Guideline for Energy Performance Benchmark in Cement Industry in ASEAN

2025

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FOREWORD

It is with great pleasure that I present the Guideline for Energy Performance Benchmark in Cement Industry in ASEAN. This guideline serves as a fundamental resource for industry players, policymakers, and stakeholders, providing a standardised framework to assess and compare energy efficiency across cement plants in ASEAN Member States (AMS). By establishing clear benchmarking methodologies, this guideline facilitates fair comparisons, enabling the identification of best practices and opportunities for improvement in energy-intensive industries.

The industrial sector plays a pivotal role in ASEAN's economic growth, yet it is also one of the largest energy consumers. According to the 8th ASEAN Energy Outlook, industrial energy consumption continues to rise, accounting to 43% of the region's Total Final Energy Consumption (TFEC) in 2022, emphasising the urgent need for enhanced energy efficiency measures. The cement industry, in particular, is a major contributor to this demand, given its reliance on high-temperature thermal processes. Recognising this challenge, benchmarking energy use in the cement industry is essential in strengthening regional energy efficiency initiatives to achieve sustainability and competitiveness in the industrial sector.

As part of the ASEAN Plan of Action for Energy Cooperation (APAEC) 2021–2025, under the Energy Efficiency and Conservation (EE&C) Programme Area, the development of energy performance benchmark guidelines has been prioritised to support the region's energy efficiency goals. Recognising its strategic importance, this study has been acknowledged by the Lao PDR Chairmanship as one of its priority deliverables for 2024, underscoring ASEAN's collective commitment to accelerating energy efficiency improvements through data-driven policymaking. The implementation of the guideline provides cement manufacturers with a systematic approach to monitor, compare, and enhance their energy performance. By identifying top-performing plants and sharing lessons learned, benchmarking efforts will help accelerate the adoption of best practices and emerging technologies across the region.

The ASEAN Centre for Energy (ACE) has played a pivotal role in leading this initiative. This publication outlines methodologies for benchmarking Specific Energy Consumption (SEC) values, assessing significant energy uses, and identifying potential energy savings within cement plants. It also establishes key parameters for data collection, analysis, and normalisation, ensuring that benchmarking efforts produce fair, meaningful, and actionable insights.

I would like to extend my deepest appreciation to all contributors, including ACE in-house team, AMS representatives, technical working group on industry, industry experts, and other supporting organisations, for their valuable efforts in developing this guideline. Their dedication has been instrumental in advancing ASEAN's commitment to energy efficiency. I hope that this guideline will serve as a cornerstone for future benchmarking activities in other industries, supporting ASEAN's broader ambition to reduce energy intensity and build a more sustainable industrial future.

Dato' Ir. Ts. Razib Dawood

Executive Director
ASEAN Centre for Energy

EXECUTIVE SUMMARY

The Energy Performance Benchmark Guideline for the Cement Industry in ASEAN provides a structured approach to assessing energy efficiency in cement production across ASEAN Member States (AMS). Given the cement industry's high energy consumption, benchmarking energy performance is essential to drive efficiency improvements and reduce greenhouse gas emissions. This guideline serves as a reference for industry stakeholders and policy makers to measure Specific Energy Consumption (SEC), conduct meaningful comparisons, and implement best practices.

The industrial sector in ASEAN accounts for 43% of total final energy consumption, with cement production being one of the most energy-intensive sub-sectors. Given the industry's dependence on high-temperature thermal processes, reducing energy intensity is a critical challenge. Benchmarking energy performance is an essential tool to identify inefficiencies and establish performance baselines. This guideline outlines a step-by-step methodology for benchmarking energy performance, including data collection, normalisation, and analysis.

Benchmarking begins with defining the scope of energy performance measurement, which involves determining whether SEC calculations should cover overall energy consumption or focus on specific processes such as clinker production, cement grinding, or auxiliary operations. Data collection is the next critical step, requiring accurate measurement of both thermal and electrical energy use. Establishing a reliable database of SEC values allows cement plants to compare their performance against industry benchmarks, identifying gaps and opportunities. Normalisation is equally essential to ensure fair comparisons, as variations in production scale, fuel type, and process efficiency can affect SEC values. Statistical analysis such as regression help account for external factors and provide meaningful comparisons.

Several key factors influence energy performance benchmarking. The type of kiln technology used significantly impacts energy consumption, with modern kilns with preheater offering higher efficiency than the older ones. The clinker-to-cement ratio is another major determinant, as reducing clinker content using Supplementary Cementitious Materials (SCMs) can lower overall energy use. Fuel type is also critical, with coal remaining the dominant fuel source, although alternative fuels such as biomass are gaining traction. Additionally, waste heat recovery systems can enhance efficiency by reusing excess heat.

To improve energy efficiency, cement plants should adopt a systematic approach to monitoring SEC values and conducting regular benchmarking. Upgrading to energy-efficient technologies, optimising production processes, and increasing the use of alternative fuels are key strategies for reducing energy intensity. Policy makers should support these efforts by developing regulatory frameworks that encourage investments in energy efficiency.

ASEAN can leverage benchmarking to assess energy intensity across Member States, ensuring fair comparisons. Identifying top performers enables knowledge-sharing, while underperforming facilities can target improvements through technology upgrades and policy interventions. Strong collaboration, data sharing, and agreed parameters are essential for consistency and reliability of the parameter. Through effective benchmarking, ASEAN can enhance cooperation, monitor the energy intensity progress achievement, drive industrial efficiency, and support long-term sustainability

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NOMENCLATURE

ACE	: ASEAN Centre for Energy
AMS	: ASEAN Member States
CKD	: Clinker Kiln Dust
EnB	: Energy Baseline
EnPI	: Energy Performance Indicator
FDI	: Foreign Direct Investment
IEA	: International Energy Agency
IPCC	: Intergovernmental Panel on Climate Change
ISO	: International Organization for Standardization
GCCA	: Global Cement and Concrete Association
GJ	: Gigajoule
kWh	: Kilowatt-hour
SBTi	: Science-Based Target Initiative
SCM	: Supplementary Cementitious Materials
SEC	: Specific Energy Consumption
SEU	: Significant Energy Use (SEU)
UNIDO	: United Nations Industrial Development Organization
VIF	: Variance Inflation Factor
VRM	: Vertical Roller Mill
WHR	: Waste Heat Recovery
USGS	: United States Geological Survey

1 INTRODUCTION

1.1 Background

Over the past decades, ASEAN economies have demonstrated remarkable resilience, maintaining a consistent upward trajectory even amidst global economic downturns. By 2030, the region is expected to emerge as the world's fourth-largest economy, driven in large part by substantial inwards flows of Foreign Direct Investment (FDI), particularly channelled into the manufacturing, wholesale, and retail sectors [1]. This highlights the critical role of the industrial sector as the backbone of ASEAN's economic growth. Notably, this growth pattern is mirrored in the sector's energy consumption, with the **industrial sector accounting for 43.0% of total final energy use across the region in 2022**, far surpassing the transportation and residential sectors [2]. As the industrial sector is heavily dependent on fossil fuels, it is considered a "hard-to-abate" sector when it comes to decarbonisation. To address this, tailored strategies are necessary for each sub-sector to mitigate emissions and reduce energy consumption.

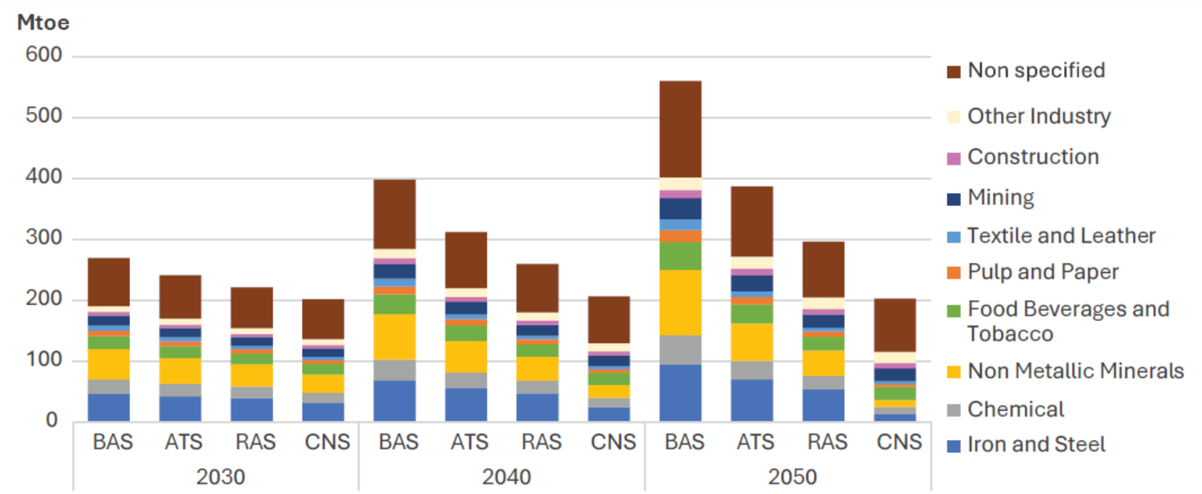

Figure 1. TFEC Projection Industrial Sector in ASEAN [2]

The **non-metallic minerals (cement, ceramics, glass), iron and steel, and chemical industries are among the most energy-intensive sectors**, together accounting for more than half of total industrial energy consumption in 2022 [2]. A key challenge in decarbonising these industries is their dependence on high-temperature thermal processes, which typically rely on burning fossil fuels to achieve the necessary operational temperatures. Although electrification of these processes is a potential solution, the technology is not yet commercially viable at scale for many sub-sectors [3]. Furthermore, the shift to electrification must be accompanied by a parallel decarbonisation of the electricity supply—whether from grid power or on-site generation—ensuring that energy is sourced sustainably. Without this, the benefits of electrification could be undermined by continued reliance on fossil-fuel-based power generation.

In the immediate and mid-term future, improving energy efficiency within the industrial sector stands out as a low-hanging-fruit strategy before alternative technologies or fuels become widely available. Efficiency improvements can be realised through a combination of reducing material demand and optimising processes throughout the industry's value chain. This could include upgrading production technologies, minimising energy losses, and implementing more efficient resource management practices. However, the industrial sector faces significant barriers to adopting energy efficiency measures, including the risk of stranded assets and fuel lock-in. Stranded assets refer to the devaluation of industrial equipment well before its expected economic life ends, often due to the introduction of new, more efficient technologies. Fuel lock-in occurs when companies invest heavily in specific technologies, becoming overly reliant on a particular type of fuel, making it difficult to transition to alternative energy sources.

A foundational step toward improving energy efficiency is to understand the existing patterns of energy consumption within similar industries. Energy benchmarking provides a method for assessing energy use by comparing consumption across similar industries, taking into account factors such as production capacity, technology employed, and end products. Benchmarking serves as a valuable tool for industry players to evaluate their current energy performance against industry standards, helping them identify opportunities for improvement. The process provides clear, comparable metrics that can be understood across regions and industries, making it easier for businesses to adopt best practices [4].

This study will focus on developing an energy performance benchmark and guidelines specifically for the cement industry within various industrial sub-sectors in ASEAN. The decision to prioritise the cement industry was reached after extensive consultations with ASEAN Member States (AMS) over multiple occasions. At the EE&C-SSN Meeting held in Lao PDR on 15 May 2024, ASEAN Centre for Energy (ACE) organised a Focus Group Discussion (FGD) to gather initial qualitative inputs for conducting energy performance benchmarking. During the FGD, the majority of AMS representatives suggested selecting either the cement industry or the food and beverage sector, as both represent a significant share of industrial activity in their respective countries. The details of FGD results can be found in **APPENDIX A.**

Simultaneously, ACE circulated a preliminary questionnaire to AMS, seeking additional input on benchmarking preferences. The results echoed the FGD discussions, with most countries recommending an energy-intensive industry like cement or food and beverage as the focus of the study. The details of preliminary questionnaire can be found in **APPENDIX B.**

After careful evaluation, ACE proposed that the cement industry be selected for this benchmarking study. The rationale behind this choice is that the cement industry exhibits less variability than the food and beverage sector, enabling a more consistent and meaningful comparison across ASEAN countries. This allows for a more comprehensive and fair assessment of energy performance.

1.2 Objectives and Outcomes

The objective of this study is to analyse energy consumption patterns within the selected industrial sub-sector through benchmarking, leading to the identification of best practices for energy efficiency and improvement areas, ultimately reducing energy intensity in the industrial sector across the ASEAN region.

The outcomes of this study are is a guideline for performing energy performance benchmark in the cement industry using Specific Energy Consumption (SEC) indicator.

Energy benchmarking offers a multitude of benefits, not just for industry stakeholders but also for policymakers. By assessing energy use and identifying areas for improvement, companies can uncover untapped potential for energy savings. At the same time, benchmarking can help governments and decision-makers identify the gaps and barriers that need to be addressed to promote energy efficiency on a larger scale. It also enables the formulation of targeted policies and regulations that support energy performance improvements across the industrial sector, fostering a more sustainable economic growth trajectory for Southeast Asia.

1.3 Report Structure

Chapter 1 – **Introduction**: This chapter provides the background for the study, explaining the importance of energy benchmarking in advancing energy management within the industrial sector. It also discusses the selection process that led to the focus on the cement industry. Additionally, it outlines the objectives of the study and the expected outcomes.

Chapter 2 – **Cement Production Process**: This section offers an overview of the cement industry landscape in ASEAN, followed by a detailed explanation of the production process. It covers the stages from raw material extraction, grinding, and calcination, to final grinding and packaging. The aim is to provide readers with a deeper understanding of how energy flows and is consumed throughout each step of the process.

Chapter 3 – **Energy Utilisation in the Cement Industry**: This chapter focuses on energy use within the cement industry, introducing Specific Energy Consumption (SEC) as a key metric for measuring energy intensity and assessing benchmarking efforts in the sector.

Chapter 4 – **Guideline to Establish SEC and Baseline**: This chapter guides policymakers and industry stakeholders on accurately establish SEC values, ensuring that the extracted data reflects the true performance of the cement production process. This step is crucial for conducting fair assessments across industry participants and identifying outliers that could distort the conclusions of the benchmarking exercise.

Chapter 5 – **Guideline to Perform Energy Benchmarking**: This section outlines the methodology for conducting energy benchmarking, emphasizing the importance of data availability and defining the scope of the study. It also discusses methods for data normalization, result analysis, visualization of benchmarking activities, and performing gap analysis. The chapter concludes with recommendations for closing the gap between top-performing and lower-performing companies in the region.

2 CEMENT PRODUCTION PROCESS

2.1 Overview

From the data published by United States Geological Survey (USGS) in 2022 [5], a graph is presented that estimates the annual cement production by various ASEAN countries from 2014 to 2022, illustrating significant growth with nearly 50% increase within 8 years. **Vietnam** consistently leads as the largest producer, reflecting its robust domestic cement industry and its role as a major exporter within the region. This growth aligns with Vietnam's extensive urbanisation and infrastructure development, which drive high domestic demand for cement. **Thailand** and **Indonesia** follow, representing substantial contributions to the total cement output. These countries have experienced a steady increase in production capacity, fuelled by both local demand and increasing exports to neighbouring countries.

