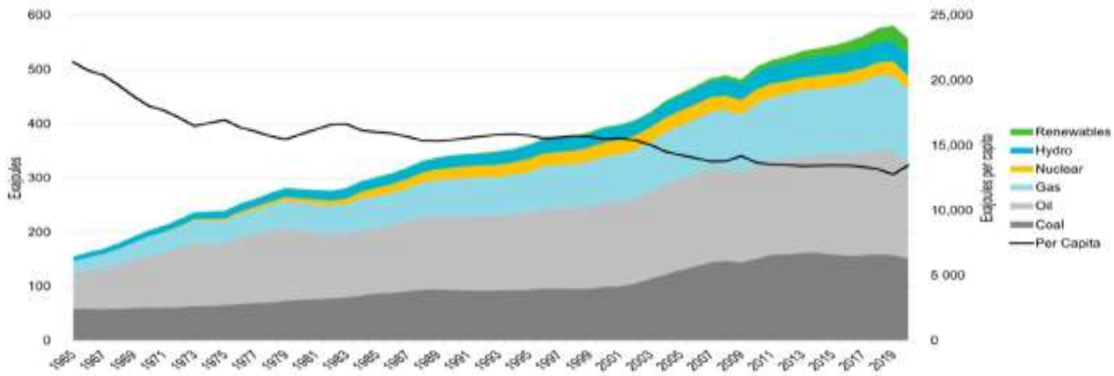

Figure 1. illustration of the global primary energy consumption from 1965 to 2020 (adapted from (Rodrigue, 2020)

The main objective of international energy use and consumption standards is to decarbonise energy systems by reducing the overall amount of carbon dioxide (CO_2,eq) emissions. Each individual policy specifies its own set of guidelines. There are two options to attain this goal: improving energy conversion efficiency or using primary energy sources with reduced CO_2,eq emissions. Within this particular framework, the promotion of enhanced energy-efficient procedures and the implementation of energy management strategies would result in a decrease in overall greenhouse gas (GHG) emissions and the corresponding total energy usage (Gennitsaris et al., 2023). Figure 2 illustrates the schematic of UK energy flow. From the diagram, it can be seen that at present, only a fraction of about 20-30% of the chemical energy from the burned fuel is usually converted into meaningful work or warmth. The industrial sector in the European Union is a significant consumer of energy. Consequently, the European Union implemented laws aimed at decreasing emissions, enhancing energy efficiency, and promoting the use of renewable energy sources. The attainment of the European energy efficiency targets should also be accomplished through the utilization of indicative national energy efficiency contributions. Energy Efficiency is a key component of the EU's Energy Union plan, which aims to enhance the economic competitiveness and sustainability of the European economy. It also seeks to decrease emissions and reduce reliance on external sources of energy, while simultaneously bolstering energy security and promoting employment growth. Given that a significant portion of energy consumption in the European Union relies on non-renewable resources, implementing measures that promote energy efficiency can effectively decrease the need for importing fossil fuels. This, in turn, enhances energy security while also being economically efficient (Branca et al., 2021).

