Faculty of Engineering and Built Environment

Department of Electrical, Electronic and Computer Engineering

Implementation of ISO 50001:2018 Energy Management Systems in Steelwork Manufacturing

Prepared by Lutho Mkosana

Student number: 213136589.

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Supervisor: Dr Ali M. A. Almaktoof

Co-Supervisor: Prof Marco Adonis

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DECLARATION

I, Lutho Mkosana, declare that the contents of this thesis represent my unaided work and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my opinions, not necessarily those of the Cape Peninsula University of Technology.

Signed: Date 15 October 2025

ABSTRACT

Effective energy management is vital to coping with the dual challenges of increasing operational costs and the pressure to reduce environmental impact that a lot of industrial sectors are under. Standards like the ISO 50001 offer a framework that businesses can use to achieve their goals, by focusing on continuous improvements in areas like taking a structured approach to things - such as the Plan, Do, Check, Act (PDCA) cycle and getting a clear picture of energy use through detailed energy evaluations. According to the research, the PDCA Cycle is also effective at continuously improving energy performance over time and provides an opportunity for industry to get certification for the standard, reduce their carbon footprint and realize cost savings in their operations using this model.

The research endeavours to develop a unique implementation strategy tailored specifically for steel and provides a comprehensive approach to its creation through a combination of energy auditing, case studies, mathematical modelling and literature reviews. The methodology of this research study is qualitative in nature and investigates the application of the standard for measuring and understanding energy consumption.

The research provides an algorithmic approach for improving energy audits and thereby enables optimization of energy utilisation through real-time simulation of steel manufacturing processes using Python coding. Case study examples such as at the Vishvesvaraya Iron & Steel Plant in India and in China indicated the use of various techniques such as using VFD (Variable Frequency Drive), changing to LED lighting, and updating to new furnaces resulted in reduced energy consumption of 10-18% and lowered operational expenses. Of course, there are some challenges to overcome, like the high upfront costs of installing new kit and getting things integrated properly - but breaking things down into manageable chunks and making sure staff are properly trained can really make a difference in the long run.

Keywords: PDCA cycle, ISO 50001, Energy Management System, Steel manufacturing industries, Energy Audit, energy consumption.

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DEFINITIONS

Energy performance is how efficiently a system or building uses energy to provide an energy service.

Energy performance indicators are a metric used to examine energy performance in an organization.

An **energy review** is a methodical investigation of energy usage, consumption, and efficiency that is based on statistics and other information. It identifies regions of significant energy use (SEU) and presents chances for energy performance enhancement.

Energy policy is the strategy chosen by a certain body (typically governmental) to address challenges relating to energy development, including energy conversion, distribution, and usage and curbing greenhouse gas emissions to enhance climate-mitigation outcomes.

PDCA cycle is a technique for iterative design and management used in business to control and enhance procedures and goods.

Direct energy consumption is the energy used in the steelmaking process to produce heat and power for the various stages involved in steel production.

Indirect energy consumption is the energy used in the production of the raw materials used in steel production, such as iron ore, limestone, and scrap steel.

Energy Management System (EnMS) is the documentation of an organization's efforts and strategies to drive energy performance improvement to show clear guidelines, procedures, set targets and policies as a strategy to analyze and track energy usage.

Variable Voltage Variable Frequency (VVVF) drives, also known as Variable Frequency Drives (VFDs) or Variable Speed Drives (VSDs)- regulate the operation of electric motors by adjusting the input frequency and voltage to control a motor’s speed and torque.

Normal distribution represents data that cluster evenly around the mean, forming a bell-shaped curve whose spread is determined by the standard deviation.

ABBREVIATIONS

AI	Artificial Intelligence
ANSI	American National Standards Institutes
BAT	Best Affordable Technology
BF	Blast Furnace
BOF	Basic Oxygen Furnace
BPT	Best Practice Technology
EAF	Electric Arc Furnace
EnMS	Energy Management Systems
EnPIs	Energy Performance Indicator
GHG	Greenhouse Gas
HVAC	Heating Ventilation and Air Conditioning
IEO	International Energy Outlook
ISO	International Organization for Standardization
MSE	Management Systems for Energy
PDCA	Plan –Do –Check –Act
PV	Photovoltaic
SEU	Significant Energy Use
SANS	South African National Standards
SDG	Sustainable development goal
TGR-OBF	Top Gas Recycling- Oxygen Blast Furnace
VISL	Vishvesvaraya Iron and Steel Limited
VVVF	Variable Voltage Variable Frequency

CHAPTER ONE

INTRODUCTION

1.1 Background

Energy management has become a strategic imperative in high-consumption sectors such as steel manufacturing and in turn makes up high cost, consumption and pressure to reduce carbon emissions within the industry sector. This research aims to develop a framework for successfully implementing the ISO 50001:2018 standard to reduce these effects within the steel manufacturing industry.

The study encourages steel manufacturers to improve management of their energy usage through routine energy audits, mathematical models and evidence taken from case studies. This thesis investigates the implementation of ISO 50001 in steel manufacturing, focusing on practical strategies, measurable outcomes, and scalability, aligning with the industry's demand for energy-efficient and sustainable practices. Rather than focusing on the standard in isolation, the study investigates how it can be operationalized through algorithmic methods and data-driven audits specific to the steel sector.

The use of the standard has the potential to lower an organization's greenhouse gas emissions while reducing the cost of energy per unit of production. Furthermore, the impact on the environment is lowered while the economic influence increases (Liu, He and Chen, 2021). Steel industries are responsible for a significant increase in global demand and domestic energy demand (Khan, 2019). ISO is an international organization that sets, develops, and publishes standards so that organizations and industries can adopt them for effective and efficient sustainable development of energy (Fihurka, 2018).

The ISO 50001:2018 standard goals are also in line with the United Nations Sustainable Development Goals (SDGs), such as SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). As companies have an idea about starting up and running their day-to-day operations, most of them worry much about the target of the results and neglect the steps taken to achieve the results. These guidelines are established by the International Organization for Standardization to remove environmental influences that affect energy usage through a policy. As a result, the company gains from the standards by controlling its energy efficiency and reducing its consumption expenses.

Wang (2010) agrees climate change is a global concern, and organizational energy consumption has a major influence. Most climate-related research compares the current state with the period before industrialization where human activity, particularly the burning of coal-emerged, is a significant source of the rise in greenhouse gas release. Materials used in energy-intensive industries, such as steel manufacturing, are often the subject of technical analysis due to their impact on emissions. As illustrated in Figure 1, the iron and steel sector alone represents 27% of global industrial CO_2 discharge (Naimoli and Ladislaw, 2020).

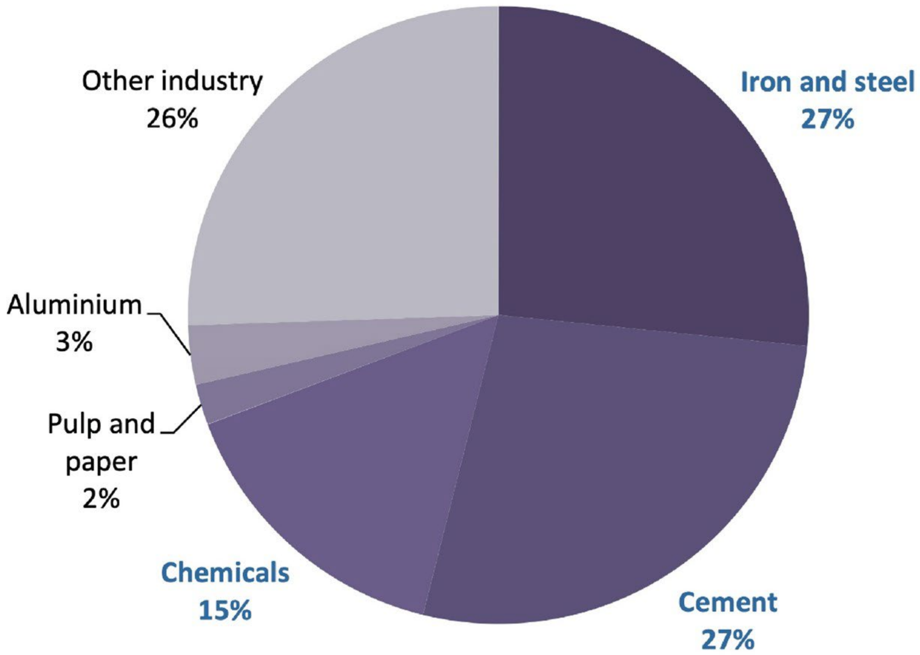

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Figure 1: Share of global emissions by industry sector (Naimoli and Ladislaw, 2020)

ISO 50001 aims to look at a proper and efficient way of energy consumption and reducing emissions without reducing production. Steel manufacturing industries are a good example that can show the application of ISO 50001 as they contribute to the energy consumption of a country. Companies need to be conscious of regular energy audits and have their organizations certified with the ISO 50001:2018 energy management system (EnMS). The manufacturing sector needs more awareness of the use of ISO 50001 energy management standards to increase energy efficiency, which pushes more efforts to reduce global energy demand and enhance overall operational performance. ISO 50001 EnMS have proven to be a solution for conserving power.

1.2. Energy Management System (EnMS)

An EnMS creates a formalized approach that enables organizations to achieve their energy efficiency by managing energy use, producing cost savings, and aligning sustainability goals. This documentation is an organization's efforts and strategies to drive energy performance improvements (Almaguer, 2019). Within this document, clear guidelines, procedures, set targets and policies are presented as a strategy to analyze and track energy usage (Prashar, 2017). The people responsible for the organization would be the energy manager, project manager and management representatives. It is essential to understand the energy flow within the organization first to identify areas of improvement.

EnMS are important for the conservation and proper use of energy, the industrial sector alone constitutes near 54% of global energy supply (Haiwei and Wang, 2009). Haiwei and Wang, (2009) also references a case study for the International Energy Outlook 2016 (EIA, 2016) with an increase in the average consumption rate of 1.2% per year worldwide.

The EnMS strategy that is presented is based on the Plan-Do-Check-Act (PDCA) cycle, is based on energy optimization within the organization (Prashar, 2017). The PDCA cycle covers different forms of organization, which vary from the cost of a new installation. Training of staff members for effective management and use of equipment; introduction of new technologies; and efficient operational activities may include incorporation of new activities or energy sources that will make an EnMS more economical for steel manufacturing industries (Department of Energy: Republic of South Africa, 2005).

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The PDCA cycle forms a sequence to give the standard descriptive activities to follow in implementing ISO 50001 standards (Glavas *et al.*, 2018). The ISO 50001 standard follows the PDCA cycle, which was developed by William Edwards Deming. It is important to understand that the PDCA cycle is not exclusive to the ISO 50001 standard but is also utilized by many other EnMS (Glavas *et al.*, 2018).

The continuous improvement goals of the ISO 50001:2018 standard is well-aligned with the structured, iterative PDCA cycle. Achieving sustainable energy management requires constant monitoring and modification, which is made possible by PDCA's cyclic model, given the high energy demands and process variability in steel manufacture (Xu, 2020). The cycle provides a framework structure that involves continuous checking and acting for organizations to note areas of improvement, so they use their energy efficiently (Glavas *et al.*, 2018). With these characteristics, organizations can integrate energy management that can improve quality (ISO 9001: quality management), and environmental management (ISO 14001) (Fihurka, 2018).

The ISO 50001:2011 standard was later improved and updated to integrate these standards into the ISO 50001:2018 standard (Poveda-orjuela and Pulido-rojano, 2019). The PDCA cycle focuses on the managerial and operational levels of the organization. Figure 2 shows the management cycle of the PDCA cycle structure in a continuous loop.

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Figure 2: PDCA management procedure (Prashar, 2017)

Organizations need to implement principles of the ISO 50001 standard in a dynamic manner that facilitates both strategic alignment and practical actions. The PDCA cycle offers such a mechanism that allows embedding energy performance improvements into daily operations. It encourages a culture of ongoing development in which preparation, execution, assessment, and correction are frequent. This section describes how each stage promotes energy utilization in the steel production facilities.

Plan:

The first requirement of implementing the ISO 50001 standard is to have an energy-based policy for the organization and then do an energy audit of the organization where a collection of data is necessary. The data collection includes consumption, energy production, and costs. From the planning, the organization must create management roles to assess possible energy-saving activities and draft an action plan to follow (Prashar, 2017). This involves energy objectives and clearly defined energy indicators for monitoring energy use (Jovanović, Filipović and Bakić, 2017).

Do:

This stage of the cycle deals with implementation and operation as per the energy planning in the planning stage (Glavas *et al.*, 2018). This stage is the action plan, where organizational staff members are motivated and sent to training on energy-saving and the appropriate use of machinery for achieving high efficiency (Prashar, 2017). Steelwork manufacturing industries should have set goals in the planning stage. Once these targets have been reached, they should be noted (Fiedler and Mircea, 2012). This promotes good control and awareness of energy use.

Check:

During this stage of the cycle, the results of the energy indicators are evaluated; processes and decisions are made (Jovanović, Filipović and Bakić, 2017). Based on the findings of the energy audit and monitoring of the energy indicators, corrective measures are implemented. This stage may seem like a simple one; however, it is important in achieving continuous energy performance that it tracks energy use from the baseline, comparing it with past or future targets and observing potential improvement.

Act:

The last stage of the cycle concerns actions like maintenance of machinery or energy indicators, assessing compliance, and repeating internal audits (Fiedler and Mircea, 2012; Menghi *et al.*, 2019a). It is the process done by the person responsible through management reviews and corrective actions.

The PDCA cycle forms a framework for organizations and can be easily adapted to any type. The difference is the methods of action and strategies that are put in place to suit their own organizational needs (Jovanović, Filipović and Bakić, 2017). Implementing such strategies at an international level will, in turn, have a positive effect on the global price of energy and emission targets.

1.3. Research Problem

The steel industry remains one of the most energy-intensive sectors globally, with blast furnaces and electric arc furnaces consuming substantial amounts of energy and contributing significantly to greenhouse gas emissions. They lack awareness of other means to maximize production without emitting excess greenhouse gases. The significance of the problem is bringing out awareness about energy management systems that are very beneficial to organizations and the world.

As world energy consumption is rising, it is necessary to conserve power as much as possible. The rising consumption harms the climate in the long run, requiring an urgent need for systematic energy conversations and frameworks. However, most companies are not ISO 50001 certified yet, highlighting a critical gap between available solutions and current practices.

1.4. Aims and Objectives

The main research objective is to provide guidance and awareness of energy management through energy audit strategies for Steelwork manufacturing industries.

To achieve the above objective, the following needs to be completed:

1. Complete a literature study on implementing ISO 50001:2018 EnMS for Steelwork manufacturing industries.
2. Identify strategies to implement ISO 50001:2018 in Steel manufacturing industries.
3. Develop a mathematical model and algorithmic framework for energy audit to enhance organizational energy efficiency.
4. Apply the model to real-world scenarios in the Vishvesvaraya Iron and Steel plant and the China Iron and Steel industry case studies.
5. Comparative Study before ISO implementation and after implementation for the effectiveness of the model.

1.5. Research Contributions and Impact

The research contributes as a guide that gives energy managers and auditors in both academic and industrial discourse to better understanding of the ISO 50001 EnMS Standard.

The research contributions aim to raise interest in energy managers, government, and Industrial organizations for certification (Liu, He and Chen, 2021). This study provides insight into the challenges and benefits of implementing ISO 50001. To bring it into the perspective of a real-world situation, a case study approach is used to provide further support. Bridging the gap between ISO 50001 theory and practical tools for steel energy management. The research offers a scalable, algorithm-based method that can help manufacturers of steel monitors and enhance their energy efficiency. The research contributes to raising awareness of how ISO 5001 can help better handle the industry of steel manufacturing.

1.6. Organization of the Thesis

Figure 3 shows the thesis structure from the introduction to the conclusion. The structure of the thesis has a composition of five chapters; the details of what each chapter entails are as follows:

Chapter One: Introduction – This chapter gives a synopsis and background of ISO 50001:2018 energy management standards in the steelwork manufacturing industry. This paper presents a guide to the standard in the steelwork manufacturing industry through energy audit techniques. The research problems and contributions are also included.

Chapter Two: Literature review – This Chapter contains a comprehensive study of the ISO 50001:2018 EnMS and its benefits in the context of the manufacturing industry that is available in the literature.

Chapter Three: Methodology and data collection – This chapter contains the key principles, and the method used in producing a guide for techniques to implement ISO energy management in Steel manufacturing industries. It focuses on energy audits, case studies, and mathematical modeling to employ a qualitative research design.

Chapter Four: Data analysis and findings – This Chapter presents practical strategies and key principles to equip organizations to comply with the standard to enhance energy efficiency. It also includes a review of a case study that assists the organization with the necessary tools and knowledge to comply with the standards. It also highlights findings derived from real-world applications and positive outcomes referenced from case studies and journals on implementing energy management. In the last section of the paper, the conclusions are presented.

Chapter Five: Conclusion and Recommendations – This final chapter summarizes the findings that are based on implementing ISO 50001:2018 from audit techniques and the PDCA cycle. The suggested algorithm improves energy management techniques, and case studies show notable energy savings. The study emphasizes the necessity of ongoing development and recommendations, incorporating AI-powered monitoring, and adhering to international sustainability objectives. It also offers a scalable framework that enables enterprises to maximize energy use while preserving operational effectiveness.

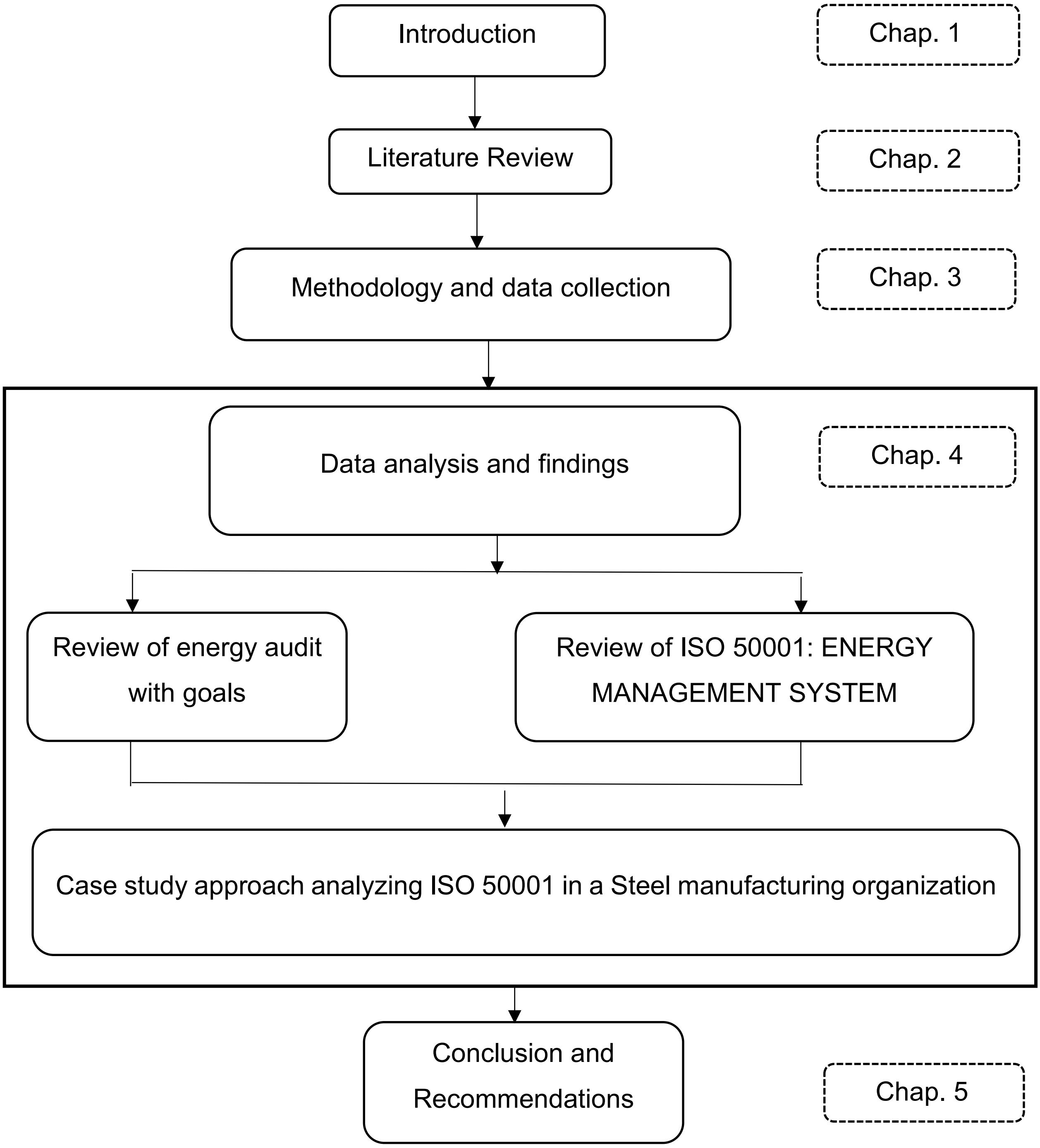


Figure 3: Organization of the Thesis

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The steel manufacturing industry covers a large field, which brings concern to energy demand. It is a fundamental aspect which links to the global market and economy because it is dependent on fossil fuels. The steelwork manufacturing industry is a significant contributor to global energy consumption and greenhouse gas emissions, which is approximately 7-9% of global carbon dioxide emissions (Kim *et al.*, 2022). Optimizing energy use is both financially and environmentally necessary due to growing operational expenses and regulatory demand to minimize emissions.