On the other hand, countries like **Malaysia** and **Philippines** show smaller but still significant contributions to the region's cement production. Philippines has seen variable production levels, influenced by fluctuating local construction demand and economic conditions. Malaysia's production reflects its ongoing development projects and the government's focus on enhancing infrastructure. Meanwhile, **Singapore** does not have integrated cement plants where the closest activities related to this sector are cement pre-mixing, grinding, importing, and repackaging. Overall, the rising trend across most countries from 2014 to 2022 can be attributed to the region's economic growth, urbanisation, and the continuous expansion of the construction sector, which in turn drives the cement industry in ASEAN.

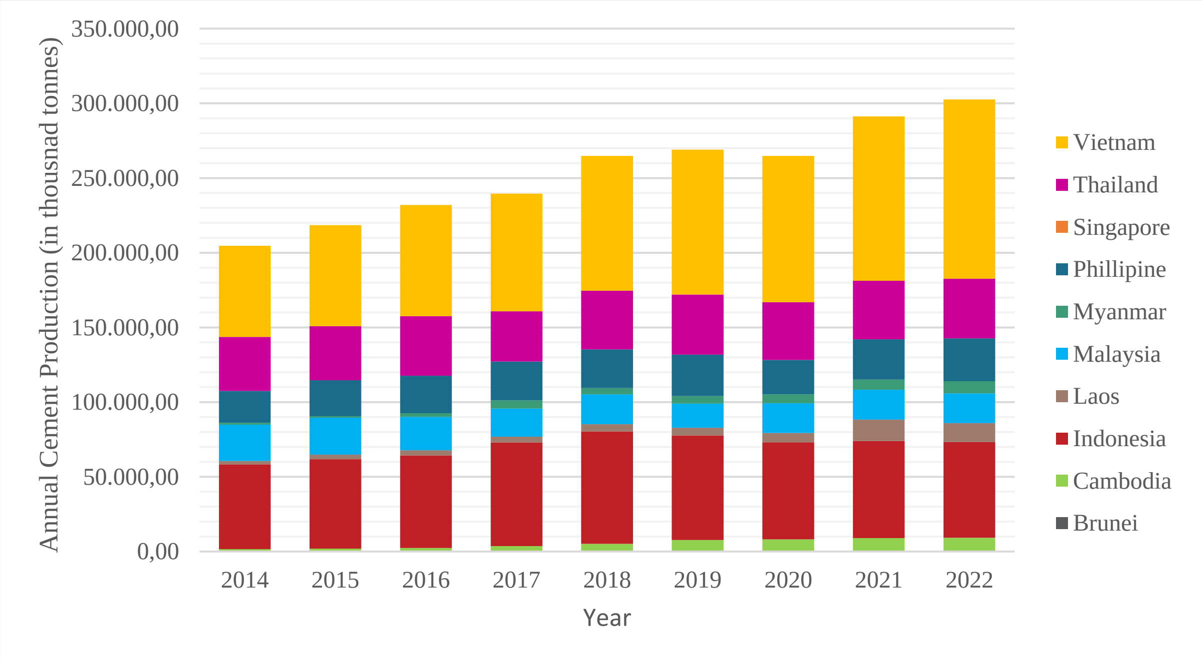

Figure 2. Annual Cement Production in ASEAN [6]

The production of cement involves several key chemical and physical processes. One of the most critical stages is **calcination**, where calcium carbonate ($CaCO_3$) is heated to approximately 900°C, resulting in its **decomposition into calcium oxide (CaO)** and the release of carbon dioxide (CO_2) gas. This process is both energy-intensive and a major source of CO_2 emissions in cement manufacturing. Following calcination, the **clinkering process** takes place, during which calcium oxide reacts with silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3) at even higher temperatures, **typically between 1400°C and 1500°C**. This process is also known as sintering. These reactions form key compounds such as calcium silicates, aluminates, and calcium ferrites, which combine to **create clinker, the intermediate product of cement.**

After the clinkering process, **the clinker is cooled and then ground together with small amounts of gypsum ($CaSO_4 \cdot 2H_2O$)**, which regulates the setting time of the cement. In some cases, other additives like limestone, slag, or fly ash are also blended during this stage to enhance the properties of the final product, such as strength and durability, while also reducing the clinker content and associated CO_2 emissions. The result of this final grinding process is Portland cement, the most commonly used type of cement worldwide.

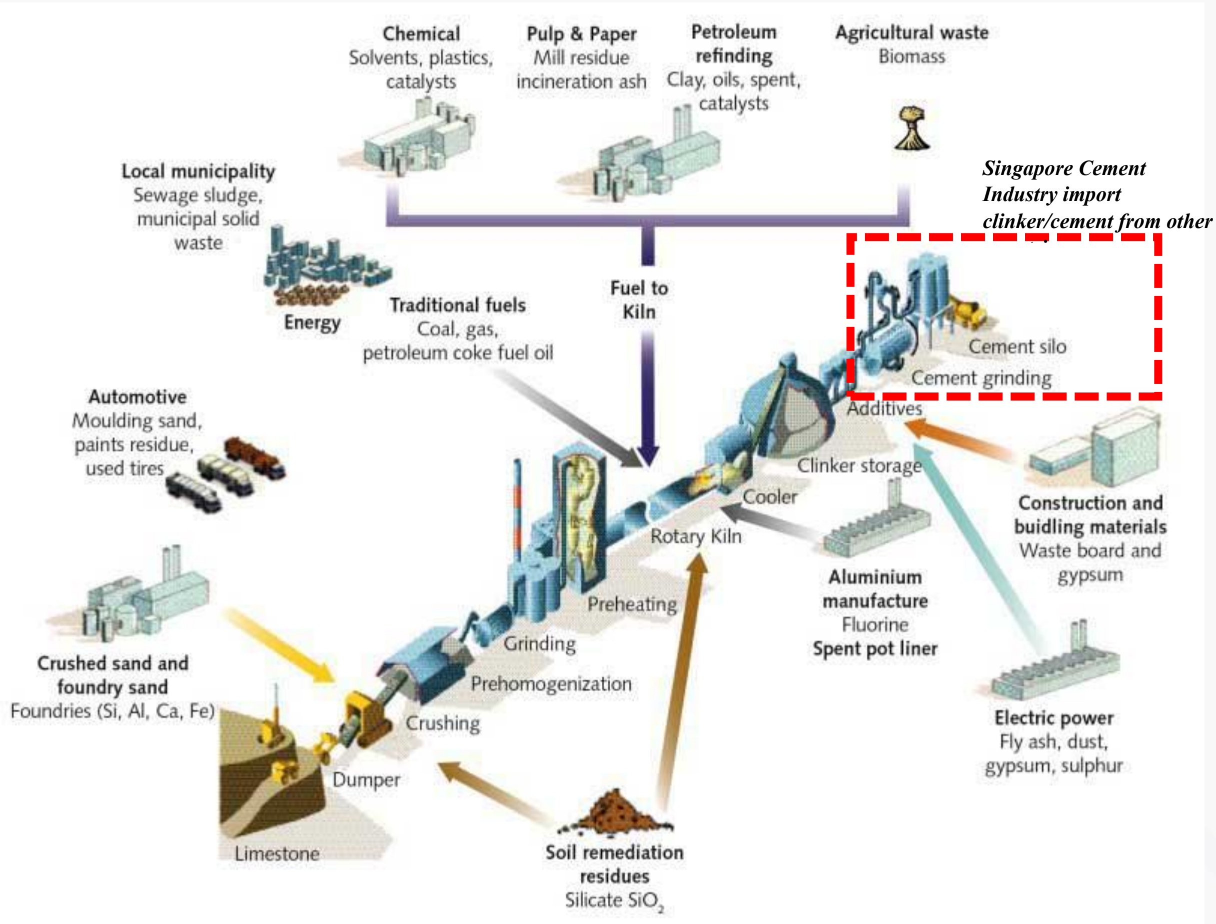

Figure 3. Typical Integrated Cement Manufacturing Process [7]

The overall cement production process is energy-intensive and involves both thermal and electrical energy consumption, with significant carbon emissions generated, particularly during calcination. Reducing the energy intensity and improving the efficiency of these processes are key challenges for the industry in terms of sustainability and emissions reduction.

2.2 Different Type of Processes and Cement Products

The **dry process** and **wet process** are the two main methods for cement production, with key differences in energy efficiency and raw material preparation. The dry process is more energy efficient as it uses dry raw materials that are ground and heated directly, minimising the need for water evaporation during production, recommended particularly when the raw material contains less than 15% of water [8]. In contrast, the wet process mixes raw materials with water to form a slurry, which requires more energy to heat and evaporate the moisture during kiln operation. While wet process allows for wider range of raw material with higher moisture content, dry process has become more prominent due to its far lower energy use that ultimately reduces operational cost. The **dry process typically uses about 3.4 GJ/ton** of cement, while the **wet process can use up to 5.3 GJ/ton of cement** [9].

Cement is produced in various types, which are [10]:

- **Ordinary Portland Cement (OPC):** most widely used type for buildings and infrastructure projects, comes in different grades based on compression strength. This equals to CEM I based on European Standard (EN 197-1) with clinker ratio >95%.
- **Portland Pozzolana Cement (PPC):** contains pozzolanic materials like fly ash or silica fumes which then are mixed with OPC. It is considered eco-friendly and high resistant against chemical reactions which make it suitable for structures exposed to water. This equals to CEM IV based on European Standard (EN 197-1) with clinker ratio between 65%-94%.
- **Sulphate-Resisting Cement (SRC):** Applicable for marine / coastal infrastructure due to its sulphur-resistant property. It contains lower tricalcium aluminate (C3A) to resist sulphate attack. This equals to CEM V based on European Standard (EN 197-1) with clinker ratio 40%-64%.
- **Other:** There are some other types of cement created for different purposes such as rapid-hardening cement, low heat cement, and white cement.

2.3 Raw Materials Extraction

The primary raw materials required for cement production, predominantly limestone and clay or shale, are commonly mined in proximity to the cement manufacturing facilities. Utilising drilling and blasting methods, these raw materials are unearthed and subsequently transported to the cement plants. Upon arrival, these materials undergo a series of preparatory steps including temporary storage and **pre-homogenisation to ensure quality and uniformity before entering the production process**.

Figure 4. Raw Material Extraction at Quarry [11]

Once at the cement plant, the materials are further processed; limestone and other raw materials are crushed using industrial crushers to reduce them to the appropriate size for processing. Post-crushing, these materials are stored in warehouses, ensuring they are adequately preserved and accessible for the next stages of cement production. This storage also aids in the further blending and homogenisation of the raw materials, optimising the consistency of the final product. These preparatory steps are crucial as they significantly impact the efficiency of the cement production process, allowing the creation of a homogenous raw mix that ensures the quality and strength of the cement produced.

2.4 Preparation of Raw Materials

After being temporarily stored and pre-homogenised, raw materials **undergo a drying and grinding process in a raw mill**, with the exact proportions of materials meticulously calculated prior to milling. The primary dry grinding systems employed include tube mills (both centre discharge and air swept varieties) and vertical roller mills. The particle size and fineness of the milled product are critical as they influence the efficiency of the subsequent burning process. Adjusting the air separator, typically used for this purpose, helps achieve the desired fineness and uniform particle distribution, enhancing the combustion process.

These separators are favoured due to their lower energy consumption, improved system output, and enhanced uniformity of the product. Generally, **it takes about 1.5 to 1.6 tons of dry raw materials to produce one ton of clinker**, though this figure can vary based on specific material consumption rates. Modern cement plants increasingly utilise energy-efficient vertical roller mills and advanced separator technologies.

In the raw mill, components such as iron sand, silica sand, and high-grade limestone are ground together to an average size of 0.01 – 0.03 mm [12]. This mixture undergoes **size reduction and moisture evaporation, aided by hot air from the suspension preheater and clinker cooler**. Finer particles have larger surface area, reacting more easily with other components necessary to the clinker formation and requires less heat.

If the kiln is temporarily offline, some plants have air heaters to ensure a continuous heat supply. The finely ground material is then mostly separated from the hot air, with around 10% being carried off and captured by baghouse filters for particulate removal. Any coarse materials or rejects from this process are recycled back into the mill for regrinding.

The hot gases from the clinker cooler and preheater usually bypass through a conditioning tower equipped with a water spray system, especially when the roller mill is not in operation. The temperature of these gases typically ranges from 360°C to 370°C but can vary depending on whether the raw mill is active, with temperatures significantly dropping when the mill is off. This system ensures optimal handling and recycling of heat and materials within the plant, contributing to energy efficiency and reduced environmental impact.

2.5 Fuel Type in Cement Production

Coal remains the primary fuel used in the cement industry, with its preparation involving several stages of processing in a coal mill before it is used in the kiln. The coal is crushed, dried, ground, and homogenized to achieve a specific fineness; this is crucial as **the granularity of coal affects combustion efficiency**. Pulverized coal that is too fine can lead to excessively high flame temperatures, while coarser coal might not burn completely, resulting in inefficient energy use and increased emissions. It is estimated that **200 kg of coal are used to produce 1 ton of cement** [13].

The types of coal mills commonly employed include air swept tube mills, vertical roller mills, and impact mills, with vertical roller mills being prevalent in cement plants. These mills are favoured for their efficiency and ability to produce the necessary fine coal. After grinding, the coal is typically stored in silos before it is fed into the kiln for combustion.

Beyond coal, the cement industry also utilises alternative fuels such as biomass, natural gas, and oil to meet energy demands and reduce carbon emissions. Biomass fuels, like rice husks, wood chips, and palm kernel shells, are renewable and can help decrease dependency on fossil fuels. They are carbon-neutral, which means they can reduce the overall carbon footprint of cement production.

Natural gas is another alternative, providing a cleaner burning option compared to coal. It emits fewer air pollutants and carbon dioxide, making it a favourable choice for environmental compliance and improved public health outcomes. However, the availability and cost can be limiting factors depending on regional natural gas supply infrastructure.

Oil is used less frequently due to its higher cost and greater carbon intensity compared to other fuels. However, in regions where oil is abundantly available, it may be used as a supplementary fuel during periods of high demand or when other fuels are not feasible.

Table 1. Properties of Fuels

No.	Fuel Type	Net Calorific Value [MJ/kg]	Emission Factor [kg CO_2/MJ]
1	Coal	26-32	0.098 – 0.101
2	Natural Gas	48-50	0.056 – 0.058
3	Biomass	15-31	0.070 – 0.132
4	Petroleum Coke	32-41	0.097 – 0.115

Source: [14] [15]

Each of these fuel types has its characteristics and implications for cement production, affecting everything from the cost of manufacture to the plant's environmental impact. These characteristics will slightly vary across countries and regions. Adopting a diversified fuel strategy can help cement plants reduce costs, secure energy supply, and mitigate environmental impacts, aligning with global trends towards sustainability in industrial production.