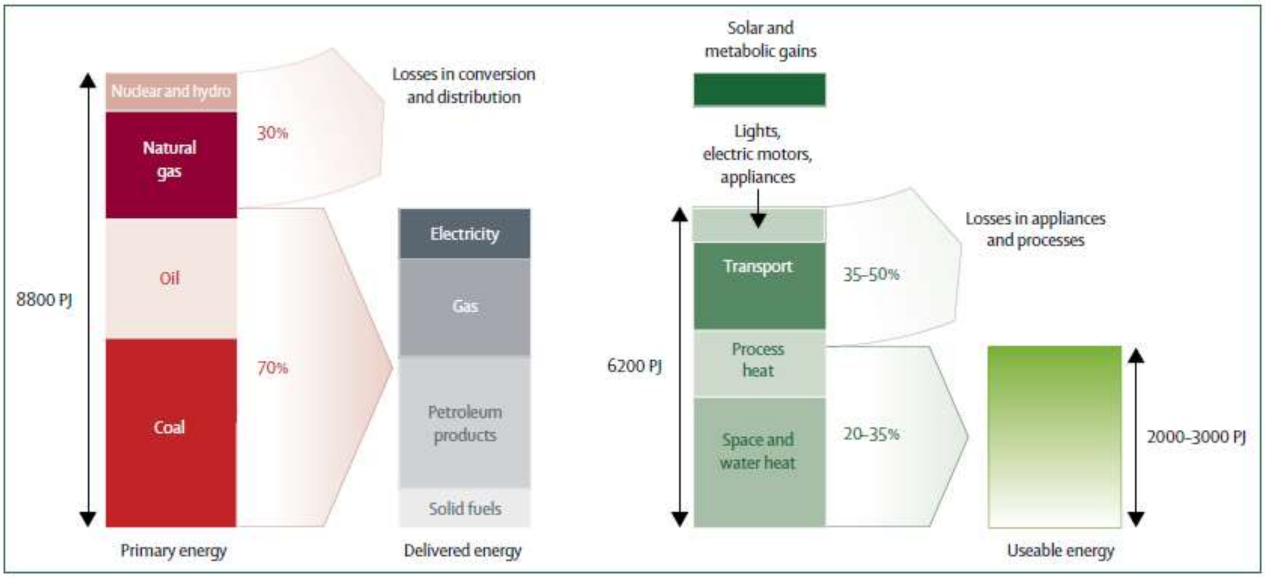

Figure 2 Schematic of UK energy flow (adapted from (Wilkinson, Smith, Beevers, Tonne, & Oreszczyn, 2007))

1.3. The State of Energy in Nigeria

Nigeria is the leading energy powerhouse in Africa. Nigeria is the most productive oil-producing country on the continent, and together with Libya, it holds two-thirds of Africa's crude oil reserves. It is the second highest ranked country in terms of natural gas, behind Algeria. Nigeria is home to the majority of Africa's bitumen and lignite reserves. Nigeria's collection of conventional energy reserves is unparalleled among all other countries in Africa. Thus, it is unsurprising that energy export serves as the cornerstone of the Nigerian economy. Moreover, fundamental energy resources exert a significant influence over the nation's supply of industrial raw materials. Nigeria possesses a plethora of natural energy resources. The nation holds the sixth greatest stockpile of crude oil globally. Nigeria possesses an approximate oil reserve of 36.2 billion barrels (Oyedepo, 2012),(Sambo, 2008).

Nigeria possesses abundant biomass resources that may be utilized for both conventional and contemporary energy purposes, such as the production of electricity. Table 1 displays Nigeria's energy reserves and potentials. The energy sector's poor development and inefficient management have led to a supply and demand gap.

The current energy consumption patterns worldwide indicate that Nigeria and other African countries have the lowest rates of consumption. However, Nigeria has a shortage of usable energy due to the growing demand, which is common in a developing economy. Ironically, the country has the capacity to possess renewable energy resources. Nigeria possesses abundant conventional energy resources, such as oil, natural gas, lignite, and coal. Additionally, it possesses abundant renewable energy resources, including wood, solar electricity, hydropower, and wind energy (Okafor & Joe-Uzuegbu, 2010).

Table 1 Nigeria's energy reserves and capacity as of December 2005 adapted from (Oyedepo, 2012).

Resource type	Reserves	Reserves (BTOE)[c]	Reserves ($\times 10^7$) TJ
Crude oil	36.2 billion barrels	4.896	20.499
Natural gas	166 trillion SCF[a]	4.465	18.694
Coal and lignite	2.7 billion tonnes	1.882	7.879
Tar sands	31 billion barrels of oil equivalent	4.216	17.652
Subtotal Fossil		15.459	64.724
Hydropower, large Scale	11,000 MW		0.0341/year
Hydropower, small Scale	3,250 MW		0.0101/year
Fuel wood	13,071,464 ha[b]		
Animal waste	61 million tonnes/year		
Crop residue	83 million tonnes/year		
Solar radiation	3.5 to 7.0 kW h/m^2/day		
Wind	2 to4 m/s (annual average) at 10 m in height		

[a]SCF, standard cubic feet; [b]forest land estimate for 1981; [c]BTOE, billion tonnes of oil equivalent.