The widely accepted benchmark for putting in place a successful energy management program is the ISO 50001:2018 Energy Management System (EnMS). This chapter aims to review the application of ISO 50001:2018 EnMS in the production of steelwork.

To elaborate further on this study, this chapter focuses on the following reviews:

- Review of the Literature, processes of production of steel
- Manufacturing Steel and Energy Flow
- Analysis of ISO 50001 Energy management system in steel industries
- Demand and Consumption in Steel Production
- Renewable energy options for lowering consumption.

In any organization, the business processes that affect energy are as follows: finance, operations, quality, maintenance, human resources, procurement, environmental policy, and health and safety (Wu, Zheng and Song, 2019). To improve an organization’s energy system in steel manufacturing, it is key to understand these key processes in detail to exploit energy-saving opportunities. This occurs through the process of a management review of performance where all tasks, actions and decision-making are done in the steel manufacturing processes.

2.2. Manufacturing Steel and Energy Flow

Steel manufacturing involves the collection of raw materials through mining iron ore and other minerals that occur in nature. These materials are then heated and processed into steel, which is used in several items we use on our day-to-day basis (Dey, 2022).

According to the World Steel Association, steel has been manufactured since 2000 BC by melting wrought iron with an iron cast in the form of a furnace. Figure 4 shows a step in the steel manufacturing process when the molten iron ore is formed into a shape through the forge.

Figure 4: The advanced steel manufacturing process (Isoherranen and Kess, 2016)

The ISO 50001 energy management standard in steel manufacturing follows the relation of energy, heat, temperature, and work, which is thermodynamics (Steenkamp and Du Preez, 2015a). To exploit energy savings, the standard aims to make people aware of the energy exchange.

Steel making incorporates a closed loop system where waste such as slag are recycled into cement production or construction aggregates thus reducing environmental impact (Pelser, Vosloo and Mathews, 2018). Figure 5 visually captures the linear flow of raw materials into finished steel products. The key stages and outputs in the steelmaking process are listed:

1. Iron making (e.g., raw material preparation)

2. Steelmaking (e.g., blast furnace operation, conversion to steel)
3. Continuous casting
4. Rolling
5. Main products (e.g., steel pipe, rails)

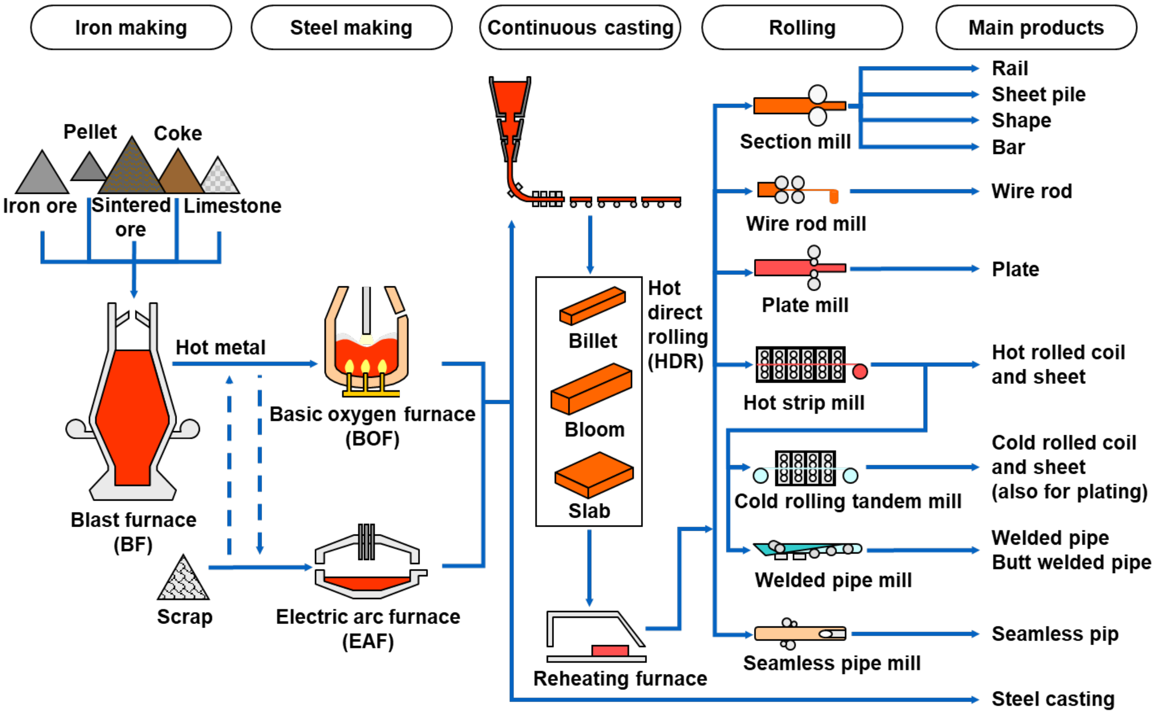


Figure 5: Steel-making flow diagram (Steenkamp and Du Preez, 2015a)

Figure 6 shows the chemical elements used and the steps in making steel. Energy is required in the making of these processes as the ISO 50001 procedure aims to make these steps more effective compared to the previous years. The chemical processes in steel making in Figure 6 occur from iron making; steel making, and continuous casting process depicted in the flow diagram in Figure 5.

The chemical process involved in steel production, mostly in the thermal treatment of minerals, uses energy in different forms. The heating and extraction process is called Pyro-metallurgy, which consists of the heat treatment of metallurgical ores to make chemical and physical modifications in the materials to make valuable metals (Habashi, 2017). As seen in Figure 5 and Figure 6, the iron-making process is the first step, and it deals with the extraction of ores

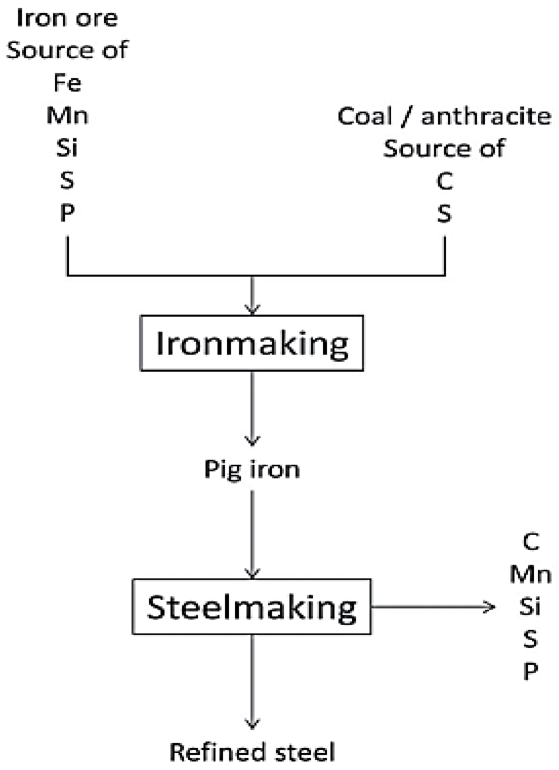


Figure 6: Overview of chemical processes in steel production (Steenkamp and Du Preez, 2015b)

Some of the chemical reactions that occur throughout the steel-making process are as follows:

- Reducing zone: C02 + C2 → C0 – Heat
- Combustion: C(coke) + 02 (from air) → C02 + Heat

  Si + 02 – SO02 + heat

  2Mn + 02 – 2Mn0

- Melting zone: 3Fe + 2C0 →Fe3C + C02

Nowadays, the system is much improved and more complex as the technology involved uses machines in factories to make a much more effective and effortless production of steel. After the extraction of metallurgy, different routes of heating steel are used. In modern-day, steel is still heated inside a furnace; then unwanted materials are removed. Subsequently, carbon and various alloying elements are introduced to the iron to enhance it (Dey, 2022). These processes involve energy exchange and require some form of efficiency, which the ISO 50001 standard can exploit and use to improve.

The processes used for smelting ore are as follows:

- Electric arc furnace.
- Blast furnace.

2.2.1. Blast Furnace

A blast furnace (basic oxygen furnace) is a metallurgical, tall, and cylindrical furnace-enclosed structure that is made of steel for smelting to make industrial materials like iron (de Castro *et al.*, 2020). The blast furnace uses oxygen and heat to remove impurities from metal (Jin *et al.*, 2017).

As seen in the flow diagram in Figure 5 and Figure 7, from the iron-making stage, the blast furnace is supplied with iron ore, coke, and limestone. Within the blast furnace, energy exchange and chemical reactions occur to heat up and smelt the mineral components. A combustion reaction occurs, which may include oil-fired, coal or gas-fired energy as a source (Ricketts, 2015).

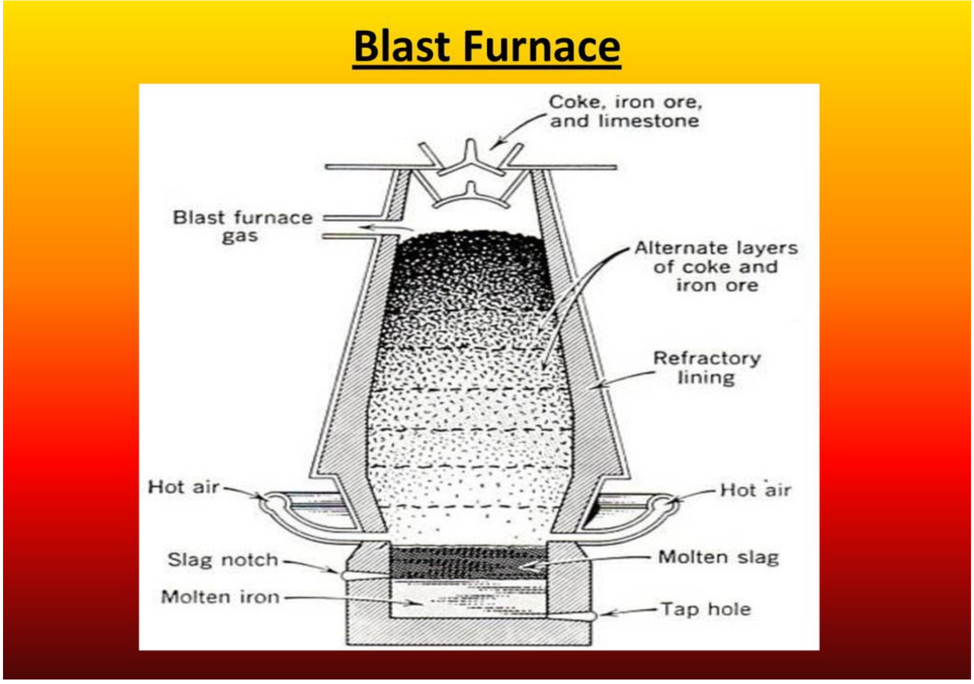


Figure 7: Blast furnace (Petrescu, Popescu and Gligor, 2014)

The optimization of a blast furnace involves utilization and controlling its energy performance according to the required temperature for melting the material. Figure 8 also shows in general how all types of furnaces are classified. The energy efficiency of a blast furnace depends on how well it does the following:

- Smelts,
- Cast and extract metal from ore,
- Melt and shape material,
- Produce fewer carbon fumes,
- Change the properties (heat treatment) (Ji, Zhang and Wang, 2010)

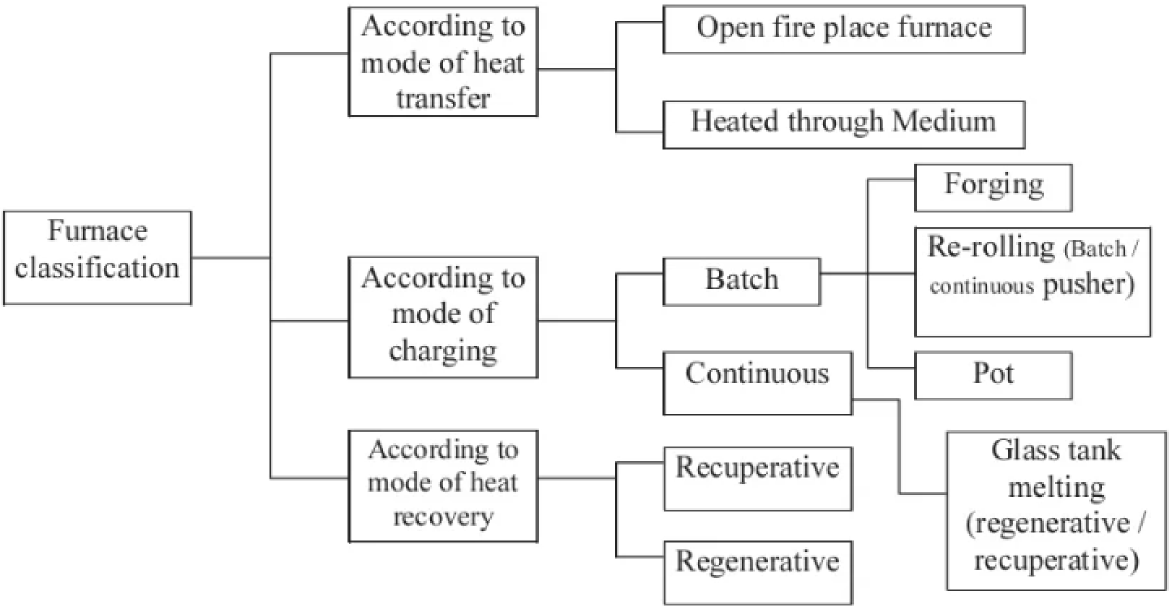


Figure 8: Furnace classification (Sarker, Corradetti and Zahan, 2013)

ISO 50001:2011 specifies all variables that are measured, monitored, and can be influenced by the organization (Castro, Fonseca and Pablo Meléndez, 2017). In the blast furnace process, the combustion reaction is very important as it plays a role in iron reduction and provides a large amount of energy. Jin et al. (2017) suggests that in a blast furnace, including a top gas recycling in its design CO2 emissions are reduced.

The top gas-recycling blast furnace (TGR-OBF), shown in Figure 9, incorporates a gas recycling system, which is integral to its design and operation.

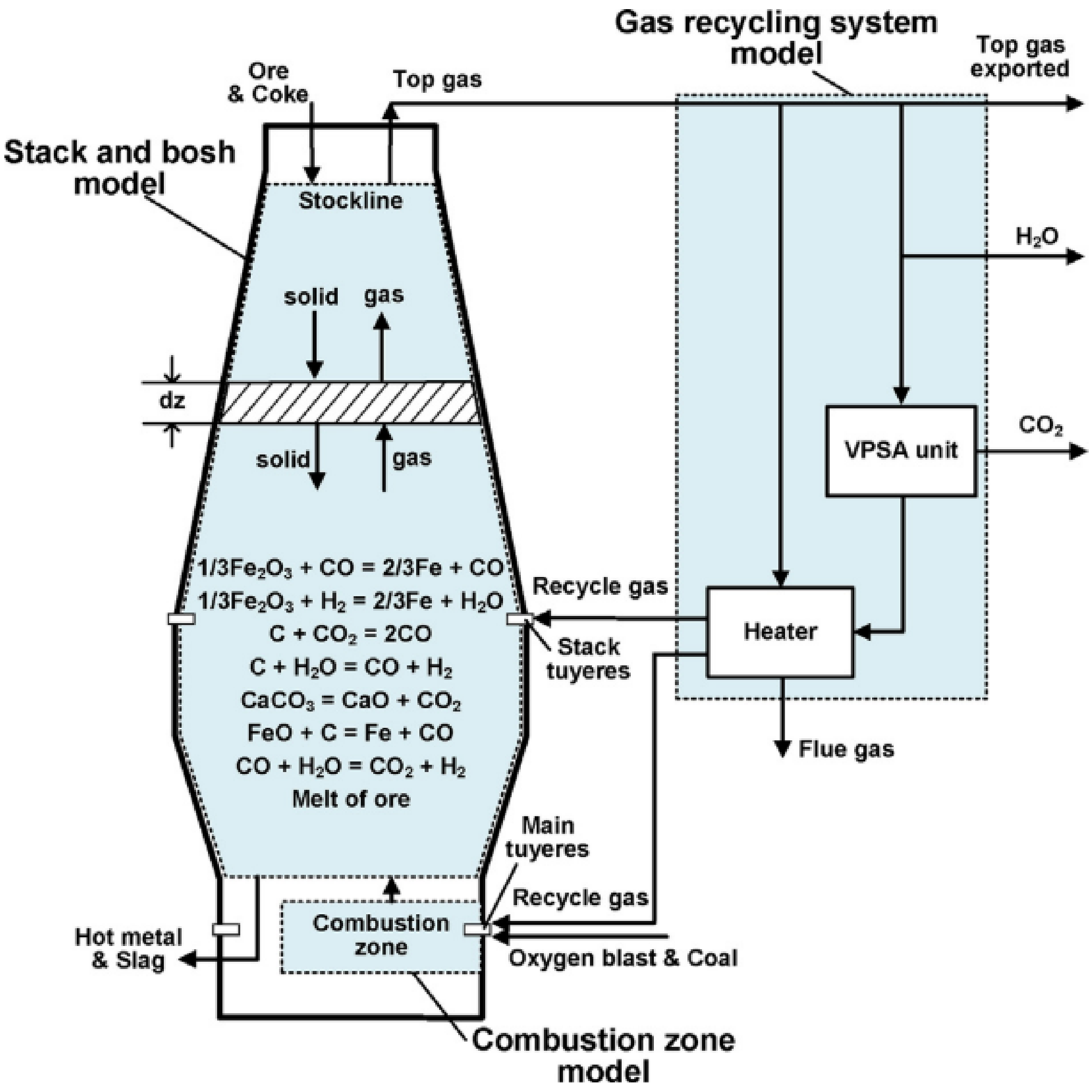


Figure 9: TGR-OBF Model (Jin *et al.*, 2017)

2.2.2. Electric Arc Furnace (EAF)

An Electric arc furnace (EAF) operates by an electric arc discharge to deliver heat to melt material. The Furnace body has a Charge door, shell, spout, hearth, shell, and other features. (Steel Supply L.P, 2020). It is substantial and is depicted in Figure 10 as a vessel walled with refractory into which two or more graphite electrodes are inserted. The one seen in the figure has three electrodes because the three-phase alternating current powers it. Electric arc furnaces have been used in steelmaking since 1889 and were invented by Paul Heroult (Cavaliere, 2016a).

They usually range in size of unit up to 400-ton units used for secondary steelmaking.