Companies often choose fuels that are readily available in their region to minimise transportation costs and ensure a steady supply. Although natural gas has higher energy density and emits less CO_2, **coal is widely used in the region due to its abundance and ease of transportation**. It is also preferred as the cost is relatively lower. However, with increasing regulations on emissions, companies are shifting towards fuels with lower emission factors, such as natural gas and biomass.

2.6 Clinker Combustion

The kiln feed, a central component in cement production, undergoes a series of high-temperature processes within the kiln system, beginning with preheating, followed by calcination—which involves the decomposition of limestone into calcium oxide (CaO) and carbon dioxide (CO2)—and culminating in **sintering or clinkering at temperatures approaching 1450°C**. After these processes, the clinker is rapidly cooled using air, reducing its temperature to about 100-200°C before it is conveyed to storage, typically in a clinker silo.

The prevalent kiln technology employed is the rotary kiln, often coupled with suspension preheaters and sometimes with pre-calciners, depending on the specific process design adopted. The rotary kiln, an inclined steel tube with a length-to-diameter ratio ranging from 10 to 40, features a slight inclination to facilitate material flow, enhancing thermal efficiency through its slow rotational speed (approximately 0.5-4.5 revolutions per minute).

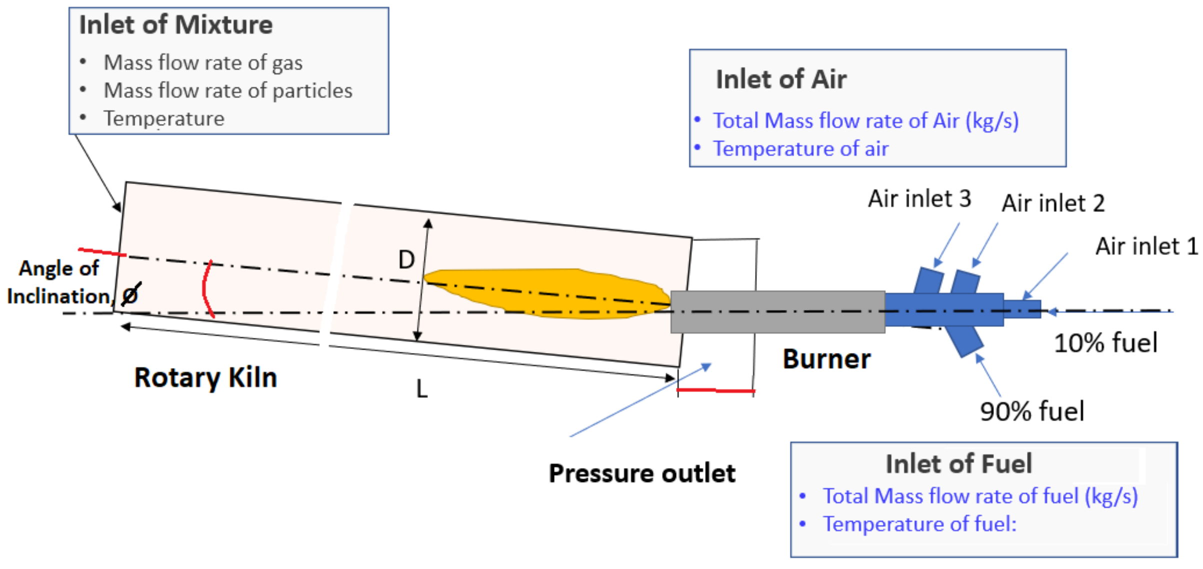

Figure 5. Illustration of Rotary Kiln [16]

Suspension preheaters enhance the energy efficiency of the system and are generally constructed with four to six cyclone stages, which can reach up to 120 meters in height. The uppermost stage may include dual cyclones for more effective dust and gas separation. Hot gases from the kiln ascend through these cyclones, effectively preheating the incoming raw material which moves in the opposite direction.

Energy management is a critical aspect of kiln operation. The residual heat from these processes is often harnessed to dry raw materials, solid fuels, or additives, significantly reducing energy consumption. Environmental controls such as Electrostatic Precipitators or Bag Filters are essential for cleaning waste gases before they are released into the atmosphere.

In addition to coal, which is the primary fuel for generating the necessary high temperatures, alternative fuels like biomass, natural gas, and industrial diesel oil (IDO) are also utilised. Biomass offers a renewable solution contributing to lower carbon emissions, while natural gas provides a cleaner alternative to coal. IDO is often used for preheating, adding flexibility to fuel choices in the cement production process.

The clinker cooler is integral to the kiln system, designed to maximize heat recovery from the clinker and facilitate its handling. Advanced clinker coolers employ several stages of cooling grates equipped with fans to optimise the cooling process and improve thermal efficiency. This setup not only recovers heat for reuse in the plant processes but also helps in managing the clinker temperature for subsequent material handling and processing.

2.7 Cement Grinding

Portland cement is typically manufactured by finely grinding clinker, a nodular material produced in the kiln, along with a small percentage of gypsum, either natural or industrial (anhydrite). This type of cement may also incorporate other materials, such as limestone or blast furnace slag, and natural or industrial pozzolans, such as volcanic tuffs or fly ash from coal-fired power plants. These additional constituents can be inter-ground with clinker or blended separately during the cement mixing process.

The integration of additives not only enhances the properties of cement but also contributes to sustainability efforts by reducing the clinker-to-cement ratio. For instance, incorporating blast furnace slag helps in lowering the greenhouse gas emissions of the cement manufacturing process. Similarly, using fly ash, a byproduct from thermal power plants, helps in recycling a waste product, thus promoting environmental sustainability.

In cement production facilities, the mixture of gypsum, clinker, and any additional additives is carefully weighed using a weigh feeder conveyor before entering the final grinding stage. This stage is crucial as it aims to achieve a specific level of fineness in the cement, compliant with regulatory standards. The milling of cement is commonly performed in a vertical roller mill (VRM) or a tube mill, both of which can operate within a closed-circuit grinding system. This setup is integral to ensuring uniformity and quality in the final product while optimising the energy efficiency of the milling process.

The use of advanced milling technologies like VRM allows for better energy management and material handling, thereby enhancing the overall efficiency of the cement production process. These innovations, along with the strategic incorporation of supplementary materials, play a pivotal role in modernising cement production and aligning it with global environmental and quality standards.

2.8 Cement Packing

A packing plant in the context of cement production incorporates a series of machines that manage the transportation of materials to a packing station, where the packer machine plays a critical role. This machine is tasked with the final step in the manufacturing process: packaging the cement into various bag sizes, typically 50 kg and 1-ton sacks, suitable for distribution and sale. The packer not only fills these bags but also ensures they are accurately weighed to meet specified standards.

This stage is crucial as it directly affects the product's marketability, ensuring that the cement is packaged securely and in quantitatively accurate measures to satisfy customer and regulatory requirements. Efficient operation at this stage can lead to optimised production flow, reduced wastage, and enhanced customer satisfaction. Advanced packaging plants now incorporate automated systems that improve the precision and speed of packaging, reflecting an evolution from manual methods to more technologically driven processes. This shift not only enhances efficiency but also reduces the labour intensity of the cement packing process, aligning with modern industry practices that emphasise sustainability and operational efficiency.

3 ENERGY UTILISATION IN CEMENT INDUSTRY

3.1 Overview

Energy consumption in cement plants is substantial and varies across different stages of production. Energy cost accounts for around 40% of total production cost in cement industry [17]. The most energy-intensive phase is the clinkering process, which involves heating the raw materials in the kiln to extremely high temperatures, often exceeding 1400°C. This step, which transforms raw materials into clinker through chemical reactions, accounts for around 90% of total energy use in a typical cement plant. Fuel, particularly coal, is the primary energy source for the kiln, though some plants also use alternative fuels like biomass or waste-derived materials to reduce carbon emissions.

Globally, **nearly 4 Gt of cement is produced annually with China as the leading producer**. This is equivalent to around 8% of global CO_2 emissions. It is estimated that **800 kg of CO_2 is emitted for every tonne of cement produced** [18] [19]. In ASEAN, around 300 Mt of cement is produced in 2022, or around 7.5% of total global cement production [6].

Typically, energy intensity for **electrical energy use** in cement production is **110 kWh/t cement** and for **thermal energy is 3.6 GJ/t cement** [17]. Electricity is used mainly for preparation process and grinding while thermal energy is consumed for sintering process by burning fuel to reach necessary temperatures.

Another critical aspect of improving energy efficiency is optimising the **clinker-to-cement ratio**. Clinker production is the most energy-intensive part of cement manufacturing, so reducing the amount of clinker in cement can significantly lower energy consumption. This is achieved by blending clinker with **Supplementary Cementitious Materials (SCMs)** such as fly ash or slag, which not only reduces energy use but also cuts CO_2 emissions. Lowering the clinker-to-cement ratio is vital for both economic and environmental reasons, as clinker production is also a major source of greenhouse gases. Reducing this ratio without compromising cement quality is a key challenge for the industry but also represents a significant opportunity for making cement production more sustainable. To illustrate, **a 0.10 decrease in ratio will lead to a reduction of 0.19 GJ/t** [20]. According to IEA, Net Zero Emission scenario requires global average of cement-to-clinker ratio is 0.65 by 2030 [21].

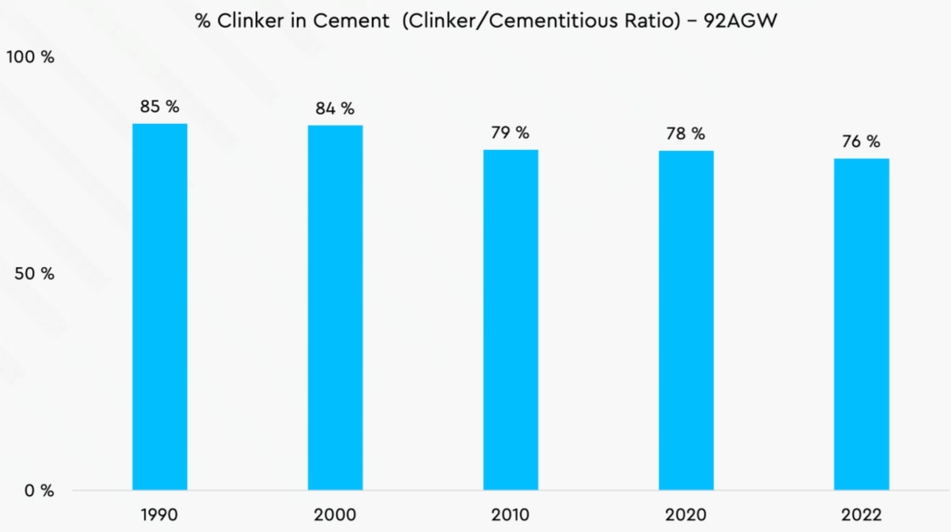

Figure 6. World clinker-to-cement ratio over time [22]

The figure above comprises of variations across regions. China has one of the lowest clinker-to-cement ratios, 0.65 in 2022, increasing from 0.57 in 2015. Meanwhile, USA and Canada have relatively higher clinker-to-cement ratio than global average, at 0.89 and 0.86 respectively in 2022 [21].

Another energy-demanding stage is grinding, which occurs both at the beginning (raw material grinding) and the end (cement grinding) of the process. Grinding the raw mix to the required fineness and then grinding the clinker into fine powder for cement requires significant electrical energy, making it the second largest energy consumer in the plant.

Given the substantial energy demands, efficiency measures are essential for reducing both costs and the environmental impact. Key measures include upgrading to more efficient kiln systems, such as those with preheaters and pre-calciners, which allow the raw materials to be preheated and partially calcined before entering the kiln. This reduces the thermal energy required in the kiln itself. Additionally, transitioning to more energy-efficient grinding technologies, like vertical roller mills (VRMs), can reduce electrical consumption compared to traditional ball mills.

Waste heat recovery systems are another crucial strategy, allowing plants to capture and reuse heat from the kiln and cooler systems, often generating electricity for the facility. This reduces dependence on external energy sources and lowers overall energy consumption. Advanced process control systems can further optimize operations, adjusting fuel and raw material inputs in real-time to maximise efficiency.

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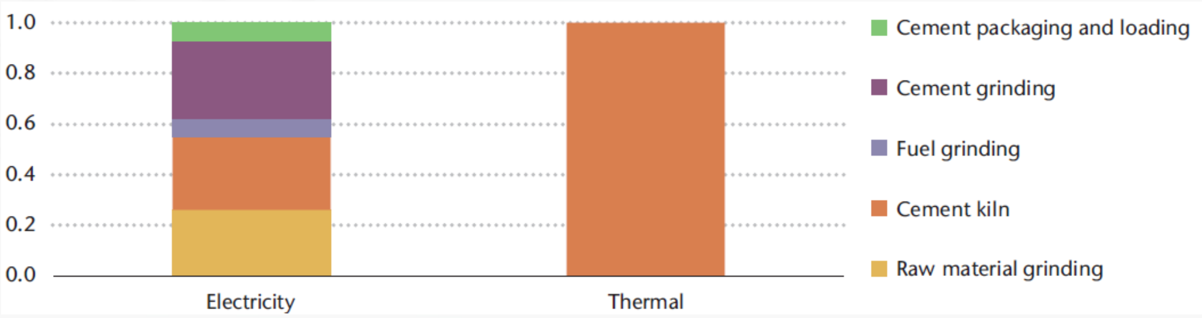


Figure 7. Energy use distribution in each step [23]

Figure 7 represents the typical distribution of energy usage in the cement industry, differentiated by type (Electricity and Thermal) and broken down by specific processes within the industry. Electricity is mostly used in raw materials grinding and cement grinding, while thermal is only used in calcination. However, to understand the magnitude of each energy carrier, a previous study unveiled the estimation of energy use based on best-available-technology for Portland cement, in each step as follows:

Table 2. International Best Available Technology (BAT) for Cement Portland Production

Production Process	Energy Type	Total Energy Use [GJ/ton]
Raw Material Preparation	Electricity	0.07
Calcination	Thermal	2.79
	Electricity	0.08
Finish Grinding	Electricity	0.06
Total		**2.92**

Source: [24]

From the Table 2, **thermal energy for making clinker takes up nearly 95% of total energy consumption for producing cement** and the rest of the processes are electrically powered. This implies that improving the energy efficiency in calcination would have the greatest impact in overall energy consumption through utilising waste heat, upgrading kiln efficiency or shifting to alternative fuels.