1.4 Energy Footprint as a Metric for Evaluating Progress Towards Energy Efficiency Objectives

The "Energy Footprint" is a component of the ecological footprint and refers to the total amount of land needed to absorb the carbon dioxide emissions resulting from the use of energy sources that are not used for food or feed purposes. Carbon footprint is a metric that quantifies the amount of forest land needed to absorb CO_2 emissions resulting from the burning of fossil fuels and the generation of power associated with a specific product, organization, sub national area, country, region, or the entire globe within a specific timeframe. The calculation of the energy footprint is a challenging task due to its complex definition. Therefore, the phrase is frequently employed to denote the amount of power required for manufacturing a product or providing a service (Lewis & Cohen, 2022). The energy footprint facilitates a more comprehensive comprehension of the spatial dispersion of energy usage and enables the comparison of energy consumption across various sectors of an enterprise. Regions where substantial energy consumption or losses have been identified may serve as indicators of opportunities to reduce the energy footprint through the implementation of suitable energy management practices and efficiency guidelines, the modernization of energy systems, or the application of innovative technological remedies. Consequently, the energy footprint serves as a benchmark at the macro level for assessing energy consumption, in addition to facilitating opportunity and prioritization analysis (Network, 2010).

2. CASE STUDIES OF ENERGY EFFICIENCY IMPROVEMENTS MADE BY SELECTED INDUSTRIES

Energy efficiency is not a top priority for small and medium-sized enterprises (SMEs), and the use of energy management systems is rare (Bröckl, 2014). Investments in energy efficiency improvement in small and medium-sized enterprises (SMEs) are quite modest. This is mostly attributed to the scarcity of appropriate money and time resources, as well as the lack of understanding regarding the numerous potential benefits that might be obtained. Furthermore, small and medium-sized enterprise (SME) owners, managers, or decision makers tend to prioritize investments in other areas rather than those that could improve the energy efficiency of their organization. Additionally, SMEs lack the necessary specialized technical staff to effectively monitor, evaluate, and enhance their energy efficiency performance. Especially during the COVID-19 pandemic, when many small and medium-sized enterprises (SMEs) faced difficulties in staying afloat, implementing energy conservation measures may not have been financially feasible (Southernwood et al., 2021).

2.1 Chemicals industry

SATECMA, a chemical manufacturer with multiple production lines, has implemented various methods to enhance its energy efficiency. Enhanced climate control systems and LED bulbs were implemented, along with improved utilization of natural light tactics. Additionally, a photovoltaic solar energy producing plant was erected. The implementation of these strategies led to a 20% decrease in the company's total energy use. This resulted in both substantial cost reductions and an enhanced reputation of the organization among consumers, public institutions, and suppliers. While pursuing ISO 14001 certification, a chemicals company based in the United Kingdom successfully reduced its energy usage by over 30%. Additionally, the detection and eradication of leaks contributed to the enhancement of the furnaces' thermal efficiency, which resulted in significantly reduced gas and steam expenses (Calogirou, 2010).

Wacker Chemie AG opted to implement a combined heat and power generation mode utilizing a gas and steam turbine power plant renowned for its exceptional efficiency. Thermal energy is dissipated at various pressure levels in the form of vapor. Occasionally, the thermal energy requirements of the organization are surpassed by the heat generated during chemical reactions occurring in different stages of production. The excess energy is allocated towards meeting the heating needs of other businesses. The pertinent heat sources and heat sinks were initially identified by the organization at its Burghausen facility in Germany. The heat generated by the central waste gas and residue incineration facilities was subsequently incorporated into pre-existing steam networks. Additionally, heat sinks were linked to surplus heat sources through local heating networks. More specifically, the company's premises generate sufficient thermal energy to supply the energy requirements of a gymnasium, an indoor tennis court, and a public swimming pool. As a consequence of the implemented modifications, substantial energy savings were realized. 421 MWh are conserved as a result of steam processes, and an additional 44,000 MWh are conserved due to facility heating and hot water preparation (Gennitsaris et al., 2023).