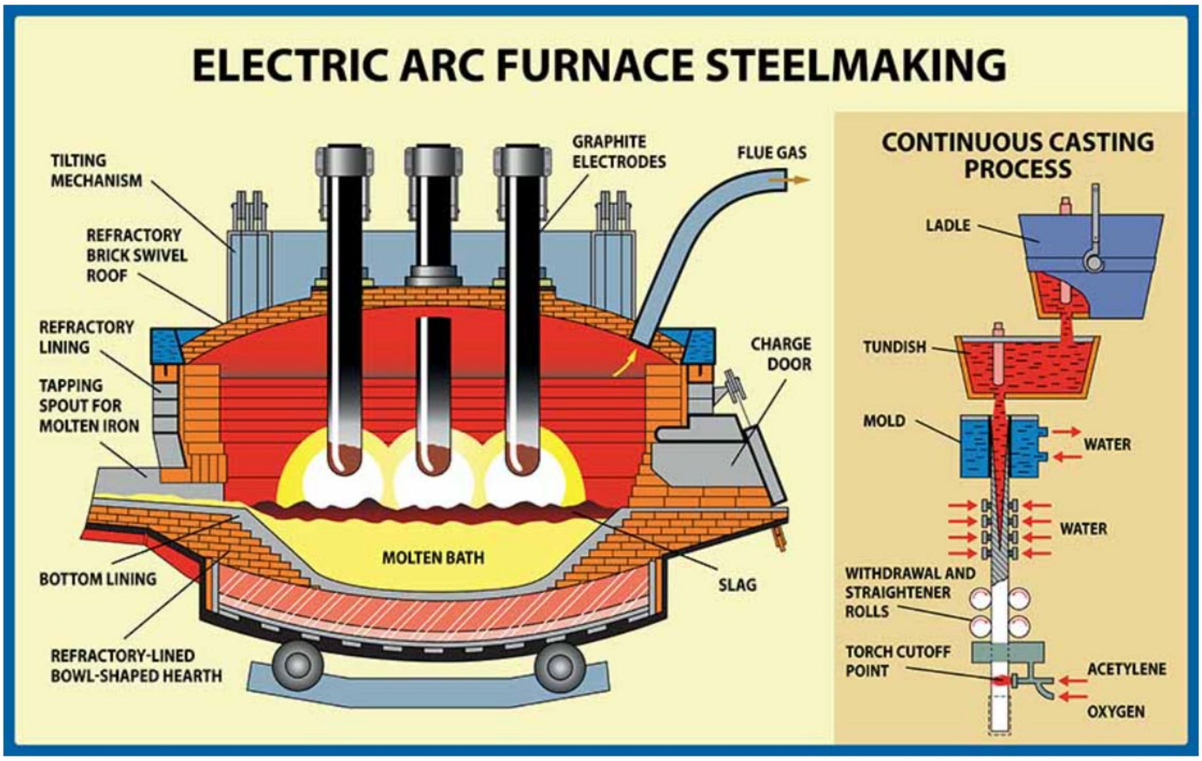


Figure 10: Electric arc model (Steel Supply L.P, 2020)

Due to the passing current through the charge and the radiant energy generated by the arc, the electric arc furnace can reach temperatures exceeding 4000°F. According to Dragna, Ioana and Constantin, (2018) Melting scrap steel and superheating it to typical tapping temperatures requires 350 - 370 kWh per ton of steel. In addition, the use of EAF has a big influence on electricity and natural gas prices; to reduce the influence, special energy technologies are integrated with the EAF. Sung et al. (2020) extensively studied a revised side-wall injector method to increase energy performance in an EAF. A reduction of 5 kWh/t in electrical energy consumption and a production gain of roughly 3.1 ton per hour resulted from the modifications (Sung *et al.*, 2020).

Figure 11 shows the summary of energy conservation technologies in steel manufacturing. The introduction of big transformers into the steel manufacturing industry in the 1880s marked the beginning of a considerable rise in global production. Due to the EAF's versatility and ability to convert ferrous scrap into refined steel, consumption could be maintained even with increasing production (Cavaliere, 2016b).

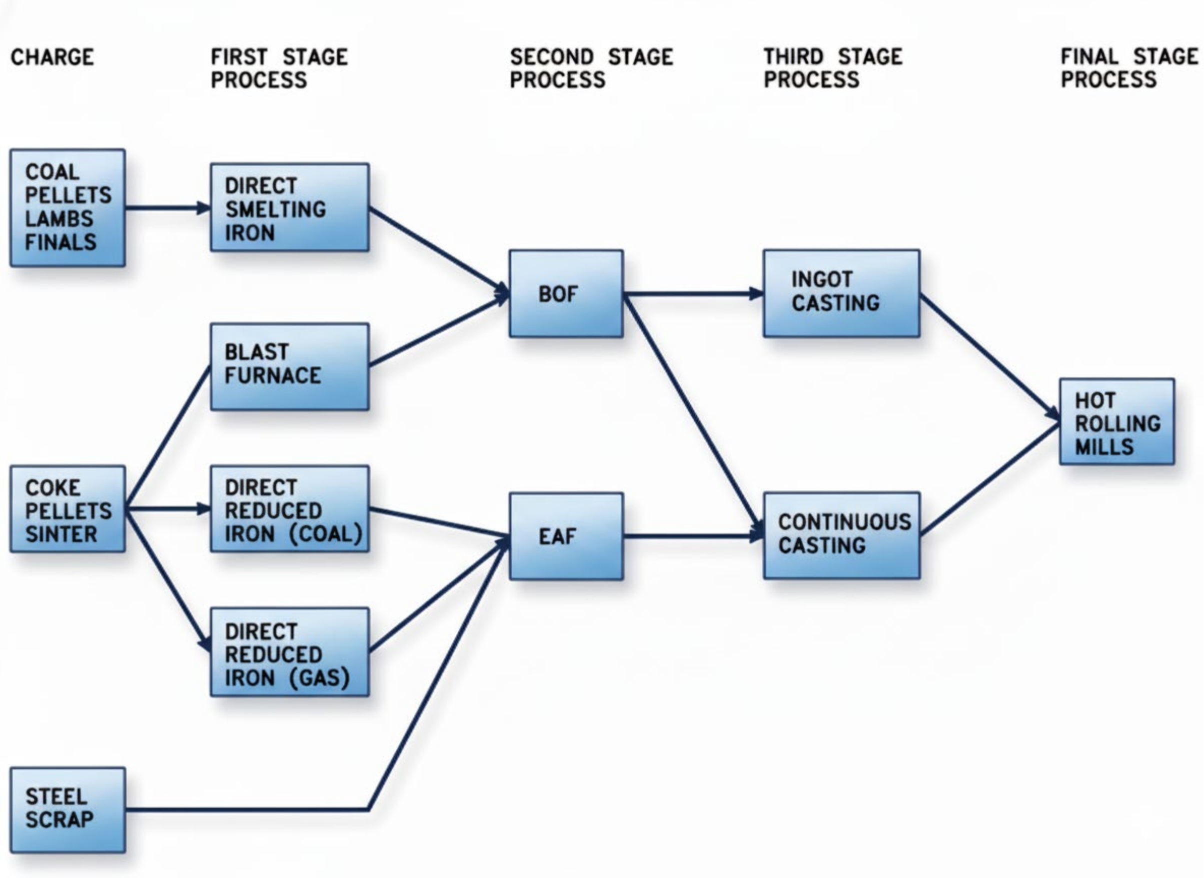


Figure 11: Summary of stages in each production route (Mohsen and Akash, 1998)

The EAF also contributes a significant amount to the global production of steel manufacturing. The global as seen in Figure 12 illustrates the crude steel production using EAF technology compared to total steel production. EAF accounts for approximately 30% of global crude steel output, reflecting its significant role in the industry. The steady rise over time suggests that EAF, which has benefits including decreased energy usage and environmental effect, is becoming more widely used.

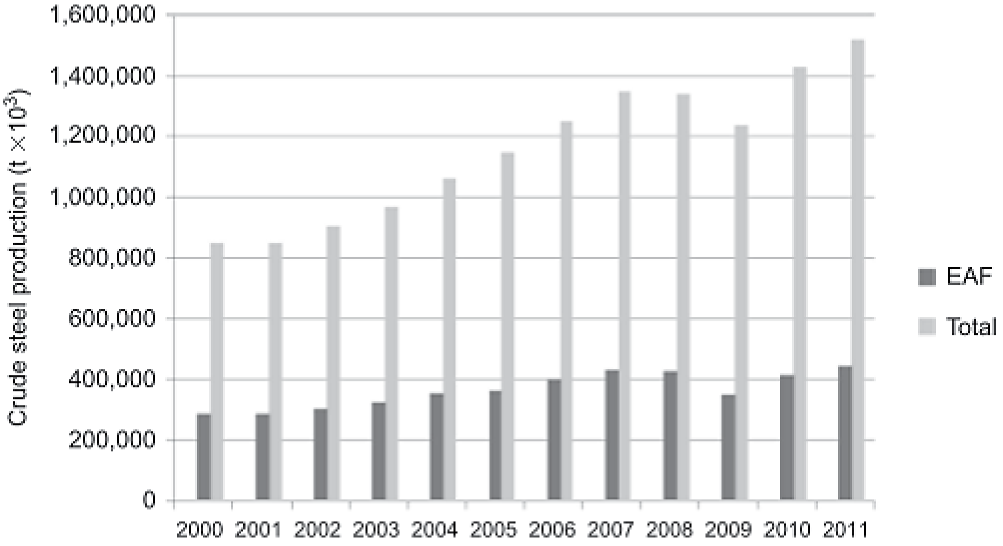


Figure 12: Worldwide production of steel with EAF (Cavaliere, 2016b)

Some of these benefits are as follows:

- The EAF is flexible as the production of steel can be varied; it can be used for melting and as a heat treatment furnace.
- Compared to the blast furnace, it is more energy efficient.
- Unlike the blast furnace, operating for years at a time, the EAF can be started and stopped for better efficiency to vary production according to demand.
- EAF allows the steel to be made from ferrous scrap into refined steel (Cavaliere, 2016b).

2.3. ISO 50001:2018 Energy Management System

The ISO 50001 standard is set up to bring out the best practices of energy management at any level of organization or project throughout the entire world. By making use of management strategies like the PDCA cycle to monitor energy usage and working effectively to keep up with energy executions (Xueqin Lü *et al.*, 2021). The PDCA model was selected due to its cyclical nature, which aligns well with the ISO 50001 standard's emphasis on steady advancement in energy performance. The implementation of ISO 50001:2018 aims to mitigate environmental impact and save energy costs by enabling systems and processes, as represented in Figure 13 (Mohamad *et al.*, 2014a). It enables organizations to create an energy strategy, set performance goals for energy, put an energy management plan in place, monitor that performance, and review it.

Figure 13 Shows the EnMS implementation and operation model that the ISO 50001:2018 standard can make use of to establish a convincing energy policy. Since 2011, numerous abstract elements of management standards, including ISO 9001:2008, ISO 14001:2004, and EN 16001:2009, have been incorporated into the enhanced 2018 edition of the ISO EnMS (Feili, Aghaee and Parvazeh,2012).

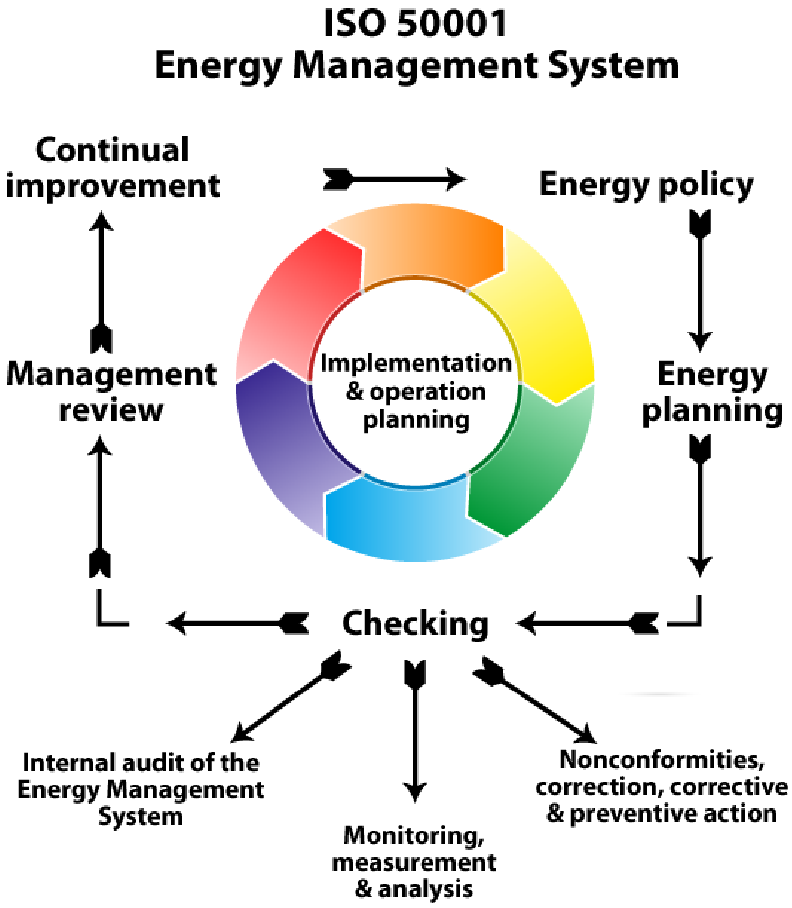


Figure 13: ISO Management System (Menghi *et al.*, 2019b)

The ISO 50001 system's wonderful feature is that it repeats itself. Along with the other management, the system aims to improve the production process continually. The findings can also be used to increase awareness because they are tracked and saved for further use. Prashar (2017) believed that the continuous improvement proposed by the PDCA cycle is best suited for both technical and non-technical conduct to help meet the organization’s financial, infrastructure, energy, and environmental goals. Table 1 shows key contents outlined and compares the different ISO standards.

Table 1: Comparison of Key Elements in ISO Management System Standards(Clara Hasselbring, 2016)

Content	ISO 50001	ISO 14001	ISO 9001
Constructs for defining guidelines	Based on a certain industrial process or the organization's overall energy consumption. ISO 50001 systems must account for all organization's energy use to comply with the government’s energy sector regulations.	Considers relevant environmental factors	Considers the quality standards of the clients
Policy	The organization's energy management strategy is demonstrated by its energy policy.	An organization's environmental policy outlines its dedication to environmental protection, how it tackles environmental issues, an(Bosu, Mahmoud and Hassan, 2023a)d related goals and targets. The organization's dedication to pollution prevention, regulatory compliance, and ongoing improvement are usually included in the policy.	Meeting the clients’ requirements
Strategy	Define baseline and performance metrics for energy and conduct energy	Compliance with relevant environmental regulations.	Establishing quality management plans, goals, and targets.

Content	ISO 50001	ISO 14001	ISO 9001
	reviews to find important energy consumption activities(Premraj et al., 2012). establishing energy goals, targets, and execution strategies in addition to adhering to pertinent regulatory requirements.	establishing environmental goals, targets, and plans for execution.	
Baseline	Energy baseline is required as the standards foundation.	No requirement	No requirement

ISO 50001 is an international standard aimed at organizations at a local level to contribute on a global scale to the effort to reduce the impacts of climate change. The predetermined outcome of an organization is to use these systematic approaches and execute energy tasks (Mohamad *et al.*, 2014b).

In addition to the following, this document applies to any organization and activity they manage:

- It does not matter how much, what type, or how much energy is consumed.
- It does not matter how big or how complex the organization is, where it is located, what products and services it offers, or what type it is.
- It applies to integrated management systems and is independent alike.
- The EnMS requires a continuous demonstration of improvement in energy but does not define the levels of improvement (Marimon and Casadesús, 2017).

2.3.1. Benefits of using ISO 50001 Standard

To investigate the effect of putting EnMS in place on business performance,(Liu, He and Chen, 2021) sampled 54 sizable Chinese iron and steel enterprises. Based on those samples and other research, they concluded that ISO 50001 could assist companies in lowering their greenhouse gas emissions and energy use. Managing energy performance and meeting regulatory requirements is integral to ISO 50001 to fulfill regulatory requirements. Additionally, implementing ISO 50001:2018 EnMS can assist enterprises in adhering to energy-related rules and standards (Cooper, 2016).

ISO 50001 EnMS enables an organization to:

- The efficiency and effectiveness of processes are improved because of management system standards.
- Reduce costs by optimizing operations.
- Increase customer expectations.
- Assist in lowering the environmental impacts, thus reducing carbon footprint.
- Increase in ease of processes and production of steel.
- Training for energy managers and personnel
- Improve energy performance.
- Cut costs and improve profits.
- Gives organizational branding and recognition.

Table 2 presents data showing the per capita consumption of finished steel products across various regions from 2017 to 2021, including Africa, Asia, Europe, and the Americas. While developed nations such as South Korea, Japan, and the European Union exhibit consistently high levels of consumption, regions like Africa display substantially lower rates, demonstrating inequalities in industrial growth and steel demand. These variances show that ISO 50001:2018 must be implemented context-specifically. Regardless of the production scale, EnMS can help optimize energy use. ISO 50001 promotes cost reduction and performance enhancement in areas with well-established steel industries, and it can direct energy-efficient industrialization and sustainable growth in developing nations.

Table 2: Kilograms of Finished Steel Products per Capita (2017–2021)(World Steel Association, 2022)

Country/Region	2017	2018	2019	2020	2021
Austria	464.3	470.7	444.4	405.2	516.9
Belgium-Luxembourg	288.4	371.9	280.3	242.8	397.2
Czechia	676.6	712.6	674.8	624.3	775.5
France	227.6	228.5	223.5	187.1	211.0
Germany	496.0	477.0	420.8	371.9	426.1
Italy	409.5	417.7	412.7	337.6	439.4
Netherlands	233.9	283.3	269.9	241.7	264.4
Poland	358.4	392.8	359.8	341.1	399.7
Romania	213.2	234.4	234.4	214.5	220.6
Spain	284.2	296.4	283.3	249.0	282.2
Sweden	416.6	407.5	378.6	310.3	355.8
Other EU	242.0	261.0	259.9	246.7	263.8
European Union (27)	342.8	353.9	332.7	294.2	344.2
Turkey	445.3	372.3	312.6	349.6	394.9
United Kingdom	164.9	161.2	151.8	132.1	159.0
Others	192.6	212.3	212.7	200.5	210.6
Other Europe	295.2	266.0	235.7	243.5	276.0
World	216.7	224.3	230.4	229.0	232.8
Russia	279.6	283.5	298.3	290.0	305.8
Ukraine	102.5	105.8	105.8	105.2	110.3
Other CIS	88.7	92.7	97.5	101.5	92.7
Russia & Other CIS + Ukraine	186.2	189.8	198.5	195.4	200.1
Canada	382.2	380.6	347.0	331.0	384.5
Mexico	206.8	200.5	190.7	165.9	186.6
United States	300.6	305.0	296.6	241.8	290.9
USMCA	282.7	283.8	273.1	228.3	270.0
Argentina	112.0	108.8	87.5	79.5	109.7
Brazil	93.9	101.2	99.4	100.9	122.7
Venezuela	17.4	5.9	4.2	3.0	2.5
Other Central & South America	74.7	70.5	71.2	57.2	79.7
Central & South America	82.4	82.7	80.4	73.9	94.7
Egypt	105.5	112.4	103.1	94.7	97.4
South Africa	90.9	87.7	81.2	63.3	83.8
Other Africa	18.2	18.5	21.2	18.4	18.2
Africa (total)	28.3	28.9	30.2	26.2	27.0
Iran	247.4	239.1	223.0	204.9	216.3
Other Middle East	230.5	216.9	208.5	195.4	191.5
Middle East	214.1	204.2	194.5	179.9	180.7

Country/Region	2017	2018	2019	2020	2021
China	544.6	585.6	636.0	699.6	666.5
India	66.2	71.5	75.1	64.7	76.0
Japan	504.9	514.2	498.3	416.1	456.2
South Korea	1102.1	1049.6	1039.1	955.0	1075.6
Taiwan, China	745.7	749.7	740.9	789.0	885.6
Other Asia	88.1	90.0	90.8	80.1	82.8
Asia	268.3	283.7	300.0	311.8	306.2
Oceania	159.9	158.8	156.6	143.9	170.0

2.3.2. Barries of deploying ISO 50001:2018 EnMS

Multiple obstacles are encountered in the implementation of ISO 50001:2018, (EnMS), Systems by the Steel Industry. The Manufacturing sector contains numerous critical weaknesses and authors have already described some of these previously. In addition, numerous other issues were discussed to identify areas that require further investigation for evaluation. Rotzek, Scope and Günther, (2018) have highlighted that the most significant obstacles to establishing EnMS systems are a lack of knowledge and understanding of the standards, significant initial startup costs associated with implementing the standard, and the need to shift towards a more Energy Management Culture within an organization. However, these obstacles should not only be viewed as obstacles to establishing EnMS, but they are also indicative of the absence of a clear understanding of how to incorporate Energy Management Systems into the Strategic Objectives of Steel Producers. The seemingly high implementation costs of the standard are due to ineffective and inefficient management of resources and ineffective Strategic Planning for future Growth.

In a study, Sousa Lira, Salgado and Beijo, (2019) found that manufacturing has several difficulties such as low availability of skilled labor and complex manufacturing processes and a lack of ways to reduce energy consumption. This perception of the industry does not consider the overall issue of inadequate training programs for workers and support for the introduction of new technology into the industry. The findings of this study suggest that these impediments to the implementation of ISO 50001:2018 in the steel industry reflect deeper organizational inefficiencies such as a lack of commitment from top management and a misalignment between the sustainability goals and production goals. To achieve a successful implementation of ISO 50001:2018 in the steel industry, these underlying organizational issues must first be addressed rather than just focusing on technological and financial challenges.