It is also important to note that different cement type production yields different energy profile. This is indicated by different clinker-to-cement ratio as explained in section 2.2, where a higher portion of Supplementary Cementitious Materials (SCM) will result in lower clinker-to-cement ration that requires less energy to produce intermediate cement product, clinker. The difference of energy use for each different cement product with **best-available-technology** is shown below:

Table 3. International Best Practice of Energy Use for Different Cement Products

Cement Product	Clinker-to-cement ratio	Total Energy Intensity [GJ/ton]
Ordinary Portland Cement	0.95	2.92
Cement with 35% Fly Ash	0.65	2.04
Cement with 65% Slag Blast Furnace	0.35	1.65

Source: [24]

There are numerous factors affecting energy profile in cement production:

- **Fuel Type**: Different fuels have varying calorific values and emission factors. For example, coal has a calorific value of 26-32 MJ/kg, while natural gas ranges from 48-50 MJ/kg, as outlined in Table 1
- **Burner Efficiency**: burner efficiency typically ranges between 60% and 80%, depending on the type of kiln and the fuel used. For example, modern rotary kilns equipped with preheaters and pre-calciners can achieve higher efficiencies due to optimised fuel combustion and heat recovery systems.
- **Business Process**:
    - Product Type: Plants that produce only clinker have higher energy consumption compared to those that produce finished cement products.
    - Import/Export: Plants that import clinker and only grind it into cement may have lower energy consumption compared to those that produce clinker on-site.

3.2 Comparison with Other Industries

To provide a broader perspective, this section compares the energy consumption in the cement industry with other energy-intensive industries such as iron and steel, food and beverage, and textiles.

Iron and Steel Industry

Energy Consumption: The iron and steel industry are also highly energy intensive. The energy required for steel production varies depending on the process [25] [26]:

- Blast Furnace-Basic Oxygen Furnace (BF-BOF): Approximately 20-35 GJ/ton of steel.
- Electric Arc Furnace (EAF): Around 10-15 GJ/ton of steel.
- Electricity Consumption: The EAF route consumes about 400-500 kWh/ton of steel.

Food and Beverage Industry

Energy Consumption: The food and beverage industry has a lower energy intensity compared to cement and steel. Energy consumption varies widely depending on the specific processes involved [27]:

- Average Energy Use: Approximately 1-3 GJ/ton of product.

- Electricity Consumption: Typically ranges from 100-300 kWh/ton of product.

Textile Industry

Energy Consumption: The textile industry also varies greatly in values in terms of energy intensity, depending on the process such as spinning, weaving, dyeing, and finishing [28]:

- Average Energy Use: Around 10-50 GJ/ton of products.
- Electricity Consumption: Typically ranges from 200-400 kWh/ton of product.

3.3 Energy Intensity

In the cement industry, the primary indicator for measuring energy efficiency is the Specific Energy Consumption (SEC), which quantifies the amount of energy used per unit of production. Energy in this context can include both thermal energy (used for heating processes) and electrical energy (used for powering machinery), or the total combination of both. The formula for calculating SEC is straightforward:

SEC = Total Energy Used (thermal and electrical) / Total Production

This calculation allows for a clear assessment of energy efficiency by evaluating the energy required to produce a specific amount of material, typically clinker or cement.

SEC can be calculated for different production stages within a cement plant. For example:

- **SEC Electricity for the Raw Mill (kWh/ton raw meal)**: This is determined by the electrical energy consumed in the raw mill stage, where raw materials are ground. It includes both the energy used by the main drive and the low-voltage equipment within the raw mill area.
- **SEC Electricity for the Kiln (kWh/ton clinker)**: This calculation covers the energy used during the clinker production process, including energy for auxiliary components like the coal mill and preheater fans. This stage is critical since the kiln is the most energy-intensive part of cement production.
- **SEC Electricity for the Cement Mill (kWh/ton cement)**: This metric focuses on the electrical consumption during the final grinding of clinker into cement. It includes energy used by the main drives and auxiliary equipment in the cement mill.
- **SEC Electricity for the Entire Plant (kWh/ton cement)**: This broader metric encompasses energy consumption across all key processes, from the crusher to the raw mill, kiln, and cement mill, providing a comprehensive view of energy utilisation across the plant, excluding utility-related consumption.

Improving SEC values is essential for both reducing operational costs and minimizing environmental impact. Plants can achieve this by adopting energy-efficient technologies, optimizing process controls, and integrating renewable energy sources into their operations.

Energy Management is a must in today's Industry either due to the demands of the times, business needs, regulatory compliance and other causes. Since energy management is an important tool to improve energy efficiency, the use of specific energy consumption (SEC) to identify potential energy efficiency improvements is seen as an important instrument in energy management. Often, both in the literature and international standards, SEC is used as an energy performance indicator to evaluate or measure energy efficiency performance.

3.4 GHG Emission in Cement Industry

3.4.1 Source of Emission

The cement industry is a significant contributor to global anthropogenic emissions, accounting for approximately 8% of the total, which equates to about 1.6 Gt of CO_2 emitted annually as of 2022 [29]. This substantial emission level is projected to rise to 3.8 Gt CO_2 per year by mid-century, driven by factors such as population growth, urbanisation, and increased infrastructure development.

The emission intensity within the cement sector has remained relatively constant, with direct CO_2 emissions estimated at 0.6 t CO_2 per ton of cement produced [30] [31]. To align with the Net Zero Emissions (NZE) scenario, this intensity must decrease by approximately 4% annually through 2030 [32].

In cement production, around 50% of emissions originate from the calcination process, where limestone (calcium carbonate) is heated to produce lime (calcium oxide), releasing CO_2 as a byproduct. The remaining emissions primarily result from the combustion of fossil fuels to generate the high temperatures required in calcination process [32], with additional contributions from electricity usage and transportation [33].

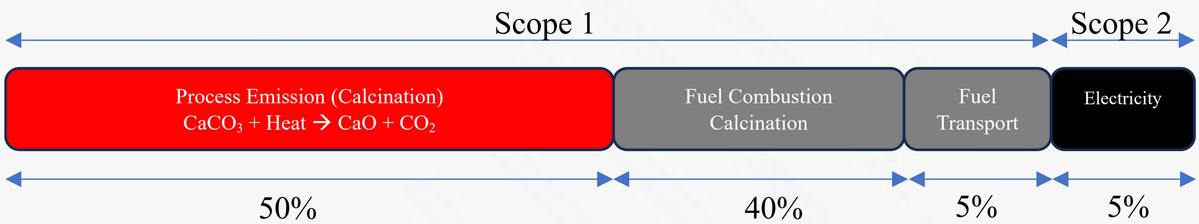


Figure 8. Source of Emission in Typical Cement Plant

Source: Image by ACE, adapted from [33] and [34]

In addition to Scope 1 and 2 emissions, it is valuable to examine Scope 3 emissions associated with cement production, including lime production, imported clinker production, mobile combustion, and waste disposal. Conducting a comprehensive analysis of these factors can provide deeper insights into emissions from cement production, even though tracking Scope 3 emissions can be challenging.

Reducing emissions from industrial processes is essential for lowering energy intensity in the cement industry. A key strategy involves decreasing the clinker-to-cement ratio by substituting clinker with Supplementary Cementitious Materials (SCM) and

Limestone Calcined Clay Cement (LC3). Additionally, adopting low-carbon fuels is crucial for cutting emissions in this sector. However, its adoption remains limited at the moment, with bioenergy currently contributing only 4% of the primary fuel sources used in thermal processes [32]

3.4.2 Estimation of GHG Emission

There are two commonly used methodologies for estimating direct process emissions in the cement industry: Clinker-Based [35] and Cement-Based approaches [36].

Clinker-Based Approach

The clinker-based methodology, developed by the World Business Council for Sustainable Development (WBCSD) and endorsed by the Intergovernmental Panel on Climate Change (IPCC), is outlined in the Cement CO_2 Protocol and the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Since the majority of energy consumption in cement production occurs during clinker production, this approach is considered straightforward. It relies on readily available facility-level data commonly used by companies. This method calculates emissions directly based on the amount of clinker produced and its calcium oxide (CaO) and magnesium oxide (MgO) content. The key steps include:

1. **Determine Actual Clinker Production**: Assess the total amount of clinker produced at the facility.

2. **Calculate the Emission Factor for Raw Material Calcination**: This step uses the lime (CaO) content in the clinker and compares the molar mass of CO_2 released per unit of CaO. The emission factor for clinker (EF clinker) is calculated as:

$$EF_{Clinker} = Fraction\ CaO\ x\ \frac{Molar\ Mass\ CO2\ \left(44.01 \frac{g}{mole}\right)}{Molas\ Mass\ CaO\ \left(56.08 \frac{g}{mole}\right)}$$

   In case where fraction of CaO is unknown, the IPCC's recommended emission factor for clinker is approximately 0.507 tons of CO_2 per ton of clinker.

3. **Calculate Clinker Kiln Dust (CKD)**: CKD, a fine powder by-product of cement production, may emit additional CO_2 due to its partial calcination. CKD is considered a loss, as it represents raw material that does not convert into clinker.

4. **Determine the Emission Factor for CKD**: This factor is derived from the clinker emission factor with adjustments for partial calcination. If CKD production data is unavailable, the CO_2 emissions from CKD are generally estimated to range between 2% and 6% of total CO_2 emissions from clinker production.

5. **Calculate Total Emissions**: Combine the emissions from clinker production and CKD to estimate the total process emissions.

Cement-Based Approach

The cement-based methodology, originating from the U.S. EPA's Climate Wise Program (1999) and adopted by the Greenhouse Gas (GHG) Protocol, calculates emissions based on the clinker-to-cement ratio and total cement production. This method is suitable when reliable data on raw material and cement ratios are available. The key steps include:

1. **Determine Cement Production Quantity**: Differentiate between types of cement produced, as each has a distinct clinker-to-cement ratio.
2. **Estimate Clinker Ratio**: Use the clinker-to-cement ratio to calculate the amount of clinker used. Adjustments are necessary if the plant uses imported clinker.
3. **Assess Raw Material Usage**: Multiply clinker production by the raw material ratio.
4. **Determine Calcium Carbonate Equivalent**: Use the $CaCO_3$ equivalent for clinker production, accounting for $MgCO_3$ if applicable.
5. **Calculate CO_2 Emissions**: The formula for calculating CO_2 emissions is:

$$CO2\ Emission = Cement\ Production\ x\ Clinker\ Ratio\ x\ Raw\ Material\ Ratio\ x$$

$$CaCO3\ equivalent\ x\ [\frac{CO2}{CaCO3} Stochiometric\ Ratio, or\ 0.44]$$

This methodology assumes that CKD is fully calcined, which may lead to an overestimation of CO_2 emissions. Additionally, it does not account for performance improvements from blending cement or substituting clinker.

Some default values that may be used if data are unavailable are as follows:

Table 4. Default Values for Emission Calculation [37]

Parameters	Values
Clinker-to-cement ratio – 100% Portland	95%
Clinker-to-cement ratio – Portland Pozzolana	75%
Clinker-to-cement ratio – Portland Slag	55%
Ton of raw material per ton of clinker	1.5
CaCO3 equivalent to raw material ratio	78%

Both methods have specific use cases and data requirements, with the clinker-based approach being more straightforward for facility-level analysis and the cement-based approach offering insights when cement and raw material ratios are well-documented.

3.4.3 Efforts To Reduce Emissions

Cement companies are increasingly encouraged to align their carbon reduction efforts with the global ambition to limit the rise in global temperatures to well below 2°C, as outlined in the Paris Agreement. One of the tools for achieving this alignment is the

Science-Based Targets initiative (SBTi), which provides a robust framework to guide companies in setting measurable and achievable emissions reduction goals. This framework is particularly valuable for the cement industry, given its significant contribution to global greenhouse gas (GHG) emissions. With the SBTi, companies can establish distinct near-term and long-term targets, aiming to achieve net-zero emissions by 2050 or earlier.

The SBTi framework involves several steps to ensure that targets are science-based and aligned with sector-specific decarbonisation pathways:

1. **Determine target boundaries and approaches**
   The first step is to define the scope and boundary of the targets. For **near-term targets** (5-10 years), companies are primarily expected to focus on **Scope 1 and Scope 2 emissions**, which represent direct emissions from cement kilns and indirect emissions from purchased electricity, respectively. However, if **Scope 3 emissions** (indirect emissions from the value chain) account for more than 40% of the company's total emissions, they must also be included in near-term goals. For **long-term targets**, covering all three scopes—Scope 1, Scope 2, and Scope 3—is essential to ensure a holistic approach to decarbonization and alignment with net-zero objectives

2. **Calculate emissions inventory**
   A comprehensive emissions inventory is essential for establishing a baseline against which future reductions can be measured. Companies must collect data on GHG emissions and production volumes for a chosen base year. This includes:
   - Quantifying Scope 1 emissions from processes like calcination and fuel combustion in cement kilns.
   - Calculating Scope 2 emissions from purchased electricity and heat.
   - Evaluating significant Scope 3 emissions, such as those from the transportation of raw materials, the use of cement in downstream applications, and end-of-life disposal

3. **Construct Targets**
   Once the emissions inventory is complete, companies can begin constructing their targets using methodologies provided by the SBTi. For the cement industry, the **Sectoral Decarbonization Approach (SDA)** is a widely used method. This approach provides a pathway for reducing emissions intensity, expressed in terms of **tons of CO_2 per ton of cementitious material (t CO_2/t cement)**, for Scope 1 and Scope 2 emissions. By following the SDA, companies can align their targets with sector-specific benchmarks that reflect the required decarbonization trajectory.

   For **Scope 3 emissions**, targets can be set using a **cross-sector absolute reduction approach**, which focuses on achieving a percentage reduction in total emissions across the entire value chain. This method accounts for the diverse sources of Scope 3 emissions and provides flexibility in addressing them through innovative practices such as the use of alternative raw materials, optimised logistics, and low-carbon product development.

Once the targets are validated and the company commits to achieving them, the focus shifts to **implementation planning**. At this stage, the company assesses and selects specific technologies and measures that align with its capacity for operational change and investment, ensuring a tailored and feasible approach to meeting the established goals. The technologies and measures that may be adopted by cement companies are:

a) **Reduce Clinker**

Clinker production is responsible for a significant portion of emissions in the cement industry, primarily due to the calcination of limestone, which contributes nearly 50% of process emissions. Transitioning to less carbon-intensive alternatives can drastically reduce emissions. For instance, using heat-stored cement-based materials (HSCMs), which are carbon-negative, offers an innovative way to decrease clinker dependency [38]. Incorporating supplementary cementitious materials (SCMs) such as fly ash, slag, or calcined clays significantly reduces the carbon footprint of cement production. One such breakthrough is Limestone Calcined Clay Cement (LC3), which has shown the potential to lower CO_2 emissions by up to 40% [39].

Another promising development is the reuse of cement paste extracted from demolished buildings, which possesses similar chemical properties to clinker. However, this approach poses challenges, such as the requirement for extremely high temperatures of up to 1,600°C, which leads to higher energy consumption. Furthermore, scaling up this technology demands robust waste cement supply chains, which remain underdeveloped in many regions.