2.2 Food and Beverage sector

In 2008, the foremost producer of haggis, the national dish of Scotland, carried out environmental and energy assessments that assisted the organization in identifying the most significant cost-reduction strategies to be executed. In relation to energy efficiency initiatives, the implementation of more streamlined culinary techniques yielded gas bill reductions of approximately 15% between 2006 and 2008. In addition to staff training and the installation of technologies that utilize refrigerator surplus heat, the company implemented schedule-based active control of heating, cooling, and lighting, as well as the replacement of lighting systems with more energy-efficient alternatives. The implementation of these strategies resulted in a decrease in energy usage and the subsequent emission of carbon dioxide. Furthermore, the organization engages in the Bright Green Placements (BEP), a placement initiative in which an environmental studies student is assigned to assist the company in accomplishing key environmental management objectives for a duration of eight weeks (Calogirou, 2010). An energy requirement is being met by a brewery situated in the city of Aying, Germany, through the implementation of a combined heat and power (CHP) system. To increase the efficacy of its CHP system, the business decided to redesign it. In addition to two additional heating circuits, the brewing and industrial hot water preparation devices were linked to the cooling circuit of the combined heat and power (CHP) system. Furthermore, an insulated reservoir containing around 30,000 litters of water was implemented to store the readily accessible thermal energy that is not usable in the manufacturing processes. The nominal electrical capacity of the installed CHP system is 200 kW, while the nominal thermal output is 230 kW. The majority of the generated electricity is utilized to meet the energy requirements of the brewery. Remunerated excess electricity is fed into the public electricity grid. In contrast to utilizing a gas-fired boiler and a separate electricity supply from the public infrastructure to generate heat, the implemented combined heat and power (CHP) system achieved an annual reduction in production-related CO2 emissions exceeding 100 tons. A 20% reduction in corresponding electricity consumption was also observed (Bierbrauen). Using a specially made heat exchanger, another German brewery, Krones A, created the ground-breaking EquiTherm method, which lowers primary energy needs by recovering waste heat from the brewing process itself. Simultaneously, cooling energy and the implicit electricity used for it are conserved, and freshwater needs are significantly decreased. The system that has been designed takes energy out of the brewing process itself at one point and feeds it back at another. Consequently, there are savings of roughly 30% and 20%, respectively, in the amount of heat energy and power used (für einzigartige Biere, für neue Hopfensorten, & bis Hopfenstopfen). Cupcakes of West dale Village, a small Canadian firm, sought to enhance its energy efficiency and save operational expenses by upgrading its lighting equipment. The shop capitalized on a government program and enhanced its lighting equipment. The enhanced lighting conditions not only led to an annual cost reduction of over CAD 400 in the shop's electricity expenses, but also enhanced the appeal of its products to customers (Gennitsaris et al., 2023).

2.3 The Metal Manufacturing Industry Sector

Significant energy cost savings were achieved in the steel rerolling subsector in India through the implementation of innovative technologies. The requirement for coal was decreased by around 30 kilograms per metric ton of product. Furthermore, the implementation of new technologies has enhanced the overall efficiency of related processes by minimizing metal losses caused by scale and oxidation. This case study of the Indian small and medium-sized enterprise (SME) steel rerolling subsector highlights the importance of the non-energy advantages gained via the implementation of energy-efficient technologies (Crittenden, 2015). AMB Alloys Ltd. is a ferroalloys manufacturer and dealer situated in Rustavi, Georgia, an industrial city. The business intended to invest a large sum of money in a new production facility. However, the business needed a comparatively short payback period to move forward with the new plant investment. AMB Alloys utilized a program of financial and technical assistance. The business examined the investment's potential for cost and energy savings, as well as its technoeconomic features and related hazards. The proposed investment of EUR 842,000 might result in an annual savings of EUR 220,000 or a reduction in its energy demand by about 4.3 MWh. As a result, the investment will be paid back in approximately four years if the related decrease in energy use is all that is required to reach the company's goals. Additionally, there will be 1.7 tons less CO_2 emissions annually from the new facility (Prashar, 2019).

2.4. The Construction industry

The construction firm Lagodekhautogza Ltd. is based in Georgia and specializes in the manufacturing of bituminous concrete, cement concrete, and road construction. In 2020, the organization was required to expand its bituminous concrete manufacturing capacity. Nevertheless, the existing production equipment was antiquated and incapable of generating the necessary quantity of output. Additionally, the organization sought to reduce its manufacturing expenses. A technical assessment for the project was provided at no cost to the company via a technical and financial support program administered by the government. In addition, the company invested EUR 254,000 in the modernization of its antiquated machinery. Having increased production capabilities, the new equipment also exhibited enhanced energy efficiency. An 55% increase was observed in the volume of production. Additionally, a yearly energy conservation of 160 MWh (equivalent to 10,000 EUR) was accomplished (Naik & Mallur, 2018).