For an organization to reach sustainability in EnMS, it must look inward and understand the challenges and barriers it might face. The following are other barriers that the steel manufacturing organization might face during the implementation of the ISO 50001:2018 energy management system for effective planning and adoption (Fiedler and Mircea, 2012):

- Requirements of resources and investments.
- Quantifying the return on investment
- Accurate data collection and estimation of targets
- Ability to adapt to the shift in organizational culture.
- Increased burden on administration
- Complexity in integrating with other standards.
- Communication with staff, management, suppliers, and stakeholders
- Keeping track of energy indicators

2.4. Energy Demand and Consumption in Steel Production

The world's industrial and commercial sector makes up about 40% of the emissions of greenhouse gases in energy consumption (Valencia *et al.*, 2020). The ISO 50001: 2018 standard provides a systematic approach aiming for a sustained improvement in energy consumption. TÜV UK Ltd, (2014) agrees that the environmental impact of energy use in the manufacture of steel is enormous, and this industry has an increased energy demand. The increasing energy demand is also rapidly altering climate change; hence, there is a need to reduce the emissions caused by steel manufacturing. As shown in Appendix A, steel production is dominated by China and Asia, with forecasts indicating sustained growth through 2023. Adopting energy management systems like ISO 50001 in these areas is crucial because of the substantial effect it has on output-concentration of carbon emissions and worldwide energy consumption (Kolagar, Saboohi and Fathi, 2022). Steel consumption per capita varies greatly by location, with rising economies showing a consistent rise, as Table 2 illustrates. The necessity for scalable ISO 50001 implementation techniques is highlighted by the fact that these consumption patterns influence the different energy demands of industrial sectors across regions (Mangla *et al.*, 2020; World Steel Association, 2022).

Figure 14 shows the energy-saving scenarios with a projection to 2050. United Nations Industrial Development Organization (UNIDO), (2014) also projects that considering the expanding production rate up to the relevant years, the production of the steel and iron sector will increase by 1.7 between 2030 and 2050.

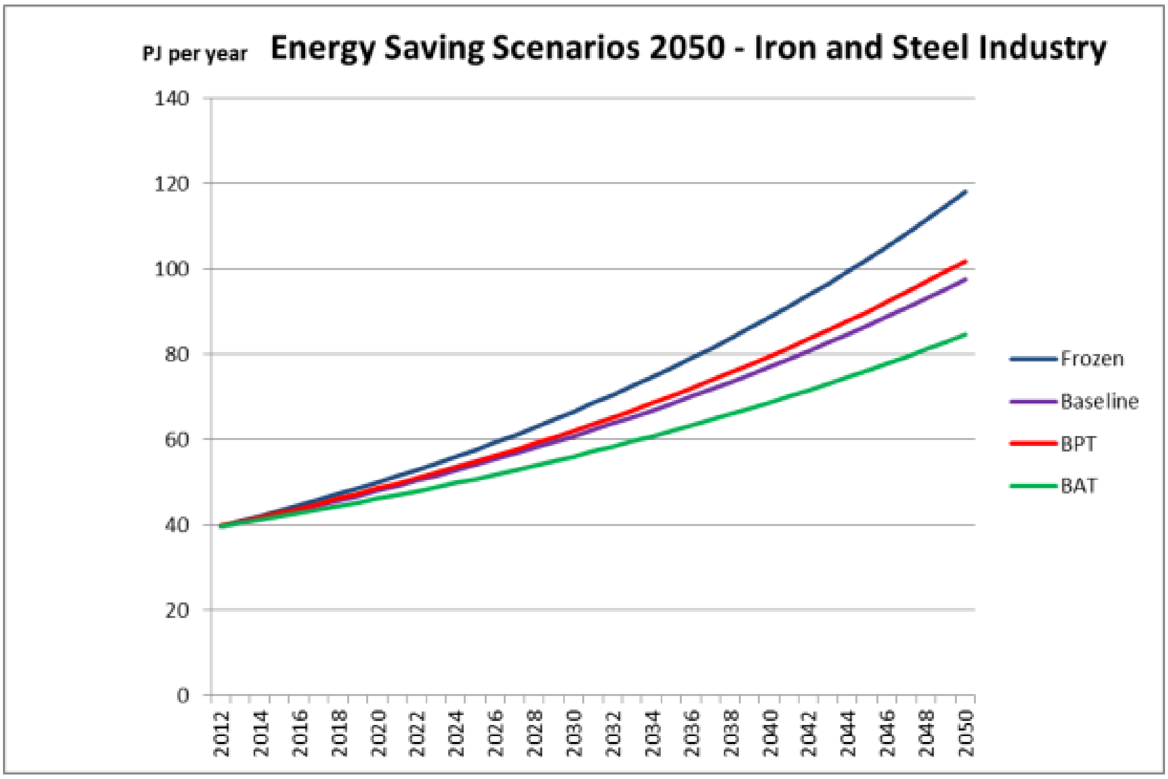


Figure 14: Energy saving scenarios projections for 2050 in the steel industry (United Nations Industrial Development Organization (UNIDO), 2014)

Figure 14 shows the different scenarios with the following outcomes:

- Frozen – This is the energy efficiency scenario where the projected energy is not improved, and no savings are made.
- Baseline – An annual rate of 0.5% improvement is made to increase energy efficiency.
- BPT (Best Practice Technology) – In this scenario, the energy efficiency for a year is estimated at 0.41%, equivalent to the plant operating at the

BPT. As seen in the figure, these values are taken from the 2012 analyzed data set for energy technologies (United Nations Industrial Development Organization (UNIDO), 2014).

- BAT (Best Affordable Technology) - This is the energy efficiency scenario where the projected energy improvement is at 0.90% a year from 2012 to 2050. These values are based on the best affordable Technology for steel making. The energy consumption for EAF overtime is estimated at 2.22 GJ per ton.

The BAT is the most desired for any organization as it is in line with the framework of energy savings and meets the needs of the ISO 50001 standard. The BAT scenario is estimated to be about 85PJ of energy consumption, which saves about 28% compared to the frozen scenario in Figure 14.

The energy manager must conduct a comprehensive audit of all processes within an organization’s energy usage, focusing on identifying the most cost-efficient technologies for steelmaking. The most affordable technologies in steel making are those that are easily accessible and cost much less. The audit completed by the energy manager would clearly show the areas that have the most energy usage and offer better affordable options. According to the data presented in Figure 15, Steel accounts for a significant portion of industrial energy consumption, with energy usage projected to increase globally across all energy sources, including natural gas, coal, electricity, and renewables. This reinforces the importance of targeted energy audits that pinpoint areas of excessive energy consumption and propose more sustainable and affordable solutions. Hasanbeigi et al. (2016a) studied that only 23% of steel makes energy use in industry, and with even minimal capital investment, when an energy manager puts strict policies in place.

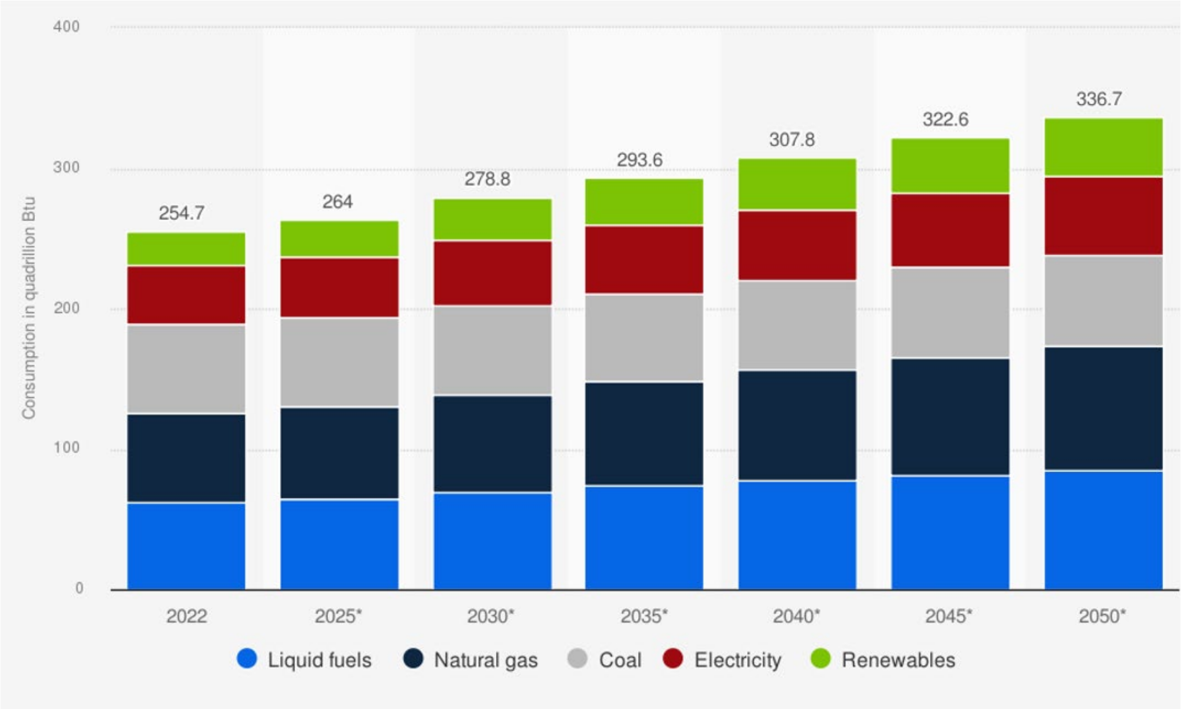


Figure 15: Energy use of industries by energy source (Satista_EIA, 2023)

The manufacture of steel is essential to the world economy and is essential to many different sectors. Steelmaking is an energy-intensive process since it requires a lot of energy to supply the required heat and power for all the different steps. With the continuing concern about the adverse effects of steel production on the environment, the increasing prices of energy, and the rising demand for energy, energy use in the production of steel is an area of concern. This segment provides a complete overview of the total amount of energy input and output, both direct and indirect, in the manufacture of steel.

Direct energy consumption is the term used for energy that is consumed for heating and generating electricity in steelmaking (Wu, Zheng and Song, 2019). In addition, Wu et al. (2019) state that "Liquid steel, as the primary raw material used to produce many different types of steel products, relies heavily on direct energy consumption." The direct energy that is utilized in this process stems from three sources of energy (i.e. electricity, coal and natural gas). Conversely, indirect energy consumption refers to energy spent in the manufacture of raw materials (such as limestone and iron ore) that will be converted into steel or scrap steel (Southworth *et al.*, 1981). It also includes the energy used for transporting raw materials, intermediate goods, and finished products, all of which are considered in Environmental Impact Assessments (EIAs). As Gonzalez & Kamiński, (2011) state, energy consumed in producing raw materials may comprise a large proportion of total energy used in the overall steel production industry.

Cavaliere (2016a) indicates coal, natural gas, oil, and electricity are the principal energy sources used by steel manufacturers. Of all the energy consumed, approximately 50-60% is associated with liquid steel production; with coal being the principal energy source (Van Der Stel *et al.*, 2013). Recently, as natural gas has become increasingly accessible, and its production cost has declined, it is being utilized more frequently as a secondary energy source. See Figure 16 for the South African energy supply. To power the various stages of steelmaking, electricity is also employed in the manufacture of steel.

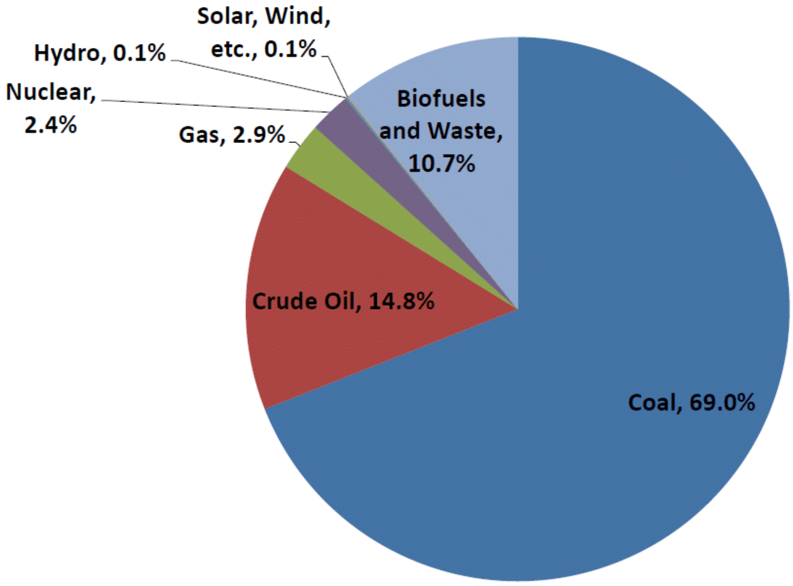


Figure 16: The South African primary energy supply (DOE, 2019)

McCall et al. (2019) concur that by putting in place various energy efficiency measures, the steel industries can lower their energy usage and lessen their environmental impact. The steel manufacturing industry has been actively taking steps to minimize its indirect energy usage by optimizing its supply chain and shortening the transportation distances for raw materials, intermediate products, and finished goods. This distribution emphasizes how high-output regions bear an excessive amount of energy load, which is why ISO 50001 implementation plans need to give priority to these areas. Figure 17 provides historical data on global crude steel production by region from 2011 to 2021.

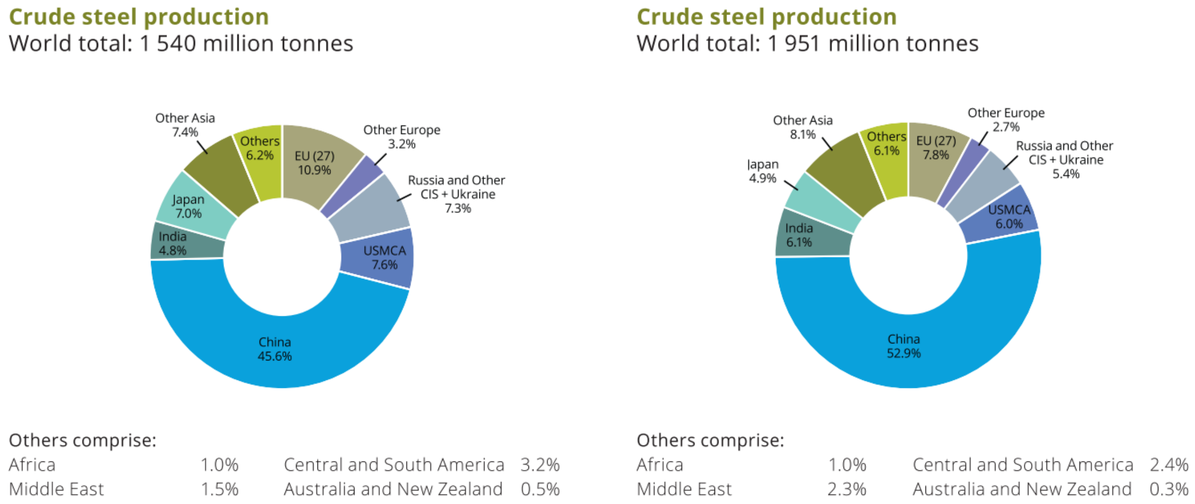


Figure 17: Global Crude Steel production between 2011 and 2021 (World Steel Association, 2022)

This highlights the need for regional and global energy optimization strategies and geographic concentration in steel outputs (worldsteel_Association, 2012; World Steel Association, 2022). To achieve this, energy-efficient technologies were implemented, including blast furnaces that enhance heat transfer and combustion efficiency, as well as electric arc furnaces that surpass the energy efficiency of traditional blast furnaces (Renman, 2011).

2.5. Renewable Energy Option for Lowering Consumption:

The high compatibility of the ISO energy management standard allows the integration of renewable energy, such as solar energy. Solar energy, like any renewable energy technology, can be used to assist in lowering energy consumption and thus reduce greenhouse gas impact (Feili, Aghaee and Parvazeh, 2012). As seen in Figure 18, renewable energy has a high potential for clean energy without negatively affecting the environment

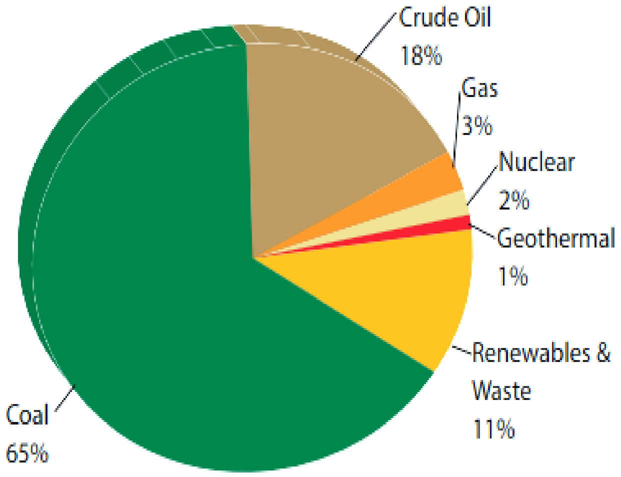


Figure 18: SA Total energy supply, 2018. Source: DoE energy balance, 2018

In any location where people live, growth in that environment is directionally proportional to the energy demand. This means that the more people in the environment, the more energy they will require for their needs.

Adding renewable energy can decrease the curb in energy demand once integrated into such an environment. The following are some notable benefits of using renewables for reducing energy consumption (Belward *et al.*, 2011):

- Reduction in energy costs: When renewable energy is used for heating, lighting, cooling, hot water, or any other aspect, significant operational cost reductions are achieved.
- Reducing the carbon footprint: Utilizing less energy that contributes to carbon emissions lowers an organization's carbon footprint.
- Smart Energy Technology usage: new monitoring technologies to simplify and increase productivity by automating tasks.
- Stable energy prices: Since the cost of renewable energy is cheap, it gradually lowers the cost of energy.

2.6. Core Objectives and Strategic Advantages of ISO 50001:2018

The standard facilitates the identification of inefficiencies, implementation of energy-saving measures, and continuous performance improvement through the PDCA cycle. This section explores the core objectives of ISO 50001:2018, highlighting its strategic advantages in fostering sustainable industrial practices, improving organizational competitiveness, and contributing to broader environmental targets.

Table 3 follows a clear breakdown overview of the crucial details of ISO 50001:2018 Energy management system. The table summarizes the principles that form the foundation for industrial energy performance strategies and align directly with the objectives of the proposed algorithm.

Table 3: Overview of ISO 50001:2018 Principles and Implementation Goals

Key elements	Description
Standard name	ISO 50001:2018 Energy management system.
Purpose	To promote the best work ethics and practices related to energy management on a global scale.
Key Strategies	Using energy audits and PDCA cycles to monitor, document, and enhance energy usage.
Environmental Impact	It aims to diminish environmental impact and energy costs.
Implementation Goals	It enables organizations to create policies and energy strategies to set performance goals and review them.
Management System Integration	It is easy to integrate with other management systems such as ISO 9001:2008 and ISO 14001:2004.
Continual Improvement	It helps to meet organizational goals by emphasizing continual improvement in both technical and non-technical aspects.
Global improvement	Through the standard, organizations will contribute globally to reducing climate change.
Applicability	The standard applies to all organizations of any size, location; services offered or level of energy consumption.
Energy Improvement Demonstration	Improvement requires monitoring systems and data record methods to demonstrate energy improvement.

2.7. Summary

The chapter provided an overview of ISO energy management system literature focused on the steel sector because this industry represents one of the highest levels of energy consumption and contributes to environmental degradation globally through the production of steel products. The level of energy demand within the global steel industry continues to rise due to continued urbanization and increased energy requirements to create an end product from melting the raw materials (i.e., iron ore and scrap metals). In addition, the article looked at how energy is used in steel creation techniques and processes. The production methods are a major contributor to the overall energy used by these methods through their large energy consumption base. Therefore, evaluating the routes of steelmaking will enable greater opportunities to manage energy use more effectively.

Coal, natural gas, and electric power are the major energy sources for steel production, with the objective of decreasing energy use through a variety of methods that improve energy efficiency. Most experts agree that ISO 50001:2018 on energy management systems serves the purpose of identifying the most effective energy technologies and solutions to meet organizational needs. ISO 50001 is designed to promote continual advancement through its PDCA cycle; however, the standard does not solely provide incentives for continual advancement. Other ISO standards have incorporated the PDCA principles; consequently, organizations adopting ISO 50001 will also utilize the PDCA approach within their other energy management systems, such as ISO 9001 and ISO 14001.

ISO 50001:2018 proposes a solution for all types of organizations with integrative options like EnMS and renewable energy to reduce consumption and improve energy efficiency. These actions have produced encouraging outcomes, and the steel sector will keep working to cut energy use and lessen environmental impact.

CHAPTER THREE

METHODOLOGY AND DATA COLLECTION

3.1 Introduction

The purpose of this study is to identify some of the issues surrounding the effective adoption of ISO 50001 and to help companies utilize their energy audits more effectively to achieve energy efficiency. This chapter discusses the procedures that can be used to assess how ISO 50001:2018 can be applied to the steel manufacturing sector. This includes a literature review, comparative analysis of case studies, and a simulation of energy use and performance metrics of a company before and after adopting ISO 50001.