Additionally, optimising energy use in clinker production is critical. One effective method is waste heat recovery, which captures excess heat from the kiln process and uses it to pre-heat the raw meal before it enters the furnace. This practice reduces the total energy required for the calcination process, improving overall efficiency and lowering emissions.

b) **Low Carbon Fuels and Electrification**

The use of alternative low-carbon fuels is another important strategy to reduce emissions in the cement industry. Biomass and refuse-derived fuels (RDF) are renewable alternatives that can replace traditional fossil fuels such as coal in cement kilns. These fuels not only reduce the carbon footprint of cement production but also offer the advantage of utilising waste materials, contributing to a circular economy.

Electrification is also gaining attention to lower emissions. Partially heating the kiln using low-emission electricity can significantly reduce reliance on fossil fuels. While this method requires investment in infrastructure and access to clean electricity sources, it has the potential to decarbonise the cement sector, particularly when combined with renewable energy sources for electricity.

c) **Carbon Capture Utilisation and Storage (CCUS)**

Carbon capture, utilisation, and storage (CCUS) technologies are among the most promising solutions for reducing emissions in the cement industry. According to the Global Cement and Concrete Association (GCCA), CCUS has the potential to mitigate up to 36% of carbon emissions from cement production [40]. These technologies work by capturing CO_2 released during the calcination process and storing it underground in geological formations.

The implementation of CCUS in the cement industry faces challenges such as high upfront costs, energy requirements for CO_2 capture, and the development of infrastructure for transportation and storage. However, with continued innovation and supportive policies, CCUS is expected to play a pivotal role in achieving carbon neutrality in the sector.

4 GUIDELINE TO ESTABLISH SEC AND BASELINE

Although calculating the SEC is relatively simple, there are many challenges in the process, such as collecting data, determining the scope and limitations, and drawing inappropriate conclusions. As a result, the use of this indicator may not fulfil its purpose. Therefore, the following steps should be considered in the process of determining SEC:

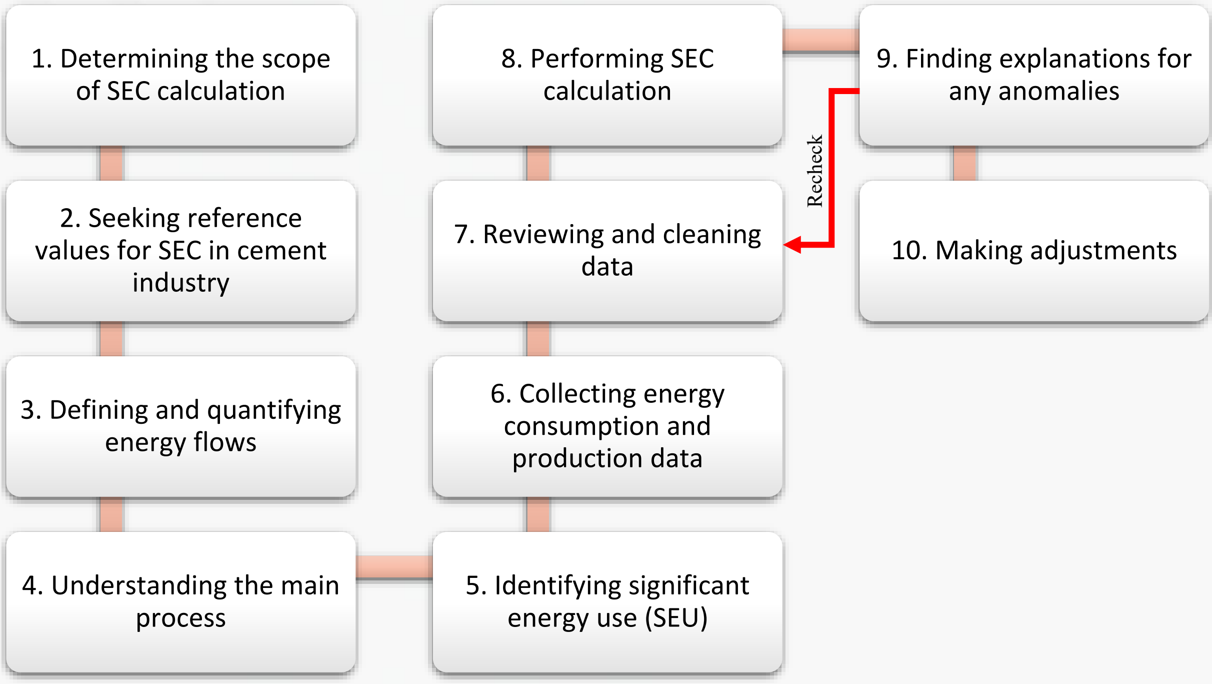


Figure 9. Flow to Calculate SEC
Source: ACE, own analysis

4.1 Determining the Scope of SEC Calculations

Specific energy consumption (SEC) is the amount of energy consumption per unit of product. The amount of energy calculated is highly dependent on the boundaries and scope that are defined in advance. The scope is often influenced by the purpose of the SEC. For example, if the calculation of SEC is intended for benchmarking purposes, then the scope limit is determined together or refers to a certain standard that issues a reference number for benchmarking. If the calculation of SEC in the industry is intended for reporting purposes, for example to the related ministries, then the determination of the scope limit of SEC calculation should follow the direction of those who request the report.

Why are limitations in SEC calculations important?

- To determine what energy consumption will be considered.
- To provide more useful information for stakeholders.
- To help manage the risks and opportunities associated with energy consumption across all values company chain.

This limitation and scope are important because the reality is that industries are very varied even though they are in the same sector. For example, the cement industry sector is often perceived as a relatively homogeneous industry. The so-called cement factory in reality differs from the scope of its activities as follows:

- **A cement factory that only processes clinker into cement and packages it**, with the largest energy user being the cement mill and the type of energy dominated by electricity
- **A cement factory with a complete and long process**, starting from mining to becoming a packaged cement product. The most dominant energy consumption is heat energy from fuel and waste heat, and in a smaller percentage is electrical energy.
- A cement factory with a complete process such as example point b but **equipped with its own power plant and port**. The dominant energy consumption is fuel and in a very small portion is electricity purchased. Electrical energy in this case is consumed in minimal amounts and functions as a backup in case of failure in the operation of its own power plant.

Limitations that needed to be discussed are:

a. Whether calculated energy is overall energy consumed by the company?

b. Is the calculation limited to the energy used for the process only?

c. Is energy consumption from the transportation sector also included in the calculation?

d. Is there any type of energy excluded from the calculation?

The method for creating boundaries and scope can also refer to the method used to calculate Green House Gas (GHG). For example, if referring to the ISO 14064 standard on GHG inventories, then the definition of industry boundaries is:

"a grouping of activities or facilities over which an organisation exercises operational or financial control or has an ownership interest"

Organisational boundaries can be established based on two primary approaches: **the control approach and the ownership approach**. In the control approach, boundaries are determined by the degree of operational or financial control a company has over another entity. For example, in the case of cement factory that operates alongside a power plant, if the cement company controls the power plant financially—such as by purchasing its fuel—even though the plant operates independently, the power plant would still fall within the organisational boundaries of the paper company. However, if the power plant is not under the financial or operational control of the cement company, it would be excluded from the company's boundary, even if it is physically located on the same site and supplies energy.

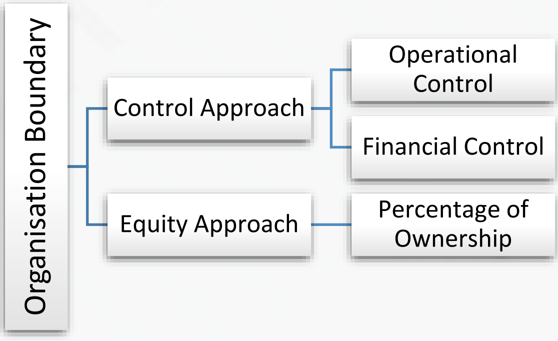


Figure 10. Organisation Boundary
Source: ACE, own analysis

In contrast, the ownership approach considers shareholding. Under this method, even if the cement company does not have operational control over the power plant, the power plant could still be included within the organisational boundary if the cement company owns shares in it. Thus, the approach chosen to define organisational boundaries significantly affects how various business entities are classified in relation to the primary company.

4.2 Seeking Reference Values for SEC in Cement Industry

The purpose of establishing a reference Specific Energy Consumption (SEC) value is to identify any significant deviations from the standard condition, which can be sourced from previous studies or international benchmarks, if available. Such deviations serve as an alert, indicating that something unusual is occurring and requires further investigation. These discrepancies could arise due to differences in scope definition or variations in energy calculation methods, which can lead to inconsistent or unfair comparisons among the entities being assessed.

Data on Specific Energy Consumption (SEC) from related industries can illustrate the various ways in which SEC is defined and calculated. Some industries determine SEC by summing the total energy consumed and dividing it by the total production output. In contrast, other industries break down SEC calculations by energy type, distinguishing between fuel energy and electrical energy. Additionally, certain sectors may calculate SEC based on specific products, highlighting that there are multiple methods to approach SEC calculation, depending on the industry's operational focus and energy use profile.

Sources regarding SEC values can be obtained from several sources, for example:

- Certification Green Industry from the Ministry of Industry or similar body
- Performance benchmarking energy Ministry of Environment and Forestry or similar body
- Results study issued by the Ministry of Energy and Mineral Resources, Ministry of Industry, universities, study centres, and others.
- Energy Audit Report

- Sources international; organisation international such as IEA, UNIDO, GCCA
- Study results from consulting agencies
- Study results from developed countries for example studies issued by the American DOE, American ASHRAE, Japanese ECCJ, RET Screen from Canada, etc

Reference values to be used are:

Parameters	Values	Source and Year
Global Average SEC Thermal	3.6 GJ/t clinker	IEA, 2022 [41]
Global Average SEC Electricity	100 kWh/t cement	IEA, 2022 [41]
Best-Available-Technology SEC Thermal	2.9 GJ/t clinker	LBNL, 2008 [24]
Best-Available-Technology SEC Electricity	59 kWh/t cement	LBNL, 2008 [24]
Global Average Clinker-to-Cement Ratio	0.76	GCCA, 2022 [42]

4.3 Defining and Quantifying Energy Flows

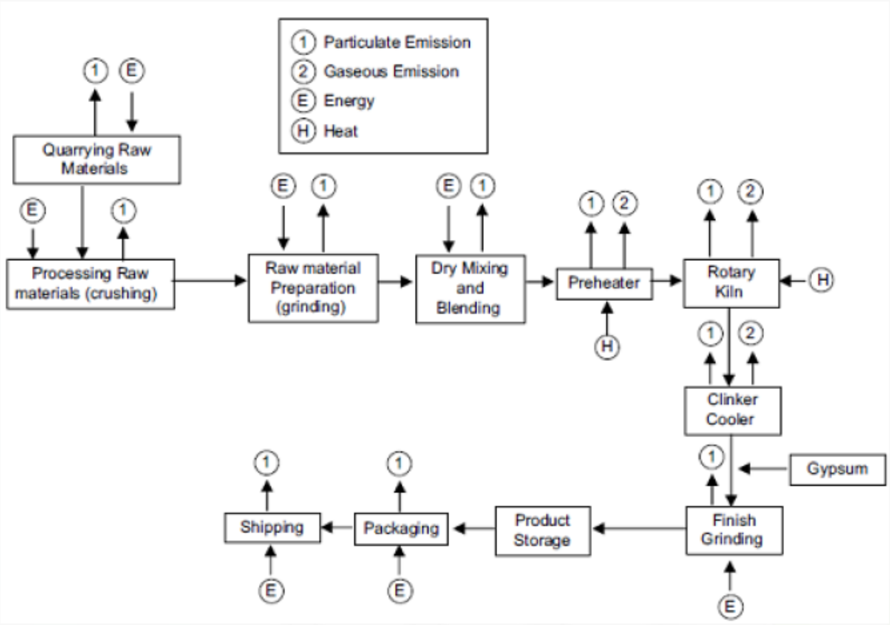


Figure 11. Process and Energy Flow of Cement Production [43]

At this stage, several key tasks must be undertaken:

- **Identify the types of energy** used by the industry within the defined operational scope. This step involves determining all forms of energy input, such as electricity, fuel (e.g., coal, oil, or natural gas), and alternative energy sources, to understand the overall energy profile.
- **Map energy usage across each stage** of the main processes within the industry's scope. This process starts by creating a basic block diagram that visually represents the flow of energy and materials. The diagram should outline

each stage, from raw material input to the final output, highlighting the points where energy is consumed in significant amounts.

- **Measure or estimate energy consumption** at each key process stage. After identifying where energy is used, it is necessary to calculate or approximate the amount of energy consumed at each stage. This may involve direct measurement through meters or using industry-standard methods to estimate energy usage based on process parameters

4.4 Understanding the Main Processes

In the cement industry, understanding the energy consumption and intensity of various processes requires close examination of key operations beyond just the kiln and raw mill. Several factors can lead to significant variations in Specific Energy Consumption (SEC) and necessitate special attention:

- **Clinker Cooling Efficiency**: The clinker cooler is an integral part of the cement production process, playing a major role in energy recovery. Inefficiencies here can lead to higher SEC values. For example, if the air used to cool the clinker is not efficiently recycled back into the kiln system as secondary or tertiary air, much of the potential thermal energy is lost. Additionally, poorly managed clinker cooling can result in excessively high exit temperatures, requiring more energy to cool further down the process line.
- **Preheater and Pre-calciner Performance**: Preheaters and pre-calciners are crucial to reducing energy consumption in modern cement plants. The number of cyclone stages and their operational efficiency are directly related to the thermal energy required for clinkering. If these systems are not functioning optimally, more fuel is required in the kiln, increasing SEC. For instance, if the preheater is operating at a lower efficiency or a blockage occurs, the raw material may not reach the required temperature, leading to incomplete calcination and the need for additional energy input in the kiln.
- **Waste Heat Recovery Systems:** In plants equipped with waste heat recovery (WHR) systems, any disruption in the system can lead to a sharp increase in energy consumption. WHR systems capture excess heat from the kiln and other processes and convert it into electrical energy, reducing the overall energy footprint of the plant. A malfunction or underperformance in this system can raise both thermal and electrical energy consumption.
- **Energy Intensity in Grinding Mills**: The efficiency of grinding processes—both for raw materials and finished cement—can have a significant impact on energy consumption. Mills that are not properly maintained or operated may use more energy per ton of material ground. For example, if the grinding media or liner wear is not monitored, the mill’s efficiency can drop, requiring more electrical energy to achieve the same level of fineness. This affects not only the SEC for cement production but also the overall energy intensity of the plant.
- **Alternative Fuels and Their Impact on SEC**: Plants that use alternative fuels such as biomass, industrial waste, or refuse-derived fuel (RDF) can see

fluctuations in SEC. While these fuels are often less expensive and environmentally friendlier, they can have variable calorific values and combustion properties, which may lead to inefficiencies in energy use if not properly managed. For example, a fuel with a lower calorific value may require more input to achieve the same energy output as traditional coal, increasing the overall SEC.