Energy efficiency improvements were implemented at the bitumen manufacturing facility in Khashuri, Georgia. Prefabricated by the Technical University of Georgia, a solid-fuel heat generator was installed in lieu of the rotating furnace's existing natural gas burner. 3000 kW was the nominal capacity of the natural gas burner. As a (solid) fuel, the novel heat generator employs agricultural by-product, grape cake. 600 kg of grape cake per hour is necessary for the heat generator to function, which is equivalent to 300 m^3/h of natural gas. By substituting the solid biomass-fueled heat generator for the natural gas burner (which consumes 480,000 m^3 of natural gas annually), the organization hopes to reach its goal. Grape cake, which is an uncomplicated by-product of the winemaking process, is presently offered at no cost by the wineries. Therefore, the sole expenditure linked to the grape cake pertains to the transportation cost from the wineries to the bitumen production location. The transportation costs associated with biomass fuel to the production site amount to approximately USD 33,600 per year. In contrast, the natural gas utilized in the gas burner incurs an annual expenditure of around USD 160,000. The annual cost savings resulting from the implementation of the suggested heat generator, powered by renewable biomass rather than imported natural gas, amount to USD 126,400. The challenges that emerged throughout the COVID-19 pandemic, particularly those associated with the escalated charges for energy providers, underscore the criticality of carrying out the designated initiative. In addition to the potential economic benefits, several other considerations must be taken into account, including the preservation of employment and the improvement of the company's competitiveness and image in the construction materials market (Gennitsaris et al., 2023).

2.5 Other Sectors

A concentration of small and medium-sized enterprises (SMEs) in the glass industry in India, known as Firozabad, introduced a straightforward waste heat recovery system that capitalized on the elevated temperatures of the furnace and exhaust gas used in glass production. A counterflow metallic recuperator comprised of five stainless steel modules has been installed in nearly every cluster unit. This installation has the potential to generate an annual energy savings of 25–30%, equivalent to a repayment period of six months (Crittenden, 2015).

Reunion Island Coffee Roasters, a firm situated in Oakville, Canada, sought methods to enhance the energy efficiency of its roastery, shipping, and distribution facility. In late 2015, the business replaced the existing lighting in the factory, which had a slow start-up time of about 30 minutes, with new energy-efficient LED lighting panels. In addition, the company implemented six motion-activated occupancy sensors to regulate the functioning of the lighting system. The lights in various portions of the facility are only activated when staff are present or moving through the respective plant regions. Consequently, the duration for which the lights remain illuminated is decreased, resulting in significant energy conservation. The electricity cost for lighting was lowered by over 25%, which is worth mentioning. The company implemented five smart thermostats to optimize the internal facility temperature by reducing heating levels while the building is unoccupied. Reunion Island implemented straightforward measures, such as applying reflecting tint to the windows of workspaces, which helped the company decrease its need on air conditioning, particularly in hotter months. In addition, the company improved the coffee roasting process by acquiring an energy-efficient roasting machine for all of its whole-bean specialty coffee. This machine consumes 80% less energy compared to larger machines (Gennitsaris et al., 2023).

3. ENERGY EFFICIENCY AND RENEWABLE ENERGY AS CLIMATE CHANGE MITIGATING MEASURES

According to the Intergovernmental Panel on Climate Change (IPCC), which is a body that was established in 1988 by the World Meteorological Organization and the United Nations Environmental Programme to provide authoritative information about the phenomenon of climate change, the warming that has occurred over the past one hundred years has been unusual and is highly unlikely to have been caused by natural causes. The warming experienced during the latter half of the century has been ascribed by the IPCC to a rise in the release of greenhouse gases into the Earth's atmosphere. The emission of these gases into the atmosphere is predominantly attributable to human activity: land-use activities such as deforestation, methane production, the combustion of fossil fuels (coals, oil, gas), and the chemical industry all contribute to the production of carbon dioxide; rice agriculture, livestock, fossil fuel use, and landfills all contribute to methane production; and agricultural soils, cattle feed lots, and landfills all contribute to nitrous oxide production. Greenhouse gas emissions have increased in tandem with human production and consumption; since the industrial revolution in 1750, CO_2 emissions have increased by 31%, methane emissions by 15%, and nitrous oxide emissions by 17%. Moreover, these gases' emissions continue to increase at a steady rate (Uyigue, 2007). The United Nations Framework Convention on Climate Change, commonly referred to as the Kyoto Protocol, incorporated the Clean Development Mechanism (CDM). CDM initiatives enable investments in developing countries by entities originating from industrialized nations. The investor in the industrialized nation receives carbon credits (certified emission reductions in this instance) in exchange for this investment. This facilitates the industrialized nation in efficiently achieving its Kyoto Protocol-mandated emission reduction targets, all the while encouraging sustainable development in developing countries. CDM projects may also be unilateral, meaning that they occur in the developing nation without an industrialized nation as a project partner (Sarah La, 2002).