In evaluating the proposed algorithmic model to increase energy efficiency, the methodology combines qualitative methods with a simulation using data from the Python simulation tool. At the same time, key changes introduced by ISO 50001:2018 have also been applied as part of the study's boundaries to ensure that they conform to current EnMS requirements.

This chapter is structured into subsections covering methodology design, data collection, energy audits, mathematical representation of energy consumption, and a summary. Together, these subsections demonstrate how the methodological approach operates the research objectives, supported by both qualitative and quantitative techniques, including simulation and case study analysis.

3.2. Methodology Design

The standard itself aims at improving energy performance and lowering energy consumption in industrial processes (Jin *et al.*, 2017). Part of the research objective is to produce a literature study and find the most effective techniques that matter most for implementing the ISO 50001: 2018 standard. These techniques also, in turn reduce energy costs and improve the overall performance of the industrial sector it is implemented on (Marimon and Casadesús, 2017; British Standards Institution, 2018).

Prior studies have emphasized the significance of performing an energy audit to find areas where energy consumption might be decreased (Mohammed and

Mahdy, 2018; Nikolaev, Efremov and Tulupov, 2021). The study uses a mixed-method design with a dominant qualitative approach supported by quantitative simulation.

The primary focus is on understanding how ISO 50001 can be applied to steel manufacturing through systematic energy management strategies. To support the understanding of energy audits and the proposed algorithm, this study referred to two case studies related to steel plants: “Energy Audit in Vishveshvarayya Iron and Steel Plant” by Nandini (2016) and “Implementation of Energy Audit in the Chinese Steel Industry Studies of Integrated Steel Plants” by Xin Wang (2008). These case studies were chosen because they represent industrial scales and operation contexts as they are contrasting. Vishveshvarayya Iron and Steel Plant (VISL) is a medium-sized, developing country example and the Chinese Steel Industry is a large-scale, integrated system so that they can be compared well for benchmarking of the proposed ISO 50001 implementation model. The findings from documented energy audit reports and scale, integrated dataset generated with Python to reflect realistic steel production and consumption patterns.

This study created an algorithmic framework in line with the PDCA cycle to demonstrate the organized implementation process of ISO 50001:2018 in the context of steel manufacturing. This framework forms the foundation of the simulation model and the algorithmic approach presented later in the study (Yildiz Teknik university, 2020; Kaselofsky *et al.*, 2021). Figure 19 shows the order of important phases and tasks.

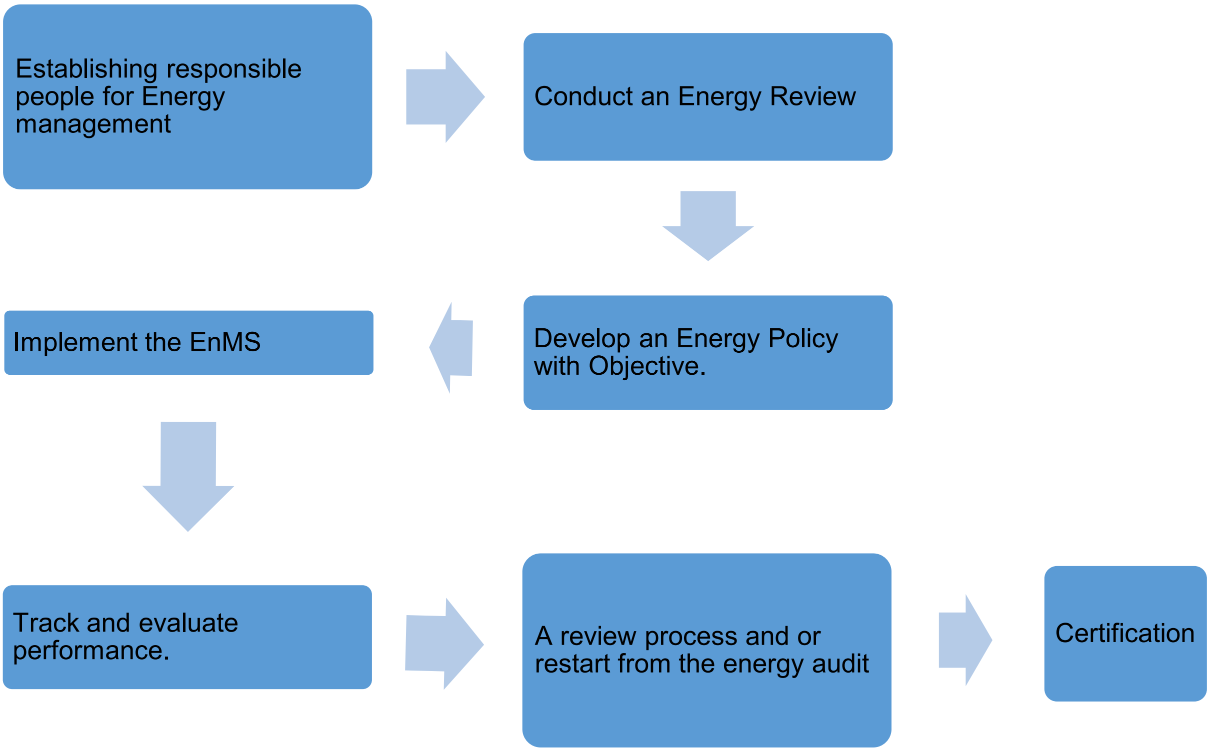


Figure 19: Implementation process algorithm

The study proposes an algorithm approach and uses it on a selected case study to demonstrate the effectiveness of the energy audit process illustrated in Figure 19. Once the methodology has been developed, it is essential to determine the data sources that were used to support the analysis and simulation. The following section describes the methods used to gather, categorize, and validate the pertinent data for this study.

3.3. Data Collection

This study is qualitative and focuses on implementing the ISO 50001:2018 standard and there won't be any interviews conducted. Comprehensive literature is a compilation of data collected from academic journals, books, industry websites and audit reports (Xin Wang, 2008; Chiu and Lo, 2015; Clean Energy Ministerial., 2020).

Data for this study was collected from two primary sources: energy audit reports and case studies of ISO 50001 implementations in similar industries.

The quantitative data sourced through the technical audit, as well as qualitative information produced from the case studies, were combined to give a more complete understanding of how ISO 50001 is implemented in a steel producing facility via a mixed-method approach. The use of a simulated Python model allowed for the identification and analysis of energy usage and savings based on examples found in the literature from ISO 50001 certified steel manufacturing plants. The information gathered during the case studies and through the literature will provide the basis for energy consumption and savings models for an operational steel manufacturing facility and the set of parameters required to model energy usage and determine efficiencies associated with ISO 50001 implementation will be analyzed in the following sections.

3.4. Mathematical Representation of Optimizing Energy Consumption

To comply with ISO 50001 and promote energy efficiency, the goal is to decrease energy consumption and improve energy performance. The development of a mathematical model supporting an ISO 50001:2018 Energy Management System includes many different variables. In industrial applications for Energy Management, the detailed description of the Energy Performance Indicator (EPI) is critical (Andersson *et al.*, 2021). This section will highlight how ISO 50001:2018 provides a systematic way to apply statistical methods, optimization methods, and EnPIs for improving energy efficiency.

ISO 50001:2018 outlines key energy management components to help organizations reduce energy use. These include (Bua *et al.*, 2017; Dinul Akhiyar, 2024):

1. Energy Policy: Organizations must establish and implement a policy demonstrating their commitment to energy efficiency and management.
2. Energy Planning: Organizations should set energy targets and objectives and create a plan to achieve them.
3. Energy Measurement and Monitoring: Companies must track and measure energy usage to identify areas for improvement.

These components ensure compliance with the standard and promote energy efficiency. Within the monitoring process, the implementation of ISO 50001 standard requires tracking and optimizing several key variables that impact energy consumption (Mohamad *et al.*, 2014a; Akbar, Pujani and Nazir, 2023).

Key Variables:

The total energy consumption for all energy processes or equipment consumed in a steel manufacturing industry is represented by the following equation:

$$\mathrm{Et} = \sum_{i=0}^{n} \mathrm{Et}(i) + Wt + Rt + Mt \qquad [1]$$

where:

- Et: Total energy consumption in period t, measured in kWh or GJ.
- $\mathrm{Et}(i)$: energy consumption of $i\mathrm{th}$ process or the amount of equipment in period t.
- n: number of processes or equipment consuming energy.
- Wt: Waste energy
- Rt: Renewable energy
- Mt: management energy

Ideally, the processes or energy use $\mathrm{Et}(i)$ can be categorized as unplanned, controlled, renewable, waste, managed energy and the sum of equipment which consumes energy. The sum of these processes, in turn makes the total energy consumption for the steel manufacturing industry (Donskov, Lyalyuk and Donskov, 2015; Wu, Zheng and Song, 2019). In Steel manufacturing industries these energies would include:

1. The melting processes in the furnace.
2. Auxiliary processes like electricity; cooling; pumping and ventilation)
3. Energy for the rolling mills

To further decrease the total energy consumption in the implementation of these energies, they can further be subcategorized to provide a detailed perspective. These energies can also be subcategorized in the following methods:

- Detailed Subcategories for Each energy: For example, in steel manufacturing, energy for furnace melting could be subdivided into pre-heating, heating, and cooling phases, each with distinct energy demands.
- Auxiliary Systems Detail: Auxiliary energy uses (e.g., pumping, ventilation) could be divided into peak vs. off-peak consumption, providing a more precise understanding of potential energy savings during lower demand periods rather than a generic or average demand throughout the period. See Figure 20 or more potential savings areas within the energy management of an organization.

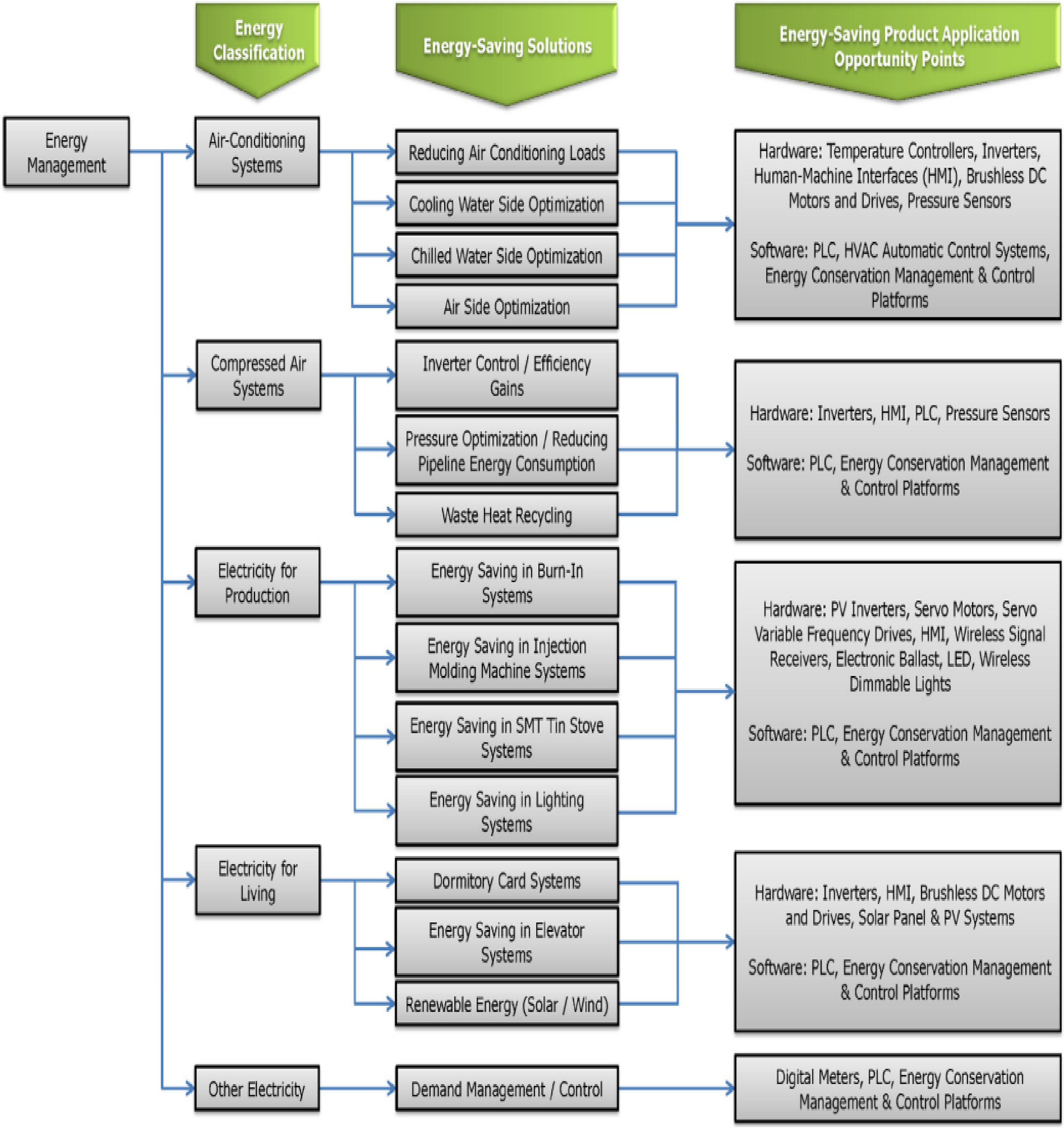


Figure 20: Types of energy use and solutions for energy conservation (Wu, Zheng and Song, 2019)

Baseline energy consumption is the initial starting point of energy consumption (in kWh) for each period (Month) using a normal distribution.

$$\mathrm{E}_{baseline}(\mathrm{t}) = \mathrm{N}(\mu = 1\ 200\ 000, \sigma = 50000) \qquad [2]$$

where:

- $\mathrm{E}_{baseline}(\mathrm{t})$: energy consumption (kWh) over the period t.
- N: Normal distribution
- μ is the mean average monthly energy usage, which is equal to 1200000 based on the review energy audit report (Bosu, Mahmoud and Hassan, 2023b).
- σ is the standard deviation, which is equal to ±50 000 natural monthly variation in energy use due to production schedules or maintenance.

Post-implementation energy consumption is the model of energy consumption after ISO 50001 implementation for each period t (Month), while assuming energy saving intervention within the steel manufacturing industry (Chiu, Lo and Tsai, 2012a).

$$\mathrm{E}_{post}(\mathrm{t}) = \mathrm{E}_{baseline}(\mathrm{t}) \times \mathrm{r}(\mathrm{t}),$$

Range= $\mathrm{r}(\mathrm{t}) = \mathrm{U}(0.85, 0.95)$ [3]

where:

- $\mathrm{E}_{post}(\mathrm{t})$: Predicted energy consumption (kWh) after energy improvements.
- $r(t)$: Efficiency factor is a stochastic (random) variable introduced into the Python simulation model to represent the realistic monthly variation in energy efficiency after ISO 50001 implementation.
- $\mathrm{E}_{baseline}(\mathrm{t})$: is the energy consumption condition pre-implementation for each period (t) to keep the realistic and logical continuity of the dataset.

Efficiency factor, drawn from uniform distribution between 0.85 and 0.95 energy savings from 5% to 15% through optimizing EnPIs. Every month, the factor is independently produced to account for varying degrees of performance improvement. The simulation's post-implementation energy savings range of 5% to 15% is derived from worldwide reports and peer-reviewed case studies that detail the impacts of ISO 50001 adoption in industrial settings. These sources validate their use for simulating realistic steel production settings by showing consistent energy reduction outcomes across this time (Chiu, Lo and Tsai, 2012a; Nandini, 2016).

Energy performance indicator is a metric that can be used to measure or assess the energy performance of an organization (Iturralde Carrera *et al.*, 2023). This indicator aims to track energy usage against production and targets set by the ISO 50001 standard. This indicator aims to monitor progress and improve efficiency towards energy management goals (Mizanur Rahman, 2018). The equation to measure the energy performance over a period is represented as follows:

$$\mathrm{EnPI(t)} = \frac{\mathrm{Et}}{\mathrm{Pt} * \mathrm{Ct}} \qquad [4]$$

where:

- Et: Total energy consumption in period t.
- $\mathrm{EnPI(t)}$: is the total energy performance indicator in period t, measured in kWh/tons.
- Pt: Production output within the period t.
- Ct: coefficient of normalization i.e. external factors like weather or production shifts.

Production output: This metric model’s month-to-month steel production uses a nominal distribution to calculate energy efficiency (Bosu, Mahmoud and Hassan, 2023b). Normal distribution describes a symmetrical plot of data around its mean value, where the width of the curve is defined by the standard deviation (Mahdavi, Desmond and Jamalizadeh, 2023).

$$\mathrm{P(t)} = \mathrm{N}(\mu = 8000, \sigma = 500\ ) \qquad [5]$$

where:

- $\mathrm{P(t)}$: Production output within the period t.

- N: Normal distribution which assumes a monthly production varied level around a typical value which aims to reflect natural fluctuations.

Energy saved is the measure of reduction in energy consumption monthly to improve efficiency which is expressed in percentages. It is expressed as the difference between the baseline and the post energy consumption.

$$\Delta \mathrm{E}(\mathrm{t}) = \mathrm{E}_{baseline}(\mathrm{t}) - \mathrm{E}_{post}(\mathrm{t}) \qquad [6]$$

where:

- $\Delta \mathrm{E}(\mathrm{t})$: Energy saved (%).

3.5. Originality of Methodology

The study is innovative in that it combines real-world case studies with algorithmic modeling, statistical simulation and benchmark analysis to evaluate the efficiency of ISO 50001 in the steel manufacturing industry. While previous studies primarily documented achieved energy savings retrospectively (Xin Wang, 2008; Chiu, Lo and Tsai, 2012a).This work develops a predictive simulation using Python from real-world outcomes (VISL, China), which is different from these studies. To account for the changes in production, the methodology normalizes outcomes using Energy Performance Indicators (kWh per ton). Additionally, it incorporates a stochastic efficiency factor, r(t) = U (0.85–0.95), to represent the monthly variability in energy savings. The algorithm operates as a closed-loop system that reflects the continuous improvement principle of ISO 50001 by aligning itself with the PDCA cycle. This method provides energy managers in the steel industry with a repeatable decision-support tool by enabling scenario-based testing of ISO implementation strategies.

3.6. Algorithms for Implementing ISO 50001 in Steel Industries.

The aim of using strategies, frameworks and algorithms is to make a set standard for an easy flow of processes in managing energy for any type of organization. The objective at the end is to improve the energy performance to a point that demonstrates compliance with ISO 50001:2018 standard requirements (Lighting and Helm, 2018). Much like in the case studies, the initial investment needed to deploy VVVFDs was a significant obstacle at the Vishveshvarayya Iron and Steel Plant. By proving a payback period of less than two years, this was lessened, and the upfront expense was justified.

Similarly, the Chinese steel industry prioritized locations with the largest energy inefficiency first to manage the high costs of furnace modifications through phased deployment.

Figure 21 is the proposed algorithm suitable for assisting the implementation process of ISO 50001:2018 in Steel manufacturing industries. For the implementation process to work effectively, it requires commitment from top management and a selected team to action and follow up the algorithm within the steel industry.