In the cement industry, the energy profile of a plant can be significantly influenced by whether the clinker used in production is produced onsite or purchased externally. Clinker production is the most energy-intensive part of the cement manufacturing process, with most of the thermal energy consumed in the kiln during the clinkering phase. Plants that produce their own clinker generally have higher energy consumption and a more complex energy profile due to the need to fuel kilns and manage the heat recovery systems.

Own-produced clinker: When a cement plant produces its own clinker, the energy demand is higher due to the kiln operation, which typically consumes significant amounts of coal, natural gas, or alternative fuels. The energy used in this process directly impacts the plant's Specific Energy Consumption (SEC). Moreover, the heat generated during clinker production can be partially recovered through waste heat recovery systems, helping to mitigate some of the energy costs. This results in higher thermal energy consumption but offers more control over the production process, which can lead to better energy management and efficiency improvements over time.

Purchased clinker: On the other hand, a cement plant that relies on purchased clinker bypasses the most energy-intensive phase of production, reducing its overall thermal energy consumption significantly. However, while the SEC related to clinker production is eliminated, the plant may still experience substantial energy use in the grinding process when converting clinker into cement. Additionally, plants using purchased clinker may face variability in the quality and composition of the material, potentially affecting the energy required for grinding and blending operations. This approach can make it easier to manage energy costs, but it limits opportunities to optimize the entire production process since the key energy-consuming phase is outsourced.

Plants that use both own-produced and purchased clinker need to carefully track energy consumption across different stages of production. This often requires separate monitoring of SEC for clinker production, grinding, and blending operations. Additionally, companies may need to account for the energy used in transporting purchased clinker, which may indirectly increase their overall energy footprint.

4.5 Identifying Significant Energy Use (SEU)

Significant Energy Users (SEU) refer to the specific processes, equipment, or systems within an industry that consume a considerable portion of the total energy used. Identifying SEUs is essential because it allows companies to focus on areas where energy-saving measures will have the most substantial impact. By targeting these high-energy consumption areas, industries can develop more effective energy management strategies, optimize processes, reduce costs, and lower their overall carbon footprint. SEUs are often the primary contributors to energy inefficiency, making them key areas for improvement to achieve better energy performance and sustainability goals. Commonly, SEUs can be categorized in several ways:

- **Significant users of overall energy consumption**: This includes the total energy consumed by the plant across all energy types. This is typically measured in Gigajoules (GJ) or Tons of Oil Equivalent (TOE).

  Example: A petrochemical plant may consume 1,753,469 GJ of natural gas and electricity annually, equivalent to 41,898.9 TOE. Mapping energy usage to specific operations or processes can help highlight significant energy users within the plant.

- **Significant energy users by primary energy type**: This involves grouping SEUs based on the type of energy they consume, such as thermal energy or electrical energy.

  Example: An ammonia plant might consume both thermal and electrical energy, with some plants generating electrical power through an in-house thermal plant. Understanding these energy flows helps identify which operations contribute most to energy consumption.

- **Significant users of secondary energy**: This refers to energy that has been converted from primary sources, such as steam, chilled water, or compressed air.

  Example: A large fertilizer plant may have significant steam consumption, categorised by steam pressure. This can help identify which processes or equipment are the largest consumers of steam within the plant.

Industries can gain insights into the main factors affecting their SEC and develop targeted energy efficiency strategies by mapping energy use across these categories,

4.6 Collecting Energy Consumption and Production Data

The required frequency and scope of data collection for calculating Specific Energy Consumption (SEC) will vary depending on the chosen organisational boundaries. At the organisational level, the data should encompass at least one complete business cycle, typically a fiscal year, to adequately capture fluctuations in production and energy use. Generally, the fiscal year runs from January to December, offering a comprehensive picture of operational highs and lows throughout the year.

However, to obtain more accurate SEC calculations at the company level, it is recommended to use **a minimum of two years of historical data for several key reasons**:

- **Operational Anomalies**: During any given year, non-routine events, such as major equipment failures, can occur. These events often disrupt the production process and skew SEC values, producing figures that are far from the average. Analysing data over a longer period helps to identify and mitigate the effects of such anomalies.
- **Data Quality**: In cases where the data quality for a particular year is compromised—due to operational abnormalities or inconsistencies in energy reporting—it is possible to shift the analysis to another year. This ensures more reliable and representative conditions for SEC evaluation.
- **Verification with Data Providers**: It is essential to cross-check the energy consumption data, often recorded by the finance department, with actual operational activities. In some cases, the energy usage recorded for a given month may reflect bills from the previous month, leading to inaccuracies in energy consumption reporting. Verifying this can ensure that the SEC figures align correctly with the corresponding production activities.

By considering these factors, companies can ensure that their SEC calculations reflect accurate and representative energy usage patterns, leading to more informed decision-making and improved energy management strategies.

4.7 Reviewing and Cleaning Data

After gathering the necessary data and performing basic calculations, such as averages and energy consumption ratios per production unit, preliminary insights can be drawn to better understand the Specific Energy Consumption (SEC) within the defined scope of the industry. However, anomalies often arise, reflected in data that deviate significantly from industry standards or historical practices—these are referred to as outliers. To address such deviations, it is crucial to already have a reference SEC value based on industry standards or past performance. At this stage, identifying the causes of these outliers is essential. In the next step, adjustments must be made, either by eliminating or modifying these abnormal data points to ensure they represent typical operating conditions.

Table 5. Example of Hypothetical Anomalies

Month	Electricity (MWh)	Cement (tons)	SEC (kWh/ton)	Raw Mill product (ton)	Clinker (ton)
Jan	790.81	35,245.37	22.44	3,000.00	1,739.68
Feb	4,235.50	30,856.27	137.27	86,187.00	49,089.57

Month	Electricity (MWh)	Cement (tons)	SEC (kWh/ton)	Raw Mill product (ton)	Clinker (ton)
Mar	422.74	38,096.92	11.10	0.00	0.00
Apr	7,698.00	66,119.87	116.42	175,193.00	101,180.10
May	7,913.84	63,054.95	125.51	181,957.00	100,459.87
Jun	7,850.47	41,899.48	187.36	170,546.00	97,423.60
Jul	8,156.80	66,166.87	123.28	184,771.00	107,026.70
Aug	8,030.35	68,975.05	116.42	177,992.00	108,644.60
Sep	7,037.79	56,678.01	124.17	175,320.00	84,580.58
Oct	7,475.89	69,223.99	108.00	191,204.00	88,003.54
Nov	7,896.51	62,982.81	125.38	203,841.00	94,974.60
Dec	5,665.92	60,222.82	94.08	123,798.00	64,601.30

Source: ACE, own analysis

For example, in a cement plant's Unit 1, preliminary SEC calculations were conducted based on electricity and cement production data, displayed in the table. **Outliers, highlighted in orange**, deviate from the expected range of 90–120 kWh/ton, according to international best practice benchmarks. Upon analysis, the outliers can be explained by production irregularities. In January and March, clinker production was significantly lower or even non-existent, resulting in lower energy consumption.

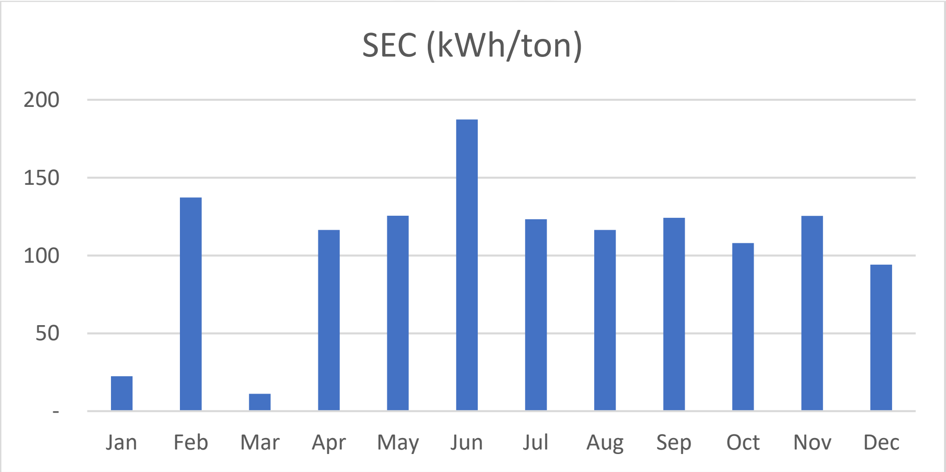


Figure 12. Example of SEC Electricity Monthly
Source: ACE, own analysis

The fluctuation in electricity SEC, measured in kWh/ton of cement, is evident in the chart where Unit 1's SEC ranged from 11 to 187 kWh/ton. By analysing additional data, including raw mill, clinker, and cement production, it becomes clear that these fluctuations are tied to operational issues. For instance, during January and March, the raw meal was nearly inactive, leading to a drop in electricity consumption since the raw mill is a major consumer of electrical energy.

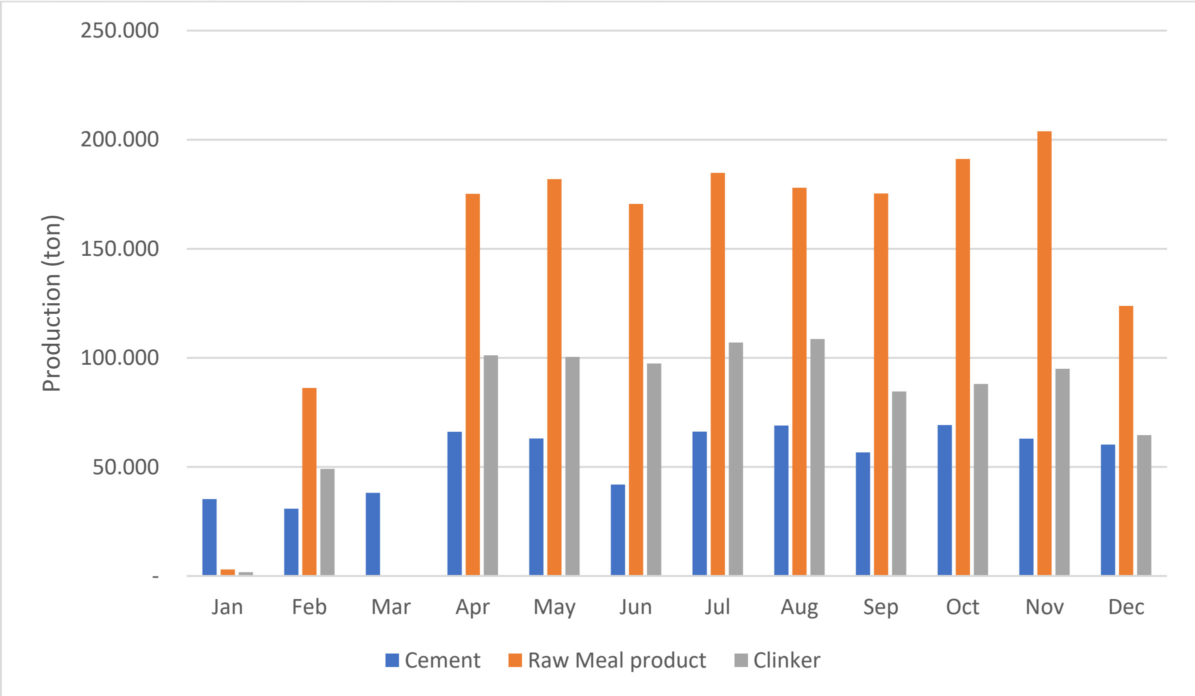


Figure 13. Example of Unit 1 Production Data
Source: ACE, own analysis

Furthermore, **Unit 1 continued to produce cement despite low clinker output, indicating that clinker was either purchased or sourced from Unit 2 or external source**. The production data support this, showing that Unit 1's clinker output was sent to Unit 2 for cement milling. This explains the spike in energy consumption during periods of high clinker production but low cement production. For example, in June, while clinker production remained high, cement production decreased, pushing the SEC value up to 187 kWh/ton of cement due to the disproportionate relationship between electricity use and cement production.

Conversely, in December, clinker and cement production were balanced, leading to a drop in SEC to 94 kWh/ton, a value aligned with industry standards for similar technology and production capacities. This example illustrates the impact that production imbalances have on SEC figures.

To resolve these discrepancies, the following steps can be taken:

- Exclude months with outliers from the analysis.
- Extend the analysis period to cover a full 12 months by including data from subsequent months to compensate for missing or anomalous periods.

- Adjust the outlier data, for example, by replacing abnormal figures with the yearly average SEC value, which in this case is 118.95 kWh/ton of cement.
- Another option could involve recalculating based on "**equivalent products**" to account for inconsistencies in production data.

4.8 Performing Analysis

4.8.1 Energy Performance

According to ISO 50003:2023 (Energy management systems - Evaluating energy performance using energy performance indicators and energy baselines), certain terminologies are necessary to measure energy performance, including Energy Performance Indicator (EnPI), Energy Performance Indicator Value (EnPI Value), Energy Baseline (EnB), and Energy Target.

EnPI is a metric used to **quantify energy performance**. When EnPI is applied to demonstrate improvements in energy performance, it reflects the energy efficiency or energy consumption. The EnPI is determined by the company based on its operational conditions, and different companies in the same sector may have varying EnPIs. Therefore, the development method of EnPIs should be documented and reported for benchmarking purposes. In relation to EnPI, the numerical representation of its quantification over time is called the **EnPI value**.

EnB serves as a **quantitative benchmark for energy performance** and acts as a **reference point to help the cement industry track improvements** in **energy performance over time**. To establish EnB, data from a specified historical period must be collected, considering both energy consumption and relevant variable data. A relevant variable is defined as a measurable factor that significantly affects energy consumption.

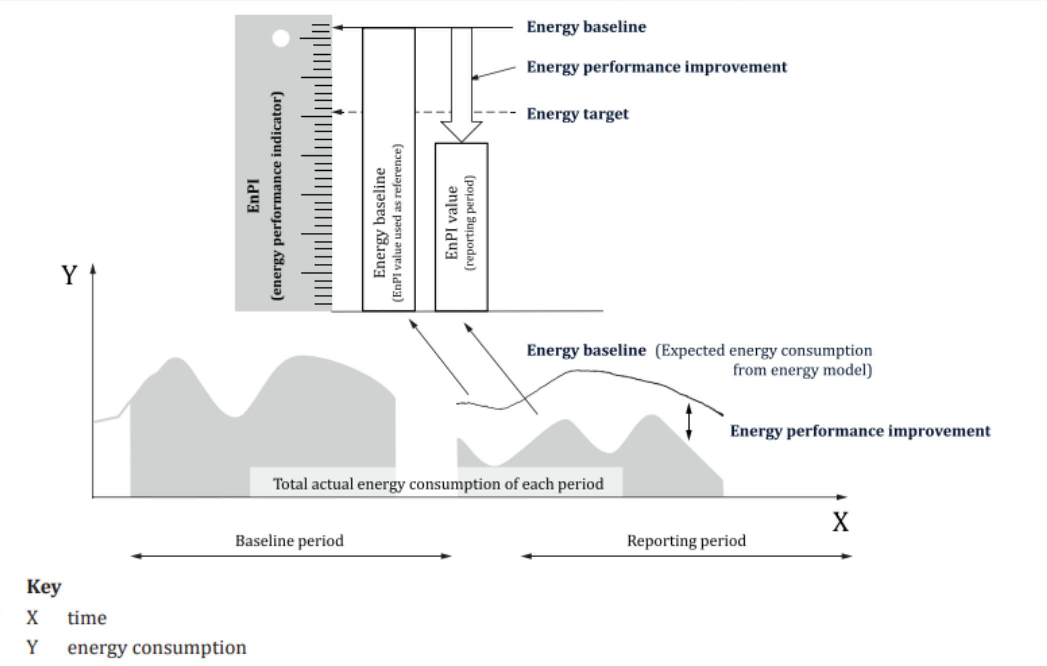


Figure 14. EnPI and EnB according to ISO 50003

In the cement industry, one key objective is to achieve energy improvement targets. To set these targets, both EnPI and EnB must be developed, monitored, and measured. Failing to develop the appropriate EnPI and EnB may lead to misinterpretation of energy target achievement. Energy performance improvement is assessed by **comparing the EnPI value against the corresponding EnB**.