3.1. Optimizing Energy Efficiency: Optimal Approaches

With an average payback period of less than 1.5 years, it is estimated that the average SME could reduce its energy expenses by 18–25% by implementing energy efficiency improvement measures. Additionally, forty percent of these reductions are estimated to be non-capital expenditures (Chen, Calabrese, & Cowling, 2024). This section provides recommendations and best practices for improving the energy efficiency of small and medium-sized enterprises (SMEs).

3.2 Knowledge of Energy Conservation and Efficiency Enhancements

One of the main factors influencing the effective application of energy management strategies in SMEs may be a greater understanding of energy efficiency, possible energy savings, and the associated advantages. Employee knowledge of these issues and the development of an energy-efficient and/or energy-saving culture within the company might both benefit from proper training for SMEs. Creating such a culture is essential to SMEs' widespread adoption of energy-saving measures (Fatima, Oksman, & Lahdelma, 2021).

3.3. Energy Supply and Process Design Metrics

Numerous inexpensive and straightforward measures/actions for conserving energy have already been proposed. However, the greatest savings in energy efficiency could be attained by implementing substantial modifications to the energy supply and/or process design. Compared to simplified measures, substantial modifications invariably entail substantial financial and business risk, as well as substantial investment expenditures. Potential modifications could encompass the integration of suitable combined heat and power (CHP) facilities, the reconfiguration of manufacturing processes and/or lines, the utilization of advanced prediction, simulation, and control methodologies, and the establishment of a linkage between the facility and the nearby heating or cooling network for the purpose of redirecting waste energy or heat (Castro Oliveira, Iten, & Matos, 2022).

3.4. Green Power and Energy Retention

The potential for the installation of on-site rooftop solar PV systems by industrial facilities is substantial. Given that a significant portion of the pertinent processes in both the manufacturing and services sectors are electrified, it is anticipated that their energy consumption requirements could be aligned with periods of substantial solar generation. Additionally, solar water heating could be utilized as a substitute for preheating or heating. This enables water to be heated significantly above 80 degrees Celsius. Additionally, as the cost of batteries decreases, onsite battery storage may be a viable option to consider. In addition to facilitating greater on-site utilization of solar PV systems during the day, batteries offer a contingency measure in the case of a grid outage. Particularly for the food and beverage industry, thermal energy storage is possible in phase-changing materials, water, or the substantial mass of food products refrigerated (Royo et al., 2019), (Oliveira, Iten, & Fernandes, 2022).

3.5. Combined Heat and Power (CHP)

Traditional thermal-electric power generation methods demonstrate comparatively diminished fuel-to-power efficiencies due to the substantial dissipation of high-temperature heat into the surroundings via the stack. This explains why energy efficiency rates for common conventional (thermal) engines typically do not surpass 38–40%. Energy efficiency ratings for reciprocating engines fall within the specified range of 28–38%. Small gas turbines, which have a nominal power of no more than 5 MW, exhibit energy efficiency rates ranging from 20% to 25%. Conversely, larger gas turbines, which have a nominal power of between 5 MW and 500 MW, demonstrate efficiency rates between 25% and 35%. Contemporary gas turbine power facilities that surpass 500 MW in nominal output have the potential to achieve efficiency rates in the vicinity of

50%. Convertible heat (CHP) technology captures and recycles thermal energy (heat) that would otherwise be lost to the atmosphere. Utilizing the thermal energy that has been harnessed, steam can be generated; this steam, in turn, can be utilized to power a steam turbine. On a smaller scale, reciprocating engines powered by gas or oil, CHP systems, or industrial gas turbines are utilized. The heat captured can be utilized in thermal processes other than the production of electricity, including water heating and steam production. The aggregate efficiency of combined heat and power (CHP) plants is generally significantly greater than that of conventional power plants, ranging from 75% to 85% [31]. Nevertheless, the general efficacy of small-scale CHP systems, commonly implemented in small and medium-sized enterprises (SMEs), ranges from 62% to 75% (Energy, 2004).

3.6. Operational Process and Maintenance-Related Metrics

Small and medium-sized enterprises (SMEs) can enhance their energy efficiency by implementing a number of straightforward steps pertaining to operational and maintenance tasks (Fernandes et al., 2016), (Fawkes, Oung, Thorpe, Zhu, & Farrell, 2016).