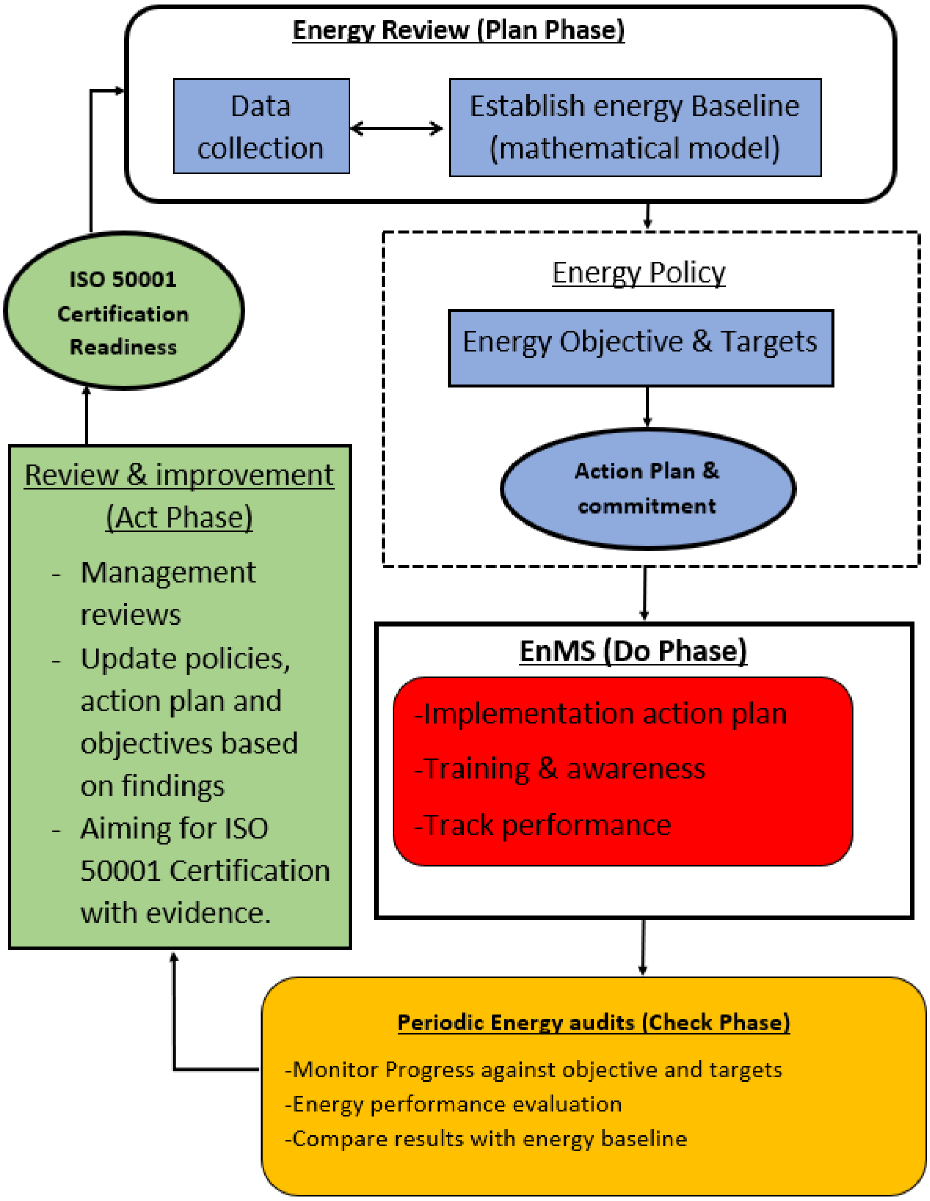


Figure 21: Proposed algorithm for implementation of Iso 50001:2018

It is essential to have the support of resources like training and money allocation to create a positive culture for the success of implementing ISO 50001. The algorithm is a closed-loop process which can be explained in four steps.

The proposed algorithm for ISO 50001:2018 implementation in steel manufacturing includes the following stages:

Step 1: Initial energy review

This step of the process entails establishing a baseline or status core of the existing energy consumption of an organization by collecting data on energy consumption.

It aims to collect data on the existing management process for performance, energy-saving opportunities, measurements of energy usage especially of high demand and trend analysis (Adenuga, Mpofu and Boitumelo, 2019; Bosu, Mahmoud and Hassan, 2023a).

Step 2: Energy policy development

In this section of the process, the organization must develop a policy with set targets and measurable goals for reduction, aligned with ISO 50001:2018. It should clearly define the action items that it should do to reach its targets. These targets are based on the measurable items obtained on the energy review that align with the organization. The actions should also commit responsible personnel who will follow up on the timeline for implementation. In steel manufacturing organizations, all employees must undergo awareness training to improve their energy-related skills and the role they play in achieving energy efficiency (Edson L. Meyer. Odeku, 2009; Bertoldi and Mosconi, 2020).

Step 3: Implementing EnMS saving measures

This section of the documentation in energy policy is a comprehensive description of practices that are used to contribute to either change or improve energy management saving practices. Some of these practices address the use of new equipment that will modify the process flow and improve efficiency. It includes having energy performance indicators that are measurable and easy to monitor (Pachauri and Spreng, 2011; Bua *et al.*, 2017). When big changes like these happen in steel manufacturing industries, it is advisable to promote the credibility of the company by also making the major stakeholders and clients aware of energy improvement which can benefit them as well.

Step 4: Regular energy audits and certifications

This section promotes a systematic and continuous improvement approach through the PDCA cycle and adjusts practices as needed to ensure continuous improvement. Energy audits, such as those outlined in ISO 50002, are valuable tools to identify energy-saving opportunities and promote sustainability in industrial facilities like steel plants. This stage reviews the entire process and the established energy management system through monitoring energy use.

A third-party certifying body will determine whether to grant an organization with an ISO 50001:2018 certificate based on its assessment of the organization. Timeframe for reaching a progressive change in Energy Consumption and Efficiency for a company depends on the size of the organization. Steel manufacturing companies could attain ISO 50001:2018 Certification, provided they have developed proven, successful EnMS's and the organization can demonstrate on-going trends in energy savings.

3.7. Limitations

When looking at the findings of this research and any future refinements to be made, there are many limitations associated with this research. The primary limitation is that case studies rely entirely on data collected from one or two plants, therefore case studies cannot adequately represent the current trends happening at steel plants in real-time. Due to the fluidity and complexity associated with most steel manufacturing operations, conducting only case studies may not allow for a complete and accurate depiction of a steel manufacturing facility's production environment (due to unforeseen circumstances) and impede the applicability of these findings to real-world circumstances.

Although no interviews were done to protect the subject's identity and have them sign a consent form. This meant that we could focus on the case studies at hand and avoid the hassle and headache of collecting and handling individuals' personal information. Utilizing steady-state energy consumption and production output, all results that were produced from these simulations had limits on how deep the exploration could be completed through live interviews, so the production outputs were reviewed thoroughly utilizing a wide range of secondary information to create a more comprehensive view. Other items such as maintenance schedules, economic influences from outside entities and accidents occurring during the simulation were excluded from the results as well. Finally, all the experiences revealed through the qualitative data will provide an element of bias, offering a great deal of additional insight; however, it is likely that these experiences can be affected depending on the type of information the researcher had when reviewing the data.

3.8. Summary

The chapter discusses the methodology used in this study for implementing ISO 50001:2018, which includes conducting an energy audit and developing an energy policy. The methodology expands on the research design, data collection, and analysis methods. The research approach prioritized case study data, enabling an in-depth examination of specific steel manufacturing scenarios. However, there are limitations to the research. The use of case studies may not accurately portray the complexities of how steel production plants operate at any given point in time; therefore, it is unlikely that the findings will be generalized to diverse and fluid workplaces.

Due to the overall qualitative nature of the research conducted for my study as well as the dependence of the study on articles published through Peer Review and Academic Source, my data may contain an element of subjectivity when interpreted by me. To reduce the amount of bias I saw when analyzing the data I produced, there were several ways in which to analyze the dataset on a consistent basis. In addition to being an aid for ensuring the validity and reliability of the findings, the algorithm developed to implement multiple analytical methods on the same dataset will be validated using comprehensive case studies as well as mathematical models that illustrate examples in practice of how each of the methods was implemented. Therefore, the readers of this research study will have a straightforward, consistent and reliable method for achieving energy savings in their own steel manufacturing processes based upon both complete empirical data and simulated datasets.

This includes the identification and categorization of energy processes, the application of detailed energy performance indicators, and strategies to minimize energy costs while improving operational efficiency. This study contributes to the broader discourse on sustainable industrial practices and provides a foundation for future research in energy management systems. EnMS’s successful implementation can lower energy costs and boost the sector's overall sustainability. The study emphasizes how general energy categories, like furnace melting or auxiliary activities, can mask inefficiencies and areas for development. A management strategy focusing on data and targeted sub-categorizing of energy (and energy use) processes through data has been proposed to increase precision. To achieve this, auxiliary operations (indirect) and furnace melting (direct) processes demonstrate the greatest potential for continued technology/market development.

CHAPTER FOUR

DATA ANALYSIS, FINDINGS AND IMPLEMENTATION STRATEGIES

4.1 Introduction

Energy reviews and audits are essential aspects of an industrial facility's energy management system. As this study relates to energy management systems, this chapter presents a formal assessment of data gathered to institute change and improvement in the implementation of the ISO 50001:2018 standard. The data is collected from the ISO website and literature papers relating to the EnMS standards. The management system model of continuous improvement, which is the foundation for other well-known standards like ISO 9001 or ISO 14001, also serves as the basis for ISO 50001(Garg, 2019; BSIgroup, 2024). Several studies and reports have analyzed the data and findings. This chapter explores the ISO 50002 Energy audit standard that is part of the founding foundation of the Energy management standard (IEA.org/weo, 2017). It also tests the hypothesis that is introduced for the proposed algorithm.

This chapter consists of the following subsections, namely: a review of ISO 50001: Energy Management System, and ISO 50002: 2014 energy audits. Additionally, it displays the findings and analysis of the simulation created to assess the efficacy of the suggested ISO 50001 implementation procedure in the context of steel manufacturing.

4.2. Review of ISO 50001: Energy Management System

As established in the literature, ISO 50001:2018 is an accelerated schedule and systematic approach to meeting the energy performance needs of an organization. It was first published in 2011 and revised in 2018 to align with the latest version of ISO 9001 (Quality Management System) and ISO 14001 (Environmental Management System) (Mahmood *et al.*, 2022). The standard is designed to help organizations reduce their energy consumption, costs, and greenhouse gas emissions, while also improving their overall energy efficiency (IEA.org/weo, 2017).

Figure 22 shows the breakdown of the PDCA cycle to its simplest form and what structural sections of the policy should entail. Most research standardization

Institute for Standardization, regard the PDCA cycle as the foundation that makes up the Energy Management Standard (Prashar, 2017).

Figure 22: Breakdown of the PDCA Cycle (Sickinger-Nagorni and Schwanke, 2016; nqa, 2018)

The cycle starts with setting roles and responsibilities for the energy managers to understand the needs of the organization. To form the framework of an organization’s energy use, a policy is required. Within this policy, a scope is required, along with other references relating to standards, essential documents, and an overview of the intended use of the implementation of ISO 50001 (Dekra, 2018; Poveda-Orjuela *et al.*, 2019).

The rapid growth in the number of ISO-certified sites worldwide underscores the increasing adoption of ISO 50001 as a global standard for energy management. Awareness and training to address the risk and energy flow within the organization are necessary for the operation, performance, and continual improvement (Sickinger-Nagorni and Schwanke, 2016). To further prove the benefit of the ISO 50001 standard is the growing number of end users all over the world, as shown in Figure 23. Since the introduction of the standard, a study by Prashar, (2017) reported that for a selected case of a small-sized Indian paper mill, a vacuum optimization resulted in 83.4 KWh energy saving and a 35% decrease in specific energy consumption. Figure 23 demonstrates the rapid growth in the number of certified sites worldwide between November 2011 and April 2014. Evidently from this report, the energy management activities comprise identifying, implementing energy-saving measures, and analyzing trends in energy use. These energy trends are then monitored based on consumption for the next cycle of the PDCA cycle (Mizanur Rahman, 2018).

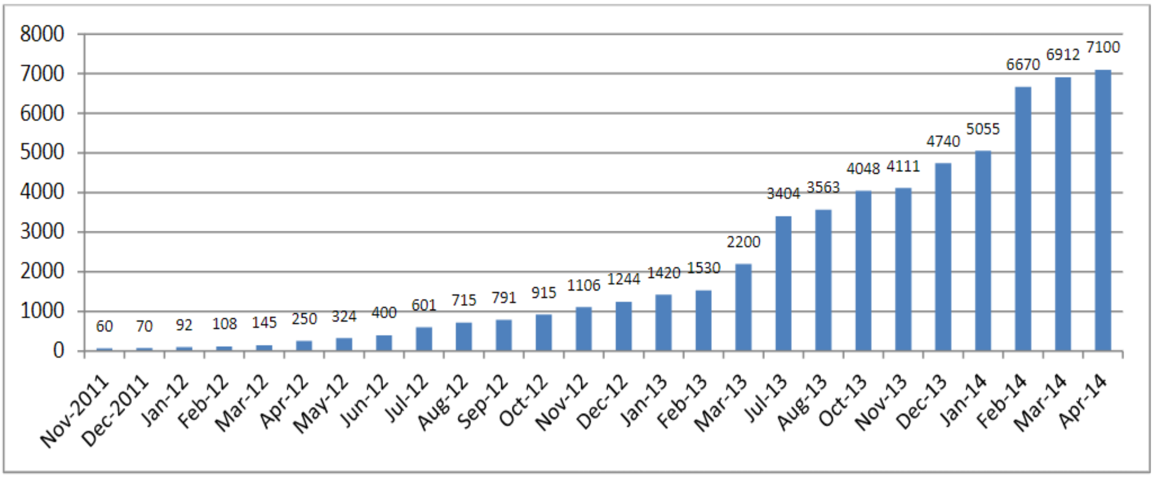


Figure 23: Number of ISO-certified sites worldwide (Nulty, 2014)

4.3. ISO 50002: 2014 Energy Audits

An energy audit is a detailed analysis of the energy performance of an organization, process, procedure, and equipment. The ISO 50002: 2014 standard is very important in setting and fulfilling the requirements for the ISO 50001:2018 energy management standard. It enables organizations to identify opportunities for the improvement of energy performance (Philippine national standard, 2014; ISO, 2014).

An energy audit based upon the algorithm approach can assist in improving energy efficiency within the steel production industry. This process consists of six steps (International Organization for Standardization, 2014a; Larrahondo and Quispe, 2021):

1. Data Collection: Collecting data related to energy consumption and production processes, including invoices for energy charges, production reports, interviews with key individuals related to the operation of the facility, and any other sources necessary to establish a valid data set in order to conduct an accurate audit.
2. Establish Baselines: Establishing baseline data related to energy consumption for each energy type (i.e., electricity, natural gas, coal, oil) utilized by the steel production facility, thereby permitting comparison of future audits.
3. Develop Algorithms: Creating an algorithm to enable the identification of production process inefficiencies and the identification of opportunities for improvement in energy consumption. The algorithms can be used to optimize the production process, decrease the amount of energy consumed for heating the metal during production, and to identify potential energy savings for HVAC and lighting applications.
4. Review Audit Results - Reviewing the findings resulting from the audit to identify opportunities for improvement and produce an estimate of both energy and dollar savings. Evaluating the cost-effectiveness of implementing each recommended improvement.
5. Implementing Improvement - Implementing the recommendations identified during the review of audit findings into production processes and energy systems throughout the steel production industry. Suggested recommendations may include replacing sub-optimal equipment, optimizing existing processes, and implementing energy-efficient installations.
6. Monitor Progress: Continuously monitor and analyze the progress of the implemented improvements to ensure they are effectively enhancing energy efficiency. Ongoing monitoring helps identify additional improvement opportunities and ensure the steel industry operates at its highest efficiency level. The latest technologies use automated methods of monitoring and measuring promptly.

It is important to note that the audit process differs from company to company depending on the organization's needs. The steps mentioned above can be used as a blueprint to be adopted on any audit report when used in conjunction with ISO 50001:2018. Figure 24 shows the steps taken by the auditors or energy manager responsible for conducting the audit report, this figure breaks down the steps taken from planning to the fieldwork test and interview that are required for the report. The audit report also follows a continuous cycle, like the PDCA cycle, so that there is continuous improvement within the steps of the review.

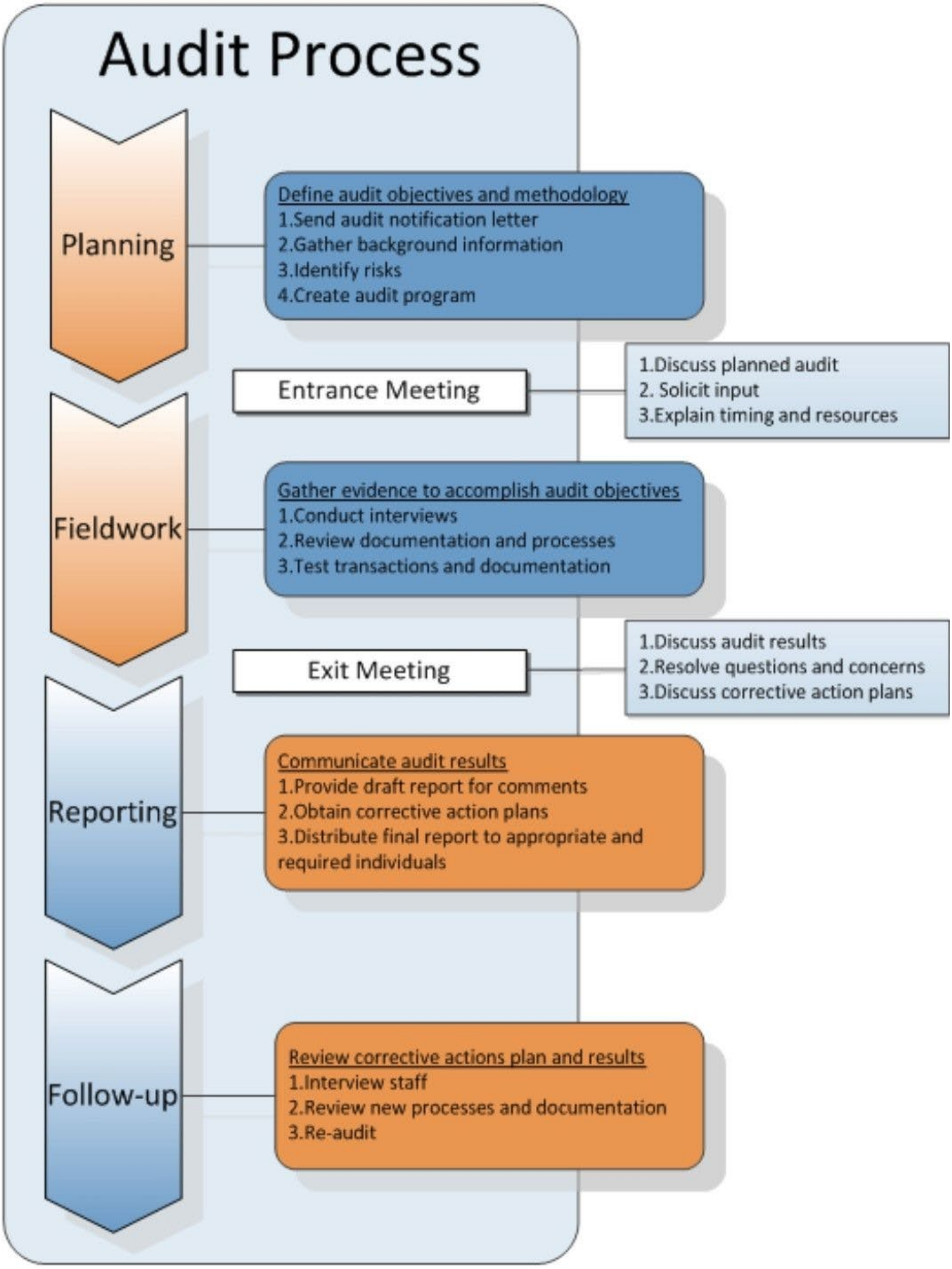


Figure 24: Comprehensive Audit Process Framework(Wu, Zheng and Song, 2019)

The advantages associated with energy audits can be broken down into three major areas: Financial; Operational; Environmental. The economic benefits of conducting an energy audit will result in lower operating costs for businesses and other organizations, whereas benefits stemming from the utility of an energy audit allow management to enhance both the safety and productivity of the business (Feili, Aghaee and Parvazeh, 2012). The most important environmental benefit from energy management is the reduction of carbon dioxide (CO_2) and other greenhouse gas emissions resulting from improved energy efficiency within industrial activities. Environmental improvements will continue to develop over time as businesses gradually implement and maintain energy efficiency measures.

The study examines how structured Energy Assessments can help identify processes that have a large share of the total energy used by a manufacturer, such as heating operations and appliances related to heating. One potential benefit of these assessments is that they identify areas where thermal energy consumption and auxiliary heating devices may be improved. The use of controls (e.g., variable frequency drives and advanced thermal regulation) on existing equipment can also result in further savings in energy consumption.

Improvements in efficiency related to achieving longer-term planning require a sustained effort through the development of strategies for continued use of the resources available to them over time before they can be fully realized. Therefore, this report highlights the need for additional resources to promote the use of ISO 50001, including incentives for achieving verified improvements in energy performance, specific assistance in purchasing energy-efficient technology, and cooperative funding alternatives between public and private organizations. All these types of resources will ultimately help eliminate the financial and institutional barriers to realizing the transition to more environmentally responsible energy-involved practices within industries.

4.4. Analysis of Energy Efficiency Improvements Through the Implementation of ISO 50001

The analysis of energy efficiency improvements through the implementation of ISO 50001 involves an understanding of how energy is used by using indicators. The analysis can be done by considering the use of Energy Performance Indicators. The different performance indicators were used in the four steel companies referenced in Table 4 to analyze their energy usage (kWh) before and after implementing ISO 50001 as well as to show the percentage decrease in energy use in these companies. The implementation of ISO 50001 led to significant reductions in annual energy consumption across various organizations, ranging from 10% to 18%. For instance, Manufacture A achieved a 15% reduction, while Production Plant C reached an 18% decrease (Dinul Akhiyar, 2024).