4.8.1.1 Energy Performance Indicator (EnPI)

When developing an EnPI, the cement industry must identify the user for each EnPI. The EnPI should reflect the specific needs of the user and align with their expectations regarding performance outcomes. The table below outlines the different types of users and the considerations for their needs during the development of the EnPI.

Table 6. EnPI Users

Types of EnPI users	Typical needs
Top management	Top management needs information from EnPIs to understand the energy performance of the organisation and to support energy performance improvement actions.
Energy management team	Group who supports the organisation, including top management in: a) setting up an EnPI, b) maintaining an EnPI, c) monitoring EnBs, current EnPI values, values of all relevant variables in predetermined intervals, d) setting energy targets and calculating extent of achievement of energy target, e) conducting normalisation and comparison of current EnPI values with EnBs and energy target, f) reporting of EnPI values and deviations, and g) interpreting the results.
Plant or facility management	Typically controls resources within the plant or facility and is responsible for results. The plant or facility manager should understand both planned energy performance and investigate and respond to significant deviations in energy performance and in financial terms. Plant or facility managers may use all of the EnPIs in their plant or facility including the EnPIs regarding their SEUs, and comparable EnPIs from other sites for benchmarking purposes.
Operation and maintenance personnel	Responsible for using EnPIs to control and ensure efficient operation by taking actions for significant deviations in energy performance, eliminating energy waste and undertaking preventive maintenance. Operation and maintenance personnel may use the EnPIs relevant to the process or equipment for which they have responsibility.
Engineers	Plan, execute and evaluate an energy performance improvement action using suitable EnPIs including the method(s) used to evaluate energy performance improvement.
External users	External users such as regulatory bodies, professional and sector associations, EnMS auditors, customers or other organisations can need information from EnPIs to feed into their relevant processes.
EnPI owner	Person who is responsible for monitoring, analysing and reporting an EnPI and its values.

Source: ISO 50006:2023

To effectively measure, monitor, analyse, and evaluate energy performance, it is crucial to identify the most inefficient component of the production system. This step is essential for demonstrating improvements in energy performance. By defining an EnPI boundary, focus can be directed efficiently on the identified section. Initially, the EnPI boundary encompasses the entire organisation. In such cases, the target boundary should be subdivided into several EnPI boundaries. In the following steps, these boundaries should be narrowed to the SEU level to pinpoint areas where energy performance can be enhanced.

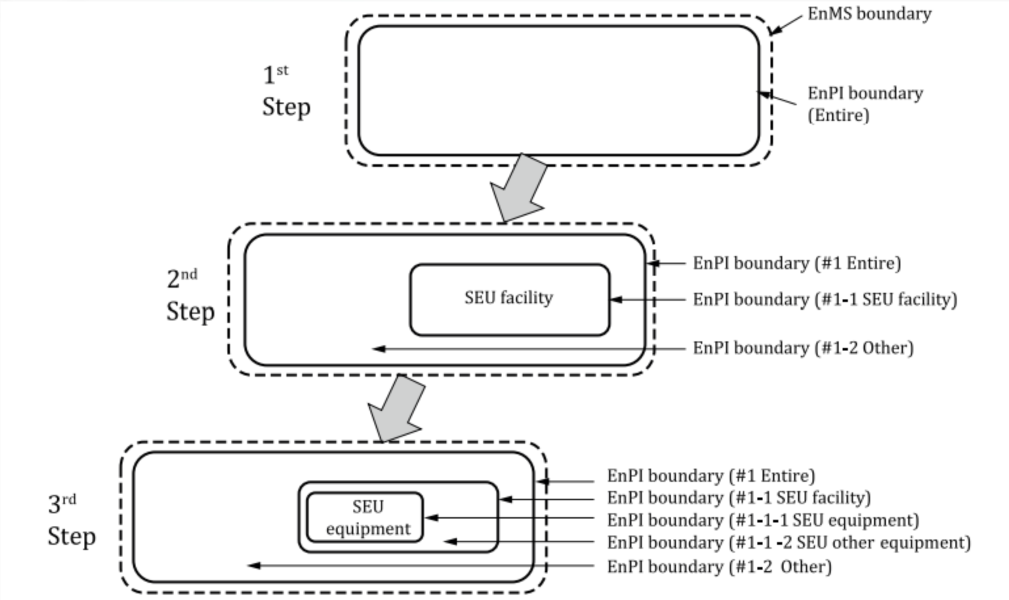


Figure 15. EnPI Boundaries Division
Source: ISO 50006:2023

When dividing the EnPI boundaries, organizations should consider that:

- the number of divisions should be minimised
- it is recommended that the boundary is first divided into two parts such as SEU and other
- facilities that work in the same way should be categorised together
- the facility can be **divided on the basis of process** (e.g. process for product X, process for product Y and utilities)
- the EnBs can be established for each operational status of the EnPI boundary
- as a minimum, it is recommended that organisations establish at least two EnB operational status conditions: **under production conditions, and under non-production conditions**

4.8.1.2 Energy Baseline (EnB)

Energy performance is assessed through comparisons with the EnB, which helps track energy performance and demonstrate improvements. To create an EnB, the following steps should be taken:

- Define the specific purpose for which the EnB will be used.
- Select an appropriate data period.
- Gather the necessary data.

- Analyse the data to develop a normalisation method (if applicable).
- Determine and evaluate the EnB

The organisation should select an appropriate time frame for the EnBs based on its energy goals, targets, and the nature of its operations**. The baseline period must be long enough to ensure that the EnPI and EnB account for factors like production seasonality, weather patterns, and other variables that impact operating patterns**. The frequency at which data is collected can influence the determination of an appropriate baseline period. If an organisation aims to track EnPIs on a daily basis, daily data will be required for the EnB, even if the baseline period spans one year. In this case, the EnB should be configured to include daily data for the entire year.

Table 7. Baseline Period EnPI

Typical Periods	Description
One year	The most common baseline where it can capture a full range of weather conditions or business cycles
Less than one year	A shorter period may be used where energy consumption is seasonal (e.g. a vegetable canning factory, ski resort). Short EnB durations can also be necessary for situations in which there is an insufficient quantity of reliable, appropriate or available historical data.
More than one year	Seasonality business trends can combine to make a multi-year EnB optimal (e.g. a company wants to track energy performance during a specific period, over multiple years)

Source: ISO 50006:2023

4.8.2 SEC Calculation

When calculating Specific Energy Consumption (SEC), several important considerations must be made to ensure accuracy:

1. **Avoid Double Counting Energy Consumption**: Double counting occurs when the same energy is recorded more than once, leading to inflated energy consumption totals. Common pitfalls include:
    - When multiple energy meters or readings are taken at various points, care must be taken to avoid summing the same energy use multiple times. To mitigate this, it's essential to first create a single-line diagram of the energy flow. This could be a diagram of the electricity system, compressed air, steam, or chilled water flow, providing a clear visual of the energy inputs and consumption points.
    - In cases where a facility both generates its own electricity (e.g., from an onsite power plant) and purchases electricity (e.g., from a grid provider), care must be taken not to add these values together indiscriminately. For example, if coal is used to generate electricity, the energy from the coal and the electricity produced from the coal should not both be included in the total

energy consumption. Instead, only the coal energy and purchased electricity should be considered.

- Similarly, when a plant uses steam generated from a Waste Heat Boiler (WHB), the energy from waste heat should not be included in the total energy consumption, as it is derived from the waste heat of processes such as chemical reactions or fuel combustion. Only externally sourced steam should be counted to avoid double counting.

2. **Accurate Product Determination and Quantification:** Caution is necessary when defining and quantifying products, especially when an industry produces multiple types of products. Some challenges include:
   - In a garment industry with diverse clothing products, deciding the appropriate SEC unit (e.g., GJ per piece or GJ per kilogram) can be difficult. Similarly, in a cement industry that sells both clinker (an intermediate product) and cement (the final product), the SEC can be calculated in several ways, such as kWh/ton of cement or GJ/ton of clinker, depending on the scope and focus.
   - For industries with multiple plants and products, like the chemical industry, SEC might be determined per plant and per product or as a total across the operation. Each approach provides different insights into energy efficiency.
   - In industries like food and beverage, with many product types, determining whether to set SEC based on individual products or on the total weight of all products produced is crucial for accurate energy reporting.

For example, an oleochemical plant consumes natural gas and electricity, producing four types of products: Fatty Acid, Glycerine, Dove, and soap. The plant's average SEC is 3.11 GJ/ton, but the SEC increased to 3.7 GJ/ton in December due to reduced production levels. In this case, the SEC calculation includes all products combined. In contrast, another oleochemical plant consumes coal and electricity and produces Fatty Acid, Fatty Alcohol, and Glycerine, with an average SEC of 15.2 GJ/ton. Even though both plants produce similar products (Fatty Acid and Glycerine), differences in the remaining products mean their SEC values cannot be directly compared.

Sample case:

A cement plant produces clinkers and cement. It is well known that cement plants not only sell cement as their final product, but also sometimes sell clinkers as an intermediate product. The electrical energy performance of the cement plant is expressed in kWh/ton of cement. The SEC of this plant is shown as follows:

Table 8. Sample Case Cement Production

Month	Cement (tons)	Electricity (kWh)	SEC (kWh/ton)
Jan	354	28,325,210	80,020
Feb	379	30,288,460	80,020
Mar	386	30,903,390	80,020
Apr	402	32,146,420	80,020

Month	Cement (tons)	Electricity (kWh)	SEC (kWh/ton)
May	339	27,141,210	80,020
Jun	296	23,648,120	80,020
Jul	351	28,090,590	80,020
Aug	423	33,859,700	80,020
Sep	396	31,672,070	80,020
Oct	410	32,810,630	80,020
Nov	380	30,420,960	80,020
Dec	394	31,566,370	80,020

Source: ACE, own analysis

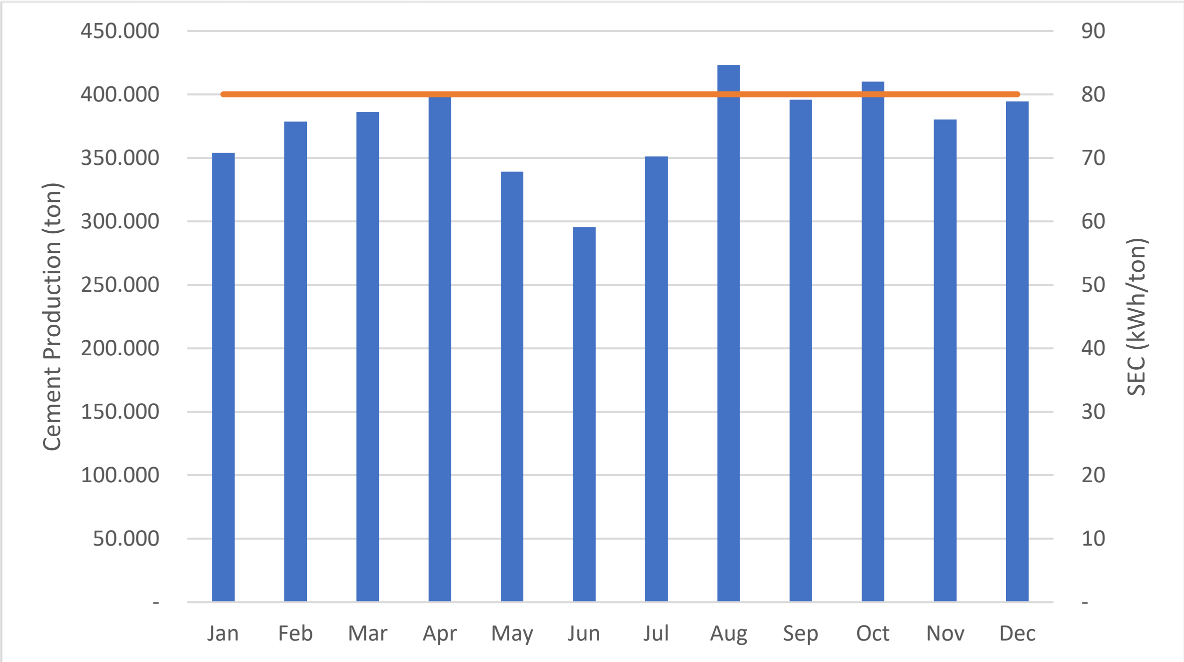


Figure 16. Sample Case Cement Production and SEC
Source: ACE, own analysis

From the graph, it can be seen that the SEC electricity figure of this factory is constant at 80 kWh/ton of cement, this is an unusual phenomenon, because theoretically and practically SEC will change at any time, because the level of production and electricity consumption changes. The answer to this anomaly is that it seems that this cement factory sells some of its clinker, so that its cement production will decrease which results in an increase in the SEC value. What the factory does is set its SEC value at 80 kWh/ton, then this figure is used to calculate its production. So that the cement production figure is the result of calculations, not the actual production figure. The cement product figures from calculations like this is known as **cement equivalent**. This method is unacceptable because it gives the impression of cheating, because the cement factory could set the SEC as low as possible according to its needs.

4.9 Finding Explanations for Any Anomalies

Abnormal SEC values refer to the following scenarios:

- **Extreme fluctuations in SEC values**: When SEC figures show extreme variation over a short period. For example, a sudden spike in SEC from a Mill facility during the second month, which deviates significantly from the previous months, would be considered abnormal.
- **Positive SEC trend relative to production**: A positive relationship between SEC and production levels is unusual and should be examined. In theory, as production increases, the SEC should decrease due to economies of scale, meaning energy use per unit should drop. A positive trend would be contrary to this, suggesting inefficiencies in the system.
- **Constant SEC over an extended period**: A stable SEC value that shows little to no variation over a long time can also be a red flag. This could indicate a lack of accurate data collection or reporting issues, as minor fluctuations are expected due to changes in production rates, energy input, or equipment performance.
- **Unusual SEC values:** Any SEC figure that does not align with expected industry standards should be considered abnormal. The best way to determine whether the SEC values of a factory or system fall within a normal range is by comparing them to publicly available benchmarks. These may include SEC figures published by research institutions, standardisation bodies, or assessment frameworks such from Ministry of Industry, Ministry of Energy, as well as local and international consulting firms.