- It is imperative that maintenance operations are executed by proficient and specialized technical personnel. Adequate time should be allotted to ensure that all pertinent maintenance tasks are completed in accordance with applicable quality standards. Ensuring adherence to a maintenance regimen and a midterm schedule is critical. When replacement activities are required, the spare parts utilized should be the most recent and effective models.
- When confronted with recurring plant malfunctions, it is imperative to ascertain the underlying causes. It is necessary to conduct investigations and tests for this purpose, and all participants must contribute to their discovery. It is of the utmost importance that any primary cause be effectively addressed so as to prevent the occurrence of additional failures throughout the facility.
- It is imperative that, throughout the process of installing new apparatus or equipment, all pertinent parts and components are meticulously affixed in accordance with the instructions outlined in the manufacturer's manual. In addition, prior to delivery, the actual installation should be thoroughly inspected to ensure that it conforms to the design.
- With respect to equipment dimensions, it is crucial to ascertain that the specifications of the equipment align with the operational demands and do not result in surplus capacity.
- With respect to apparatus operation, it is imperative to ascertain that the pertinent machinery can be safely and effortlessly deactivated when not in use. Strict adherence to facility and equipment safety regulations is required. Safety valves and suitable protective devices ought to be implemented to "guarantee" the facility's and machinery's safety. Additionally, the capability to rapidly resume the facility's operations is critical for maximizing energy efficiency.
- When faced with a selection of devices, it is advisable to utilize those that demonstrate the greatest efficiency. It is thus apparent that production managers, supervisors, and staff should possess comprehensive knowledge regarding the minimum, normal, and maximum operating conditions of all available equipment. Additionally, production processes ought to be strategically designed to reduce machinery idle time.

Additionally, every effort should be made to cease the operation of machines promptly and resume it at the latest possible hour. It is imperative that production processes be diligently monitored and evaluated with the objective of identifying opportunities to enhance efficiency.

- It is imperative to verify that all thermal and electrical insulation is in optimal condition, hence reducing heat losses and removing any power leaks.

3.7. Strategies Pertaining to the Thermal Insulation of Structures

Enterprises may have substantial opportunities to save energy in the facilities they use. An analysis of the significance of monitoring in the energy management of buildings has already been conducted. Applying suitable thermal insulation to the building structure enhances its efficiency by reducing heat losses, resulting in significant energy and cost savings. Implementing such a solution can be both expensive and require a significant amount of labor. However, there are several uncomplicated and inexpensive solutions that might improve the energy efficiency of current structures (Paik, Yoo, & Kim, 2009).

- One popular place for heat to escape from buildings is through the windows. Because of this, their frames need to be properly maintained and examined on a regular basis to guarantee that they are draught-proof and able to close securely. Replace single-glazed windows with double- or, if feasible, triple-glazed ones. Building spaces could be kept from overheating by applying appropriate shade solutions.
- Doors, like windows, should also be checked to make sure they are draught proof and able to be closed tightly. It may also be possible to regulate the temperature of interior rooms while using less energy by installing self-closing mechanisms and replacing the current doors with thicker ones.
- Checking walls and roofs on a regular basis will help you find any gaps or holes that need to be filled up or mended with the right materials. Furthermore, specialized audits might be conducted to investigate the possibility of lowering thermal losses by using the appropriate thermal insulation.

3.8. Precautions Concerning Building Climate Control

Improving and/or modifying HVAC systems could contribute significantly to achieving energy efficiency in office buildings, production plants, and other facilities of SMEs. HVAC systems should be properly regulated in order to not only ensure appropriate comfort and healthy living conditions for the staff of the organization but also to minimize its energy consumption. The main parameters that should be monitored and controlled are humidity, temperature, and air quality. Some simple and practical measures that ensure good and efficient operating conditions of HVAC systems include the following (Chen et al., 2024):

- The use of suitable control systems that maintain a constant temperature in the space is essential. For example, it is advised to set the office temperature at 19 ◦C during the winter months (when heating is in operation). Clearly, places with more foot traffic, such as hallways and storage rooms, might have it set lower than 19 ◦C. During the summer (controlling the temperature), Please ensure that the air temperature does not drop below 24 ◦C. An empirical rule states that a 3% increase in the chiller's energy consumption will occur for every 1 ◦C rise in the set cooling air temperature.

This rule applies to cooling temperatures specifically.