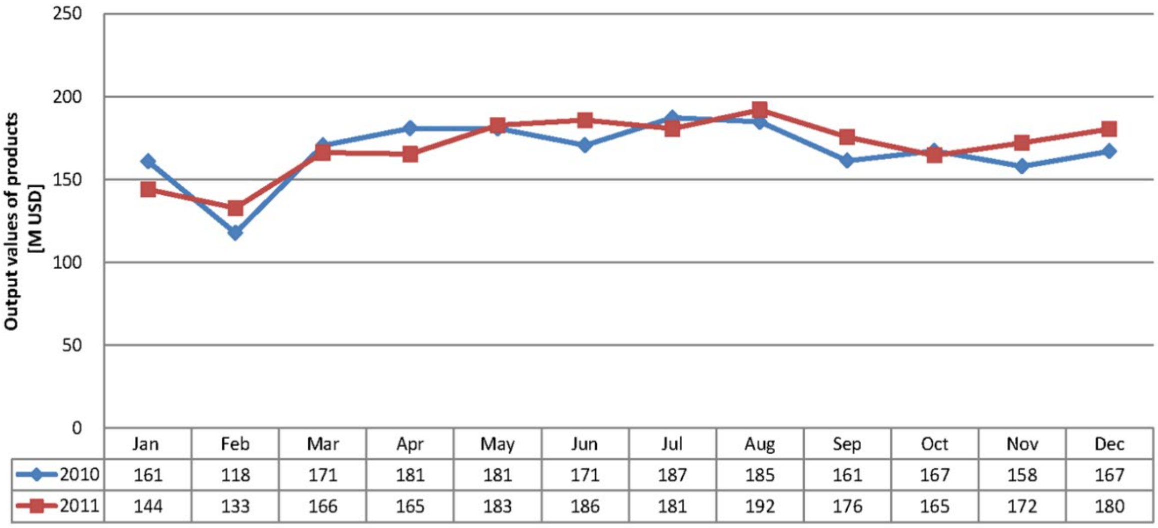
Table 4: Outline of quantifiable outcomes of the reduction in electricity use(Dinul Akhiyar, 2024)

No.	Manufacturing Industry	Pre-Implementation (kWh)	Post-Implementation (kWh)	Reduction (%)
1	Manufacture A	1,000,000	850,000	15
2	Industrial Firm B	750,000	660,000	12
3	Production Plant C	1,200,000	980,000	18
4	Factory D	900,000	810,000	10

As shown in Table 4, all companies showed decreases in EnPI values, which indicates greater energy efficiency, thus validating ISO 50001:2018 as an effective, systematic method for improving energy performance of steel companies. The algorithm developed has produced realistic results with average simulated savings of 11.2%, which closely matches the real-world savings achieved. In addition, VISL achieved savings of 10%–12%, while the Chinese steel industry reported around 15% savings, indicating the model's validity.

The simulation model and algorithm utilized the baseline energy consumption data from past steel production outputs. Throughout a 12-month period, an efficiency factor of r(t) =U (0.85,0.95) was applied monthly to reflect energy savings of between 5% - 15% that is in line with ISO 50001 outcomes. Steel production energy consumption per ton (kWh per ton) was used to determine the EnPI. These assumptions are supported by referenced literature such as Chiu et al. (2012b).

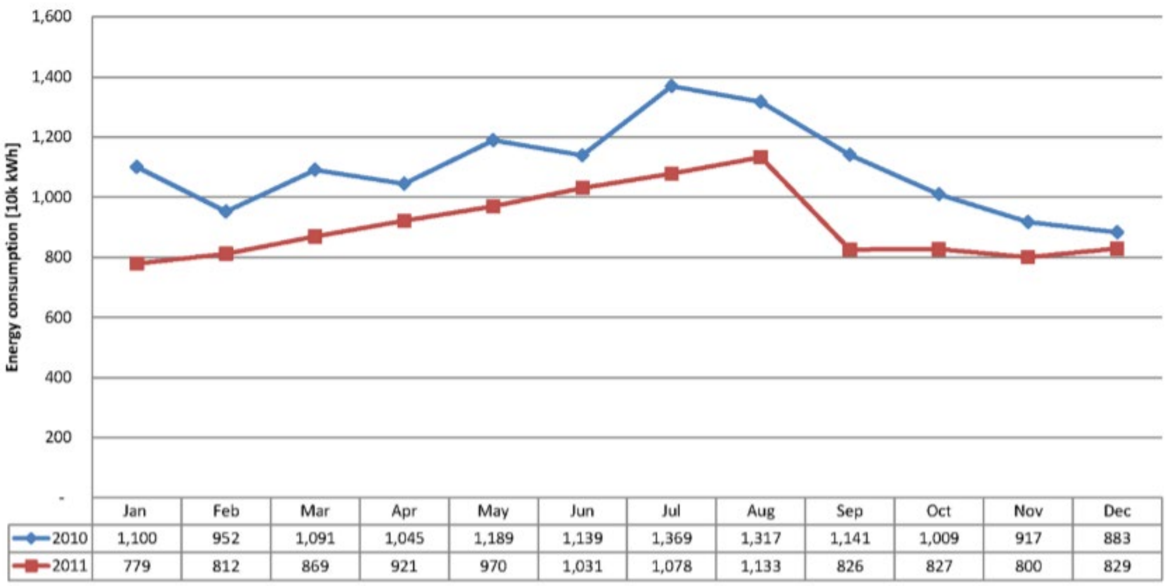
The data suggests in Figure 25 that the implementation of ISO 50001 had a positive influence on output values, as seen in the generally higher monthly figures throughout 2011 compared to 2010. Given that ISO 50001 calls for operational adjustments, the trend, which is particularly evident since mid-2011, suggests that the impact of the standard may take several months to stabilize. This is consistent with the usual implementation schedules for such standards, as this is usually the implementation stage (Chiu and Lo, 2015).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	161	118	171	181	181	171	187	185	161	167	158	167
2011	144	133	166	165	183	186	181	192	176	165	172	180

Figure 25: Compare of output values from 2010–2011 before and after the ISO 50001 standard was implemented.(Chiu, Lo and Tsai, 2012b).

According to the study of Chiu, Lo and Tsai, (2012b) the involvement of external experts and a third-party certification body likely contributed to identifying key areas for efficiency improvements, setting energy performance indicators, and implementing corrective actions. This external oversight appears to have facilitated a more effective and rigorous implementation of energy-saving measures, as seen by sustained lower energy consumption in the latter half of 2011 in Figure 26. The sharp decline in energy consumption after July 2011 post certification shows the effectiveness of the system, enabling continuous improvement.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	1,100	952	1,091	1,045	1,189	1,139	1,369	1,317	1,141	1,009	917	883
2011	779	812	869	921	970	1,031	1,078	1,133	826	827	800	829

Figure 26: Monthly Energy Consumption Before and After ISO 50001 Implementation.(Chiu, Lo and Tsai, 2012b)

4.5. Simulated Energy Performance Outcomes Based on the Proposed Algorithm

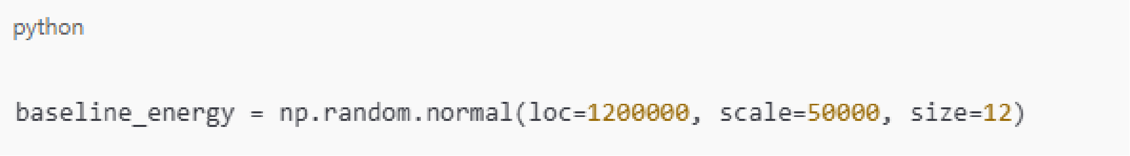
The proposed algorithm for ISO 50001:2018 implementation in Section 3.5, Figure 21 in theory is structured such that it results in measurable improvements in energy performance within the steel manufacturing industry. Its hypothesis is based on that it will yield a reduction in total energy consumption and improve the EnPIs indicator values compared to baseline performance. This section uses a Python simulation to test that hypothesize using data from literature and the mathematical model values.

The simulation generated a 12-month dataset that included steel production outputs as well as baseline and post-ISO 50001 energy consumption data. Monthly EnPIs were used to determine operational energy efficiency in terms of production volume. The data shows energy consumed before ISO (before the model was applied) compared to that consumed after implementing the ISO 50001 aligned method. Figure 26 shows energy consumed before ISO (before the model was applied) compared to that consumed after implementing the ISO 50001 aligned method. Energy usage decreased over time once the model was implemented, indicating improved energy management by applying an energy efficiency strategy based on the ISO 50001 standard.

4.5.1. Key Statistical Insights

The Python programming code uses the key variables in section 3.4 to generate synthetic data for monthly baseline, post-implementation, and steel production output of 12-month period. To represent actual operational variability, baseline energy consumption and production outputs were simulated using normal distributions. Normal distribution is a statistical method used to represent natural variability in real-world processes. It produces a bell-shaped curve, where most values cluster around a central average (mean), and fewer values occur as you move further away from that average in either direction (Mahdavi, Desmond and Jamalizadeh, 2023). Post-implementation energy values, which were based on case study evidence, included randomized efficiency increases ranging from 5% to 15%.

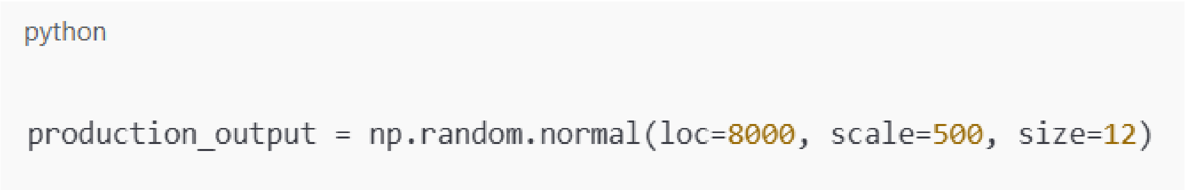
Figure 27 represents the coding of the baseline using a normal distribution to show energy usage fluctuations from month to month in steel operations. The baseline consumption uses a mean of 120 0000 kWh and a standard deviation of 50 000 kWh.



```python
baseline_energy = np.random.normal(loc=1200000, scale=50000, size=12)
```

Figure 27: Baseline calculations Python code

The same concept is used for the production output simulation; the code generates a monthly production level with a mean of 8000 tons and a deviation of 500 tons, as seen in Figure 28.



```python
production_output = np.random.normal(loc=8000, scale=500, size=12)
```

Figure 28: Production output simulation code

The simulation will react realistically if these inputs have a normal distribution instead of producing constant or uniform values. The difference between a mean average and normal distribution is that a mean uses one number while the normal distribution uses a statistical pattern (bell curve). These statistical values are clustered around a central mean extracted from literature values to give variation in the simulation. Because of this variability, the study of EnPIs is more representative of actual industrial settings, and the suggested ISO 50001-based procedure is evaluated with greater credibility. The full Python code can be seen in Appendix B, which gives energy savings output as seen in Table 5.

Table 5: Simulated Monthly Energy Consumption, Production Output, and Energy Performance Indicators Before and After ISO 50001 Implementation

Month	Baseline Energy (kWh)	Post ISO Energy (kWh)	Production tons	Baseline EnPI	Post ISO EnPI	Energy Saved (kWh)	Percent Saved (%)
Jan	1224835	1078375	7727	158,5	139,5	146460,7	11,9
Feb	1193086	1076731	8055	148,1	133,7	116355	9,8
Mar	1232384	1100758	7424	165,9	148,3	131625,4	10,7
Apr	1276151	1121894	8187	155,9	137	154257,5	12,1
May	1188292	1082754	7699	154,3	140,6	105537,8	8,9
Jun	1188293	1026625	7854	151,3	130,7	161668	13,6
Jul	1278960	1124480	7699	166,1	146,1	154479,9	12,1
Aug	1238371	1097985	8926	138,7	123	140386,5	11,3
Sep	1176526	1053705	7993	147,2	131,8	122821,1	10,4
Oct	1227128	1139409	7471	164,2	152,5	87718,06	7,1
Nov	1176829	1023802	8411	139,9	121,7	153026,2	13
Dec	1176713	1060717	7389	159,2	143,5	115996,4	9,9

The Python simulation produces data in Table 5. To further represent the data from the simulation, Figure 29 plots the baseline energy, Post ISO energy and the production output derived from the mathematical model equations. This visualization effectively represents the energy savings achieved after implementation (post-ISO energy) of the proposed algorithm for ISO implementation.

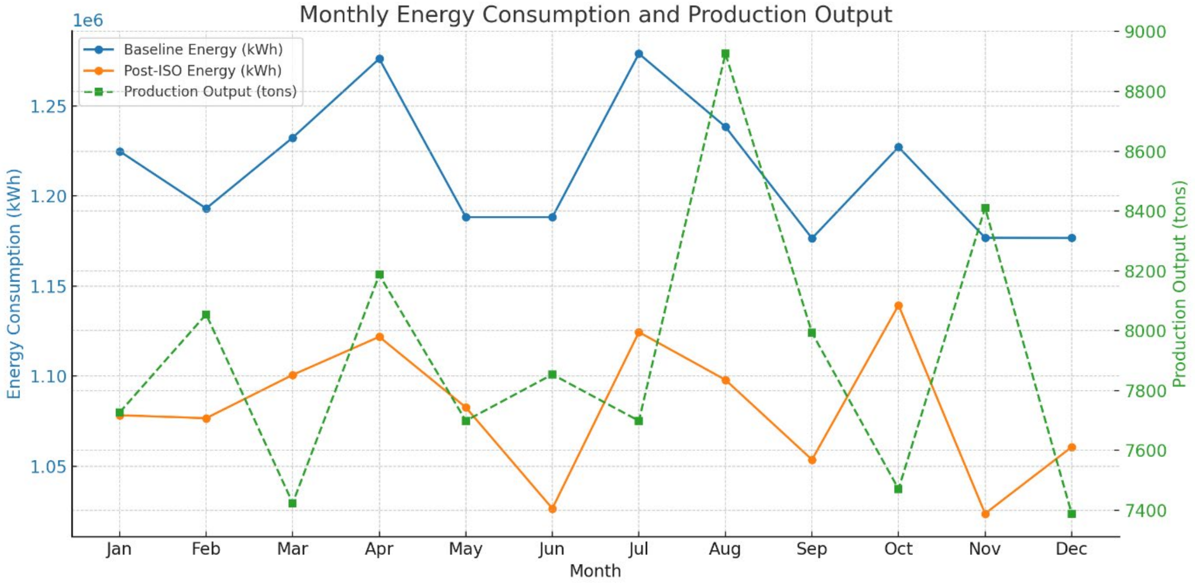


Figure 29: Monthly energy consumption and production output before and after ISO 50001 implementation

As shown in Figure 29, the post implementation energy consumption is consistently lower than the baseline consumption across all months, showing the simulations outcome to confirm the effectiveness of the algorithm on the ISO 50001 standard. The consistent trend of declining energy consumption occurs through various production outputs or activities. Additionally, the algorithm improves energy efficiency while maintaining operational performance. The drop in energy consumption in June coincides with a decrease in production when operations were low (Hasanbeigi *et al.*, 2016b). The model accurately tracks energy use and performance (EnPI) amid production changes, proving its value as a forecasting tool. However, it does not account for external factors like policy incentives, retrofit costs, or market shifts. Therefore, it should be used to predict energy savings and guide ISO 50001 strategies, not for financial projections. Recognizing these limits strengthens the analysis and highlights the model's practical utility.

4.6. Strategies to Implement iso 50001 in Steel Manufacturing Organizations

Strategic adaptation of ISO 50001 is necessary in the application of steel manufacturing industries. A variety of practices have been identified as essential to reaching certification and long-term gains such as data-driven monitoring, energy team building, and leadership participation. These practices, which build on previously suggested algorithmic frameworks, are intended to translate ISO 50001 concepts in industrial operations in a methodical and quantifiable approach.

According to previous studies on implementation of the ISO 50001:2018 standard, there were widespread reductions in both energy use and cost because of implementing the ISO standard. In one instance, a facility producing steel in India had a reduction of 3.3% in energy consumption resulting in a savings of more than $2.8 million during the first year following ISO implementation (Jayadev V. K. Shanti Swarup, 2013; Clean Energy Ministerial, 2020). In another example, a Brazilian producer of steel indicated that usage of ISO 50001:2018 EnMS resulted in reductions of 16.6% in energy use and $1.9 million in savings during the first year after the implementation of ISO 50001:2018 (Clean Energy Ministerial, 2022).

The case studies for steel production were selected based on similarities in industry, energy consumption, and size. The Vishveshvaraya Iron and Steel Plant provided the best opportunity to learn about energy efficiency on the ground in an industry that has a significant amount of energy consumption. Additionally, other steel producers in the global market can adopt energy efficiency improvements. Examples include replacing standard lights with LED lighting systems and deploying Variable Voltage Variable Frequency Drive (VVVFD) technology (Nandini, 2016). The other steel industry case study addressed was the Chinese steel industry, where on a large scale, it achieved major gains in efficiencies through systematic methods of collecting energy measurement data. By employing these methods, the Chinese steel industry has gained a comprehensive understanding of using ISO 50001 Energy Management System methodology in their operation (Wang *et al.*, 2008).

A review of the energy reports presented in both case studies was done to identify the possible approaches and thus strategies for energy management that can be used in practice. In addition, an algorithm that can serve as a backbone for the energy management system thus developed has also been laid out for use in maintaining effective management of energy usage by any type of company but most especially steel. The skeletal structure describes a series of individual steps, or processes, to be followed to implement the strategies required to achieve ISO certification.

4.7. Real-World Validation Using Case Studies

Nandini, (2016) present a case study in the Vishveshvaraya Iron and Steel plant (VISL) in India, the study audited the production process and possible energy-saving opportunities in various sections of a steel plant. Within the steel plant, the mining, safety, raw material, control, and production planning are key aspects of producing high-quality steel. The study focused on pinpointing the possible energy saving in thermal and electrical energy consumption (Nandini, 2016).

To achieve the above-mentioned, the study proposes the following for the VISL:

- Optimizing the operation of efficiency of coke, furnace oil,
- Use light diesel oil of high quality.
- Implement energy-efficient equipment to reduce energy consumption.
- The proposal of the process flows from a Blast Furnace to a Basic Oxygen Furnace to Ladle Refining and Vacuum Degassing.
- Proposal of the adoption of using variable voltage frequency drive in overhead cranes.
- Using LED lights across the plant
- Conducting studies and energy audits contributes to the steel industry's efforts to reduce its environmental footprint.

The study in the Vishvesvaraya Iron and Steel plant shows the strategies used to implement the ISO 50001 standard to promote sustainable energy practices within the steel industry. Variable Voltage Variable Frequency Drives (VVVFDs) on overhead cranes greatly decreased energy waste, saving over 700,000 kWh a year, or under R1 million in savings. Moreover, a 58% decrease in illumination energy consumption was achieved by replacing sodium vapor lamps with LED lighting, saving 1,778,280 kWh a year and generating a little over R 2.2 million in savings (Nandini, 2016).

On the other hand, Xin Wang, (2008) reference a case study for an audit of China's Iron and steel industry. This study focuses on an on-site investigation with a specific emphasis on energy consumption in a specific steel branch for the years 2005 and 2006. It is important to note that during this time between the years concerned, the ISO 50001 energy management system wasn't established yet. (Wang *et al.*, 2008) proposed the need for systematic principles and ways to analyze and interpret energy consumption accurately, as a start with energy audits to reveal the anomalies and suggest corrective measures.

Here are some of the strategies used, as proposed by the study, according to (Wang *et al.*, 2008):

- Establish guidelines for energy accounting and accuracy in the energy audit process.
- Establish a policy that differentiates the organizational and operational boundaries for energy consumption.
- Tracking and keeping of historic data and energy consumption for continuous improvement.

This case study on the China Iron and steel industry put a strong emphasis on a proposal of establishing guidelines and following a framework approach on action items that will help reduce energy consumption and align with the ISO 50001:2018 standard. The study determined that energy and heating systems to be improper and wasted many unnecessary kilowatts due to lack of proper monitoring due to consistent, systematic collection and application of data on energy usage, as well as the additional optimization of furnace operation protocols. The study found that the combination of these two efforts achieved a 15% reduction in wasted kilowatts, once again highlighting the importance of consistent monitoring and proper implementation of procedures in energy-intensive industries. Table 6 provides a visual representation comparing the Vishveshvarayya Plant and the Chinese steel industry and how this ISO 50001 standard is applied to achieve improved efficiency in energy consumption in the various manufacturing methods being used in both companies.