4.10 Making Adjustments

The term adjustment in this context refers to the following actions:

- **Data cleaning**: This involves removing or correcting data points that deviate significantly from the average to ensure accurate analysis and representation of energy use.
- **Defining the product**: Establishing whether the analysis will focus on the total product output, the final product, or intermediate products, as this impacts how energy consumption is measured and compared.
- **Categorising energy types**: Deciding whether energy will be grouped and analysed by type (e.g., electricity, thermal) or if the total energy consumption will be calculated as a single figure, ensuring consistency in energy reporting.

5 GUIDELINE TO PERFORM ENERGY BENCHMARKING

Energy benchmarking is a tool used in the cement industry to measure and compare energy performance across plants, processes, or equipment. By establishing a reference point and identifying energy consumption patterns, benchmarking allows companies to assess their energy efficiency and develop strategies for improvement. This systematic approach highlights areas where energy use is higher than necessary, identifies best practices, and encourages the adoption of more efficient technologies and processes. Benchmarking provides not only a performance evaluation but also helps organisations meet regulatory requirements, enhance their sustainability efforts, and reduce operational costs.

Energy benchmarking in the cement industry can reveal significant variations in Specific Energy Consumption (SEC), which is a critical metric given the industry's high energy intensity. Cement production is one of the most energy-consuming processes globally, accounting for approximately 7-8% of global CO_2 emissions due to its reliance on thermal energy in the kiln processes. Establishing energy benchmarks enables companies to track improvements over time, compare performance with peers, and align their operations with global sustainability goals.

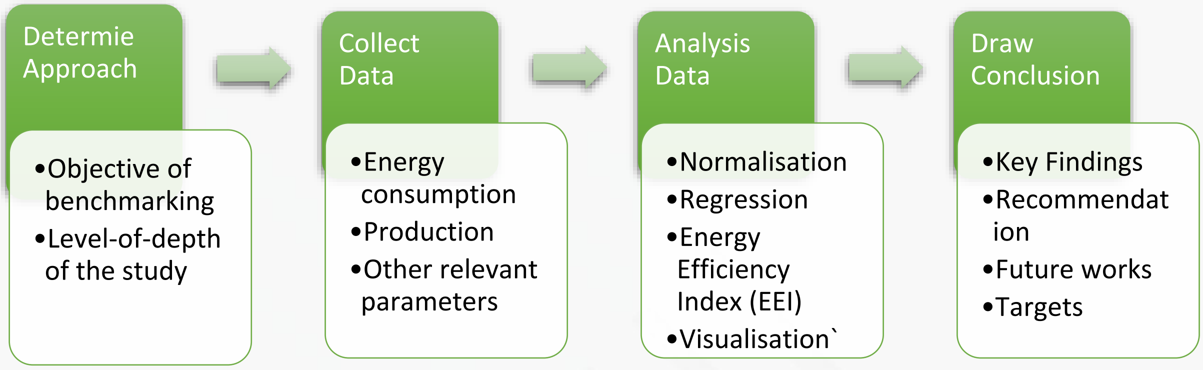


Figure 17. Flowchart of Benchmarking Energy Performance
Source: ACE, own analysis

5.1 Benchmarking Approach

The benchmarking approach **depends on the availability of data and the objectives of the study**. Different levels of benchmarking provide insights into the company's energy performance, from broad organisational assessments to detailed evaluations of specific processes or equipment.

ISO 50001 and ISO 50006: ISO 50001 is the international standard for energy management systems, promoting energy efficiency improvements in a structured manner. ISO 50006 supports the process by providing guidance on energy performance indicators (EnPIs) and baseline establishment for organisations.

Benchmarking Levels:

- **Level 1 (Company-level Benchmarking / Basic Energy Review)**: This level compares **overall energy consumption** and efficiency metrics across different plants within the same company or with different companies. The goal is to identify which facilities are performing best and which need improvements.
- **Level 2 (Process Benchmarking / Intermediate energy assessment)**: Focuses on comparing **specific processes**, such as clinker production or grinding, across multiple plants. This helps to identify process inefficiencies and opportunities for optimisation. At this stage, companies begin to implement more detailed energy audits, including process and equipment analysis to identify energy efficiency improvement opportunities to identify inefficiencies in processes and prioritise interventions based on potential energy savings. Detailed measurements were carried out on components such as the kiln (furnace), preheater and cooler. Benchmarking is carried out by analysing the energy intensity per ton of cement produced and comparing it with industry averages at the national or regional level. At this stage, companies can also start adopting energy-saving technologies such as the use of alternative fuels or waste heat.
- **Level 3 (Equipment Benchmarking / Advanced Energy Optimisation)**: Targets individual pieces of equipment, such as kilns, coolers, or mills. This level of benchmarking provides the most granular data and can be used to assess whether specific equipment is underperforming and requires upgrades or better maintenance. At this level, the company has achieved a higher level of energy efficiency by optimising all production systems and processes to integrate advanced technology and sustainable energy management systems, such as automation, real-time monitoring, and predictive maintenance to prevent energy inefficiency. Benchmarking is carried out to achieve the best benchmark in its class, where cement companies' energy consumption is already at a very efficient level, in line with the best global standards. This often includes the use of renewable energy, cogeneration, and lower emissions management.

5.2 Data Collection

Accurate data collection is fundamental to energy benchmarking, as it forms the basis for comparing energy performance fairly across different plants or processes. It is essential to ensure that data is complete, consistent, and correctly categorised to avoid skewing results. Key data points that need to be collected include:

- **Energy consumption data**: This includes both thermal and electrical energy usage at various stages of production, including raw material grinding, clinker production, and cement grinding.
- **Production data**: To calculate SEC, detailed production data such as the amount of clinker, cement, and raw material produced over the benchmarking period is necessary. It is also important to separate production and energy consumption from own-produced clinker and purchased clinker.

- **Process flow and operational data**: Information on equipment run-times, maintenance schedules, and process disruptions should also be considered to contextualize energy usage data.
- **Energy inputs and outputs**: These include the types of energy used (coal, alternative fuels, electricity), energy generation methods (on-site power plants, external grid), and any waste heat recovery systems.

5.3 Analysis and Visualisation

The next step is to analyse the collected data to identify trends, anomalies, and performance gaps. Key elements of the analysis include:

5.3.1 Normalisation

Normalisation aims to adjust data to account for variations in production output, raw material quality, energy prices, and other relevant factors affecting energy profile. This ensures that comparisons are made on a fair basis, regardless of external factors.

SEC is a useful metric for understanding energy efficiency, but several factors can influence SEC values across different cement plants. Without normalisation, comparisons may not reflect the true energy performance of each plant. Normalising the data ensures that the differences in SEC are due to operational efficiency rather than external or uncontrollable factors. Factors that should be normalised:

- **Production Capacity Utilisation:**
  Plants may operate at different levels of capacity utilisation. A plant running below its optimal capacity will have a higher SEC due to the energy required to maintain base operations. Normalising for production capacity ensures that plants operating at different utilisation levels can be compared fairly.

- **Clinker-to-Cement Ratio:**
  The clinker production process is the most energy-intensive phase of cement manufacturing. The clinker-to-cement ratio varies across plants, and a higher ratio increases SEC. Plants that use more supplementary materials (such as fly ash or slag) will have lower SEC, not necessarily due to higher efficiency but because they produce less clinker. Normalising for this ratio provides a clearer view of energy efficiency across plants.

- **Fuel Mix:**
  Different cement plants use various fuel sources such as coal, natural gas, alternative fuels (e.g., biomass), or a mix of these. Plants using alternative fuels tend to have different energy intensities due to the varying energy content and combustion properties of these fuels. Normalising for the fuel mix helps ensure that plants using different energy sources can be compared on a level playing field.

- **Environmental Conditions:**
  Weather conditions and ambient temperatures can influence energy consumption, particularly in preheating and cooling stages. Plants in colder climates might use more energy for heating, while those in warmer climates might require additional energy for cooling processes. Normalising for environmental conditions allows plants in different locations to be compared fairly.

- **Raw Material Characteristics:**
  The quality and moisture content of raw materials (limestone, clay, etc.) can significantly affect energy consumption, particularly during the drying and preheating stages. Plants that process materials with higher moisture content or harder raw materials will consume more energy. Normalising for raw material quality ensures that variations in input materials do not unfairly skew SEC comparisons.

- **Plant Age and Technology:**
  Older plants may use less energy-efficient technology compared to newer facilities that have integrated modern, energy-saving equipment. While this factor is difficult to normalise directly, comparing plants of similar technology levels or adjusting based on plant age and upgrades may help create fairer comparisons.

Example 1:

We aim to compare the coal consumption for the thermal process in cement production. During the baseline period with the base year set to 2022, the coal had a calorific value of 5,000 kcal/kg. A cement company now wishes to analyse its coal consumption in December 2024, where the recorded coal consumption was 15,000 tons. According to the Certificate of Analysis (COA), the coal used in December 2024 had a calorific value of 4,500 kcal/kg.

In this case, we cannot directly use the recorded coal consumption as it is. Since the coal in December 2024 has a lower calorific value, it generates less energy per kilogram burned compared to the coal used in the baseline period. Therefore, we need to normalise the coal consumption to account for the difference in calorific value. This normalisation will allow us to compare the energy output accurately by adjusting for the lower energy content of the coal consumed in December 2024.

The normalisation could be performed as follows:

$$Coal\ consumption\ normalised = Actual\ coal\ consumption\ x\ \frac{Calorific\ Value\ Consumed}{Calorific\ Value\ Reference}$$

The normalised coal consumption = $15{,}000\ x\ \frac{4{,}500}{5000}$ = 13,500 ton of coal in December 2024

The normalised coal consumption for December 2024 is 13,500 tons, after adjusting for the lower calorific value of the coal used in that period. This adjustment indicates that, although the cement company recorded a coal consumption of 15,000 tons in December 2024, **the actual coal consumption, in terms of energy output, would have been lower if the coal used had the same calorific value as in the baseline year of 2022 (5,000 kcal/kg)**.

This normalisation reflects the difference in energy content between the two types of coal and provides a more accurate comparison of the coal consumption in terms of energy output.

5.3.2 Regression Analysis

Use regression models to understand the relationship between energy consumption and production output. This helps identify whether increased production leads to lower energy intensity, as expected, or if inefficiencies arise at higher outputs. Steps to perform regression:

- **Collect Data**: Gather data on energy consumption (e.g., in GJ or kWh) and potential influencing variables such as production output (in tons of clinker or cement), fuel mix, kiln operating hours, and properties of raw material (chemical composition, size, water content), and other relevant factors that may affect the energy profile of cement industry.
- **Select Regression Model**
  There are some methodologies can be used for analysing relationship between variables:
  1) Statistical Model: this may include one relevant variable linear regression ($Y = mx + C$) or multiple relevant variable linear regression ($Y = m_1x_1 + m_2x_2 + \ldots + m_nx_n + C$).
  2) Aggregated Model: this combines two different energy models based on different conditions, for example "operation condition" and "part-load condition", where it can't be treated as an outlier. It can be expressed in the following model
  $Y = f(x_1, x_2, \ldots, x_n)$; if $xi > N$
  $Y = g(x_1, x_2, \ldots, x_n)$; if $xi <= N$
  Where f is energy model when relevant variable is above a threshold N, and g is energy model when relevant variable is below the threshold N.
  3) Engineering Model: this model evaluates the relationship between variables with engineering principles to calculate energy performance. It uses detailed technical data like equipment specifications and thermodynamics principles.
- **Set up Variables and Data Cleaning**: Define the dependent variable, usually energy consumption or SEC as Y, and the independent variables such as production output, kiln efficiency, or the proportion of alternative fuels, and properties of raw materials as X. It is also important to remove outliers and missing values to improve the accuracy of analysis. Below is a sample case for single variable regression linear between energy consumption and cement production as a relevant independent variable.

Table 9. Hypothetical Figures of Cement Production and Electricity Consumption

Month	Cement Production (ton)	Electricity (kWh)	SEC (kWh/ton)
Jan	12,300	2,000,000	162.60
Feb	12,600	1,300,000	103.17
Mar	12,350	1,900,000	103.24
Apr	12,190	1,300,000	106.64
May	9,000	1,700,000	188.89
Jun	10,100	1,050,000	103.96
Jul	8,000	700,000	75.00
Aug	7,000	1,100,000	157.14
Sep	5,000	1,000,000	140.00
Oct	14,300	1,700,000	118.88
Nov	17,000	2,570,000	151.18
Dec	20,000	2,900,000	145.00

Source: ACE, own analysis

After plotting the cement production with the electricity consumption, a regression line can be formulated below:

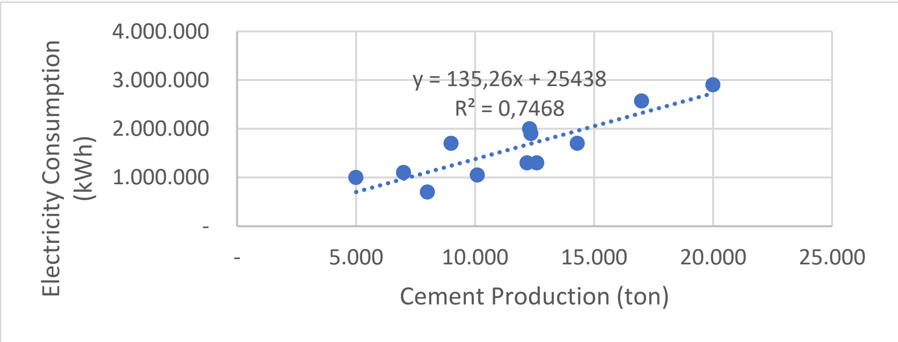


Figure 18. Single Variable Linear Regression
Source: ACE, own analysis

- **Evaluate the Model**: After running the regression, analyse the coefficients and significance levels to determine the relationship between production levels, fuel mix, and other factors with energy consumption. For example, if the production output has a negative coefficient, this means that increasing production leads to more efficient energy use (i.e., lower energy consumption per unit of production).

  Assess the **R^2 value** to see how well the regression model explains variations in energy consumption. If the **R^2 value is high (nearly 1)**, the model provides a good fit for the data. In the above case, Figure 18, it has R^2 0.7468. This means that 74.86% of variability in electricity consumption can be explained by the cement production. The rest is influenced by other factors such as clinker-to-cement ratio, machine efficiency, operational efficiency, and so forth. This shows a relatively strong relationship between cement production, as the predictor, with electricity consumption. However, there are some unexplained variances (25.14%) which are not captured by the model. To improve this, we could incorporate additional variables with more complex model.

Coefficient of Variation