- To put it simply, cooling systems dissipate heat into the surrounding air. Cooling systems obviously work better when they can freely and effectively draw air from the surrounding environment. Therefore, it is crucial to consider the placement of cooling units in relation to any existing furniture, equipment, or machinery. Due to space constraints and/or ill-considered engineering decisions, cooling units may be placed too close to hot air exhausts or with inadequate airflow from the surrounding area, reducing the system's overall efficiency. Cooling systems should be accommodated in the facility's layout so that they can access the coolest ambient air feasible without obstructions.

3.9. Steps Concerning the Illumination of Buildings

It would be possible to lower the energy consumption of lighting systems by implementing some basic strategies, methods, and technology. Enumerated and explained below are the most common and efficient measures (Gennitsaris et al., 2023).

- There are automated systems and sensors that can detect when someone is in a certain area of a building. It is possible to install such devices so that they only activate the lights in a room or other designated space when someone is in there.

- The amount of light that must be present in a given area must be proportional to the task at hand, as dictated by established rules and regulations. It is important to prevent over lamping if you want to save electricity.

- To save energy, it is recommended that all incandescent light bulbs be replaced with more efficient LED lighting.

- Natural light is often criticized for being underutilized in business areas. Maximizing the use of natural light from windows and skylights in space design reduces the need for expensive artificial lighting while saving money on utility bills. Objects like filing cabinets that block windows should be moved so that more natural light may enter the room. Workstations should also be placed near windows to maximize the amount of natural light that can reach them.

3.10 Efficient Water Chemistry for Better Energy Efficiency

It is critical to establish better water quality standards for industrial Enterprises. Plants, equipment, thermal devices, etc. often make use of water in either its liquid or gaseous form, i.e., steam, to transport and transfer heat. A number of substances, including mineral salts, dissolved organic materials, and microbiological organisms, make up water, making it far from clean. The presence of these components in water, even in trace amounts, has a negative impact on water quality and the effectiveness of a manufacturing plant's thermal machinery and devices. Consequently, keeping a tight rein on and constant eye on water quality is crucial. Small and medium-sized enterprises (SMEs) could benefit from reduced energy usage, water purchase and treatment costs, and enhanced feed water quality by including regular water testing in their maintenance schedules (Castro Oliveira et al., 2022).

3.11 Thermal Reuse

Between twenty percent and fifty percent of all industrial energy usage is thought to be waste heat. The reason behind this is that waste heat can be produced in several ways by industrial SMEs. For instance, it can be in the form of hot exhaust gases, cooling water, or the loss of heat from surfaces and components within equipment. Using heat recovery exchangers, all thermal industrial processes can lower their heat demand by reusing some of the heat that is lost. This recovered heat is more accurately called waste heat. Preheating the inputs to heat chambers using the captured heat lowers the process's total energy requirement. A nearby manufacturing plant may put the recovered heat to use. Many different heat recovery technologies are now on the market and can be used in manufacturing facilities. An easily available supply of waste heat, a relevant industrial or commercial heat demand, and the right recovery technology are all necessary for this technical alternative to be effective. If a small or medium-sized enterprise (SME) wants to use waste heat recovery technology, they should have the right people take a look at their factory to see what it needs and whether or not it's financially feasible (Jouhara et al., 2018).

4. CONCLUSION

It is abundantly clear from global energy outlook that the energy demand is substantial and growing geometrically, while the global energy supply continues to be insufficient, unstable, and irregular, and is depleting over time; fossil fuels have historically dominated the energy mix, which is not only detrimental to the environment but also rapidly depleting. Therefore, it is imperative to diversify the energy supply blend by establishing a suitable infrastructure and raising public awareness in order to harness the nation's ample renewable energy resources for development and to bolster supply security. The presented literature review is succinct and highlights the existence of numerous case studies that demonstrate effective implementations of energy efficiency improvement measures by industries across various sectors. This suggests that the obstacles to energy efficiency improvement may potentially be surmounted. In addition, numerous strategies pertaining to lighting, production apparatus, heating, cooling, and processes could be implemented by organizations in an effort to reduce their energy trajectory. A considerable number of these measures are straightforward, necessitate minimal or no initial investment, and may yield supplementary advantages, including heightened employee satisfaction, increased productivity, and an enhanced corporate reputation. However, significant energy and carbon footprint reductions are still possible through the implementation of step adjustments pertaining to process design and energy supply. Despite the fact that the latter modifications necessitate substantial investments from industries, their repayment periods are comparatively brief as a result of substantial energy and cost savings. Hence, it is indisputable that substantial potential exists for industries to enhance their energy utilization performance, thereby making a direct contribution to the mitigation of climate change and the promotion of sustainable development.

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