Table 6: Case study visual comparison

Aspect	Vishveshvarayya Plant	Chinese steel Industry
Energy reduction achieved	58% (lighting), 30% (cranes)	15% overall
Key Strategies	VVVFDs, LED retrofitting	Energy accounting, furnace optimization
Annual Energy Savings	1,778,280 kWh (lighting), 700,000 kWh (cranes)	Equivalent to 15% of baseline energy
Cost Savings	R2.2 million (lighting), R1 million (cranes) near two-year payback period	Approx. R2.5 million
Challenges	High initial investment	High costs of furnace upgrades
Mitigation Strategies	Justification through payback period	Phased implementation

The Vishvesvaraya Iron and Steel Plant case study illustrates how critically important focus technology developments are to creating measurable energy and monetary savings, as evidenced by Implementing VVVFDs on overhead cranes and replacing sodium vapor lamps with energy efficient LED lighting, which are two examples of strategic upgrading resulting in decreased energy waste and operating costs and quantifiable outcomes to both areas. The Chinese Steel Industry's experience also indicates that it is imperative for Industries to have strong energy accounting systems and prioritize high-impact areas, such as furnace optimization, to achieve large-scale energy efficiency gains. Additionally, both examples indicate a potential Increased benefit through the application of ISO 50001: 2018, an energy management framework, giving Industries the ability to methodically monitor, manage, and improve energy performance. Using this framework will enable ongoing improvements in energy consumption reduction, energy efficiency improvement, and the creation and promotion of a sustainable energy culture.

Another aspect is to break down the energy usage into distinct categories based on energy source, consumption by process stage, time-based variability and equipment efficiency. This will assist in highlighting inefficiencies within the specific operations.

Table 7 shows the comparison of energy and resource metrics before and after implementation. The table also notes the projection using the proposed algorithm in Figure 21. The algorithm projects are based on data-driven energy flow, as the main aim of the algorithm is to subcategorize energy processing for higher efficiency. The algorithm directly supports ISO 50001's energy management objectives of performance improvement, systematic approach to energy optimization and integration of operational data into decision-making.

Table 7: Comparative Metrics for before and after ISO in case studies

Metric	Before ISO 50001	After ISO 50001	Potential with Algorithm
Energy efficiency (Chinese steel)	85.4% (2005, from case study baseline)	96% (2006, after audit-based measures)	97% (algorithms can optimize by product utilization)
Water consumption (Chinese steel)	13.6 tons per ton of steel	8.5 tons per ton of steel	7.5 Per ton (predicted with algorithm-driven cooling system optimization)
Crane Operations Energy Loss (VISL)	711,693 kWh/year	Eliminated (with VVVFD implementation)	Improved throughput with 5% additional savings through predictive scheduling
Lighting Energy (VISL)	3.066 million kWh/year	1.287 million kWh/year	1.0 million kWh/year (with real-time lighting control via sensors)
Energy Savings (VISL)	No savings	~8.4 million kWh/year	~9.5 million kWh/year (with additional real-time anomaly detection)
Payback Period (Lighting)	N/A	2 years	1.8 years (with better prioritization of investments)

As shown in Table 7, the simulated recommendations and post ISO implementation patterns clearly align with the algorithm strategy. This validates that the algorithm can further make it easy to follow the implementation of the ISO 50001:2018 standard. See Appendix B for the full summary of input logic and the full Python code used for the simulation of the potential with the algorithm.

4.8. Summary

This chapter formally assesses data collected from the ISO website and some literature papers relating to ISO 50001:2018 and ISO 50002:2014. Energy reviews and audits are stressed to be very crucial components of an industrial facility like steel manufacturing organizations. The chapter delves into the compatibility of ISO 50002 and 50001. The ISO 50002 energy audits assist in identifying areas of improvement and involve data gathering, while ISO 50001 involves the establishment of a baseline and development of an algorithm to continuously monitor and improve performance. These audits are presented to be in line with the benefits of an energy management system which are financial, environmental, and operational benefits. It is proven from the data gathered that including yearly energy audits yield higher chances of reducing energy in steel manufacturing processes that aim to improve operational efficiency.

ISO 50001 and ISO 50002, when used together, offer an energy management framework that helps organizations achieve long-term energy management objectives through technological advancements like variable frequency drives and optimized heating controls. The quantifiable benefits of energy audits are also addressed in the chapter, along with the financial savings from lower running costs, the environmental benefits from lower greenhouse gas emissions, and operational improvements that increase productivity and safety.

Two case studies were reviewed to explore different methods to optimize and control energy management in steel manufacturing industries. The Vishveshvaraya Iron and Steel Plant case study focused on the production section of the steel industry, improvements to furnace oil and equipment efficiency to lower energy consumption. The second case study, the Chinese steel section which emphasized on policy measures like energy accounting, operational limits, and data tracking.

A solid foundation for meeting the of the study is to provide practical solutions for achieving ISO 50001 compliance like installing variable speed drives. The example case studies illustrate how structured approaches can show sizable cost and energy reductions while increasing sustainability in steel production. The proposed algorithm creates a feedback loop that is intended to lift energy performance in line with ISO 50002:2014’s audit requirements.

ISO certification and its benefits require a strong commitment from leadership, sufficient funding, and training of personnel to produce useful energy savings. This process was evidenced by the success stories of companies that implemented these energy efficiency measures in this study, as well as through ISO 50001’s potential to change severely energy-consuming sectors. If these practices were adopted throughout the world, there would be a dramatic reduction in global energy consumption that would support the larger sustainability objectives. Furthermore, ISO 50001:2018 demonstrated that it could provide measurable improvements in efficiency within the steel industry. The review, strategy, and validated models were derived from algorithm validation, analysis of multiple cases, and an extensive literature review, thus validating the findings of the research.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter provides an overall summary of the results and implications presented over the course of this research addressing the "Implementation of ISO 50001:2018 Energy Management Systems within the steelwork manufacturing industry." The research sought to establish an understanding of how to implement ISO 50001:2018 Energy Management Systems in this industry, as well as to educate the steel manufacturing industry about its much greater contribution to energy and environmental impacts.

The purpose of this study is to propose a mathematical tool and methodology for designing, assessing and optimizing energy performance within the steel-manufacturing industry. This model will allow an accurate assessment of the efficiency of different strategies to save energy, to get baseline measures of the amount of energy consumed and to assist steel manufacturers in achieving compliance with the objectives of ISO 50001 by using real-time data for making decisions. This chapter discusses the best practices the steel industry can achieve with the use of ISO 50001:2018 by examining the multiple, diverse energy consumption patterns that exist in steel production and the continuous nature of steel production.

5.2. Summary of Findings

Energy audits and reviews are a fundamental component of an energy management system in steel production plants. The ISO 50001:2018 standard provides an outline with which organizations can develop their energy management competencies. Furthermore, ISO 50001 helps organizations develop and implement energy management strategies that comply with other international standards such as ISO 9001 and ISO 14001. Therefore, organizations adhering to ISO 50001 will typically integrate their energy management systems within their complete management system aimed at creating continuous improvements throughout their operation.

The ISO 50002:2014 energy audit standard complements the ISO 50001 by helping uncover the areas of improvement, energy-saving opportunities and promoting sustainability in steel plants. The mathematical model developed as part of this work provides a means for the quantification of all aspects of energy savings (including the ability to compare various systems) and helps to ensure compliance with the ISO 50001 objectives. Through the use of this methodology (and the algorithm presented here), it is anticipated that the importance of using ISO 50001:2018 will be accentuated as a means to promote improved energy management within industrial organizations.

5.3. Research Objectives

This study gives guidance and awareness of the use of ISO 50001 by completing a review on steelwork manufacturing industries, using a case study energy audit report to derive implementation strategies, and setting an algorithm for those strategies.

a) Review of steelwork manufacturing industries:

The structure of ISO 50001:2018 allows organizations to implement energy-management systems to decrease costs associated with energy because of increased efficiencies and reduced environmental impacts. While noting the benefits of the energy management system, the study noted that some challenges need to be overcome. These challenges include support from top management, availability of initial investment, accurate data collection and keeping track of energy indicators to understand the flow of energy consumption.

b) Strategies for implementing ISO 50001:2018 in Steelwork manufacturing industries.

The study makes use of a comparative analysis of case studies to help understand energy management and audit standards to develop strategies to implement in the Steelwork manufacturing industries. The findings of the study suggested producing a sound policy document that accounts for operational and organizational boundaries for energy consumption to better track historical and present data related to energy usage.

In the case studies considered, it is observed that to achieve energy-saving goals in the production process of steel, organizations should investigate the following:

- Organizations should consider using High-Quality Diesel Oil for heating in furnaces and power generation, as it reduces emissions and improves combustion efficiency.
- A need for regular energy audits to note and improve the process flow in the production process.

Figure 21 in Chapter three of the study shows the proposal of an algorithm approach for steel manufacturing organizations. It illustrates how the mathematical model interacts with the algorithm to create a closed-loop system for continuous energy performance improvement. In compliance with the ISO 50002:2014 energy audit, the suggested algorithm creates a closed-loop process that aims to enhance energy performance. A phased approach to the implementation of the algorithm, focusing initially on high-impact areas like furnace optimization and lighting systems. Clear cost-benefit evaluations can help remove financial obstacles, and leadership-driven training programs that highlight the long-term advantages of energy efficiency can help overcome cultural opposition. The top management of the company must be fully committed to providing resources and training to the personnel for the organization to demonstrate significant energy-saving trends and get ISO certification.

The mathematical model developed as part of this study has provided an additional dimension to support the algorithm proposed for locating wastage or "energy inefficiencies" and for enhancing the overall use of resources to support energy efficiency throughout a business operation. The proposed ISO 50001:2018-compliant Energy Management Algorithm has been tested over a 12-month period using a Python-based simulation environment. The application of this algorithm produced both quantifiable improvements in EnPIs, and an estimated range of 5%-15% energy savings per month, consistent with the results obtained through the case studies from which the algorithm was derived. Thus, the results of the case study have provided validation for the robustness of the algorithm and the future potential for integrating structured energy optimization analysis into the process of steel manufacturing. In addition to producing improved results in terms of energy efficiency and energy cost savings, the ISO 50001:2018-compliant Energy Management Algorithm also provides a means for making informed strategic decisions regarding energy management at an organization by taking into consideration various factors such as operational limitations, process efficiency indicators, and energy use metrics.

5.4. Future Improvements

ISO 50001:2018 Energy Management Systems builds on the popular 'Plan Do Check Act' or PDCA cycle. It is expected that the organization will continue to improve both the policies governing energy use as well as the processes in place of energy. An ongoing monitoring and assessment process provides the opportunity for several enhancements or improvements to better align with the ISO 50001 Standard.

1. Real-time information – The ability for real time energy monitoring to provide instantaneous changes to the variables associated with energy consumption will better enable energy managers to quickly adjust based upon energy consumption patterns and respond proactively.

2. Environmental & Operational Influences – Future enhancements to this Model will offer greater visibility on the impact that external influences (like temperature changes due to the seasons, HVAC system operations, etc.) and changes to the operations of each property (like an increase in production levels) have on the potential discrepancies of consumption between properties.

3. Integration of Artificial Intelligence Tools – The model could be enhanced to support the use of AI and predictive planning regarding the analysis of energy-use data. Real-time monitoring technologies can be integrated into the developed model to identify energy-related inefficiencies and provide flexible solutions in conjunction with ISO 50001.

4. Compliance & Benchmarking – ISO 50001’s process involves evaluating an organization's performance compared to other organizations in the same industry as well as the applicable legal requirements. Future revisions may also focus on

establishing further definitions of Industry Best Practices (IBPs) and identifying emerging sustainability incentives and certifications.

5.5. Contribution to Industry and Society

The United Nations Sustainable Development Goals 7 and 13, which are clean and affordable energy and climate action, respectively, are supported by this research. The model developed through this research serves as a long-term solution that will enable organizations to manage their energy consumption on an ongoing basis while also adapting to changes in sustainable development standard and expectations.

In addition to immediate benefits, the implementation of the continuous improvement process through the ISO 50001 (Energy Management System) framework will help organizations realize long-term savings through reduced energy consumption and increased operational energy efficiency.

Ultimately, the implementation of ISO 50001:2018 should be reflected in the company culture with the participation of all employees and stakeholders. ISO 50001 principles should be adopted as an ongoing and sustainable organizational commitment to improve energy efficiency. The investigation of these aspects will benefit blast furnace utilization as well as cost savings. For this reason, ISO 50001 provides a means to support steel production companies and create a sustainable future.

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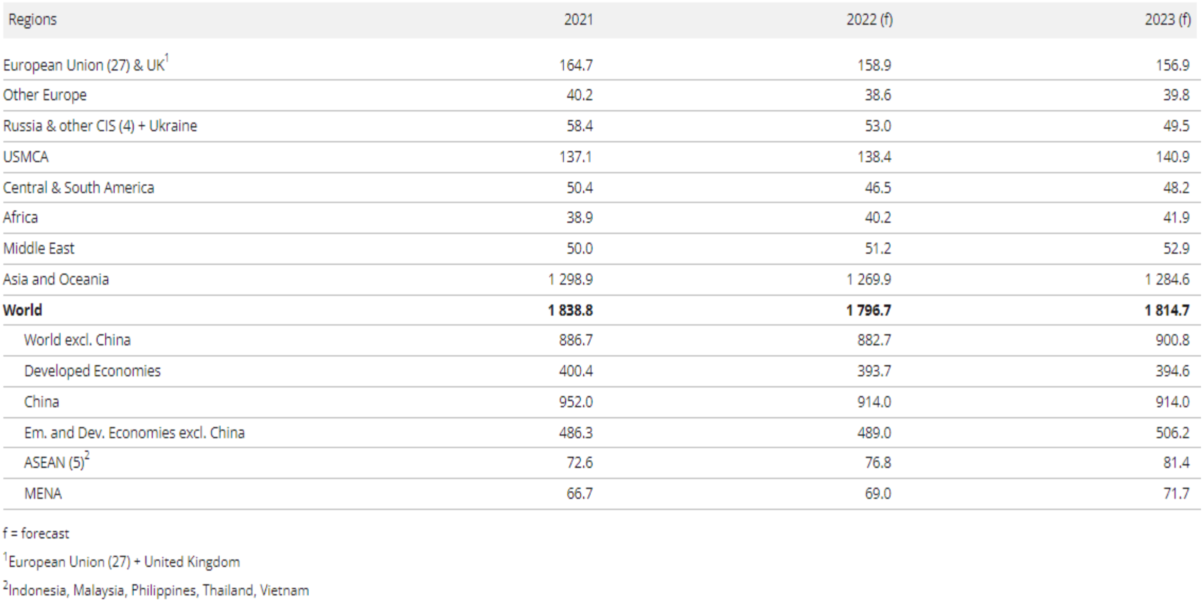
APPENDICES

Appendix A: Global and Regional Steel Production Forecast (2021-2023)



Regions	2021	2022 (f)	2023 (f)
European Union (27) & UK[1]	164.7	158.9	156.9
Other Europe	40.2	38.6	39.8
Russia & other CIS (4) + Ukraine	58.4	53.0	49.5
USMCA	137.1	138.4	140.9
Central & South America	50.4	46.5	48.2
Africa	38.9	40.2	41.9
Middle East	50.0	51.2	52.9
Asia and Oceania	1 298.9	1 269.9	1 284.6
World	**1 838.8**	**1 796.7**	**1 814.7**
World excl. China	886.7	882.7	900.8
Developed Economies	400.4	393.7	394.6
China	952.0	914.0	914.0
Em. and Dev. Economies excl. China	486.3	489.0	506.2
ASEAN (5)[2]	72.6	76.8	81.4
MENA	66.7	69.0	71.7

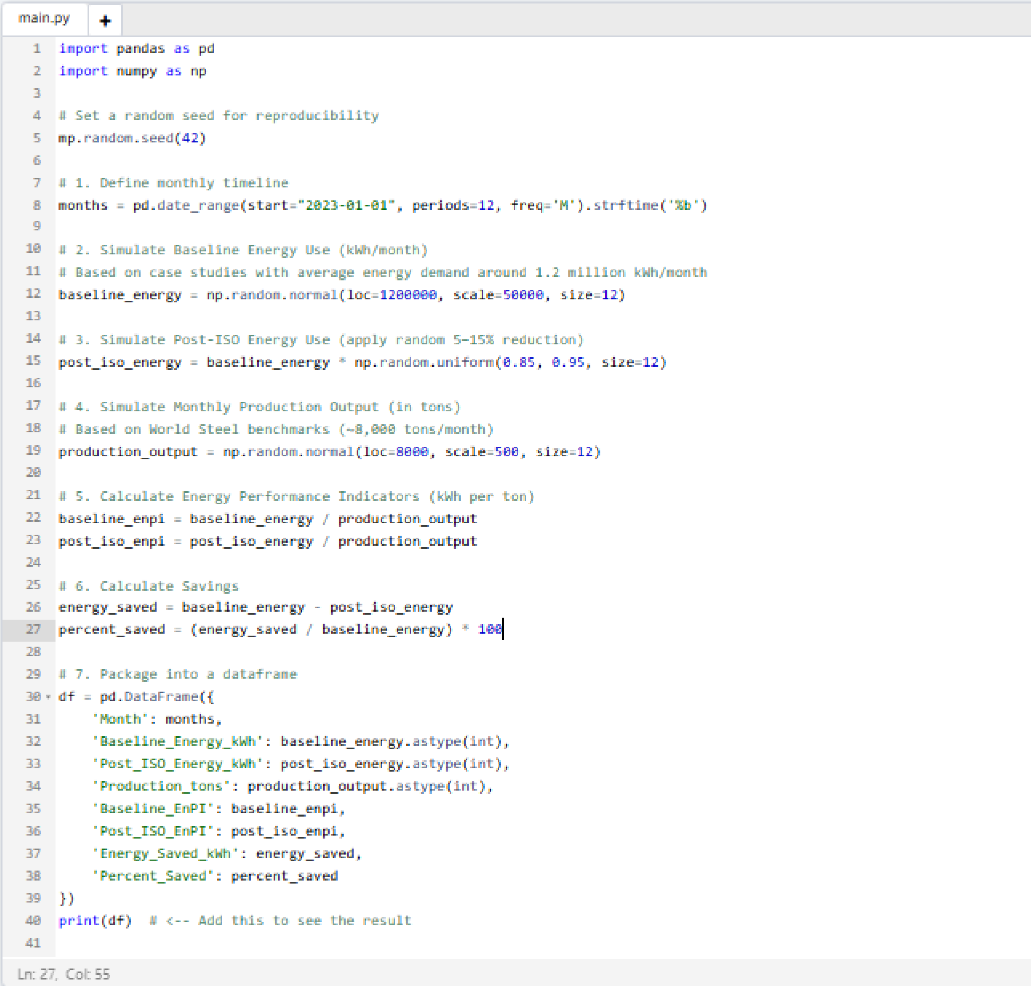
f = forecast

[1] European Union (27) + United Kingdom

[2] Indonesia, Malaysia, Philippines, Thailand, Vietnam

Figure 30: Steel Demand Forecasts for 2023 (Roudier S. Delgado Sancho L. Remus R. & Aguado-Monsonet M, 2013)

Appendix B: Energy Performance Simulation: Baseline vs Post-ISO 50001 Conditions



```python
import pandas as pd
import numpy as np

# Set a random seed for reproducibility
mp.random.seed(42)

# 1. Define monthly timeline
months = pd.date_range(start="2023-01-01", periods=12, freq='M').strftime('%b')

# 2. Simulate Baseline Energy Use (kWh/month)
# Based on case studies with average energy demand around 1.2 million kWh/month
baseline_energy = np.random.normal(loc=1200000, scale=50000, size=12)

# 3. Simulate Post-ISO Energy Use (apply random 5-15% reduction)
post_iso_energy = baseline_energy * np.random.uniform(0.85, 0.95, size=12)

# 4. Simulate Monthly Production Output (in tons)
# Based on World Steel benchmarks (~8,000 tons/month)
production_output = np.random.normal(loc=8000, scale=500, size=12)

# 5. Calculate Energy Performance Indicators (kWh per ton)
baseline_enpi = baseline_energy / production_output
post_iso_enpi = post_iso_energy / production_output

# 6. Calculate Savings
energy_saved = baseline_energy - post_iso_energy
percent_saved = (energy_saved / baseline_energy) * 100

# 7. Package into a dataframe
df = pd.DataFrame({
    'Month': months,
    'Baseline_Energy_kWh': baseline_energy.astype(int),
    'Post_ISO_Energy_kWh': post_iso_energy.astype(int),
    'Production_tons': production_output.astype(int),
    'Baseline_EnPI': baseline_enpi,
    'Post_ISO_EnPI': post_iso_enpi,
    'Energy_Saved_kWh': energy_saved,
    'Percent_Saved': percent_saved
})
print(df)  # <-- Add this to see the result

```

Figure 31: Python energy saving Simulation with ISO 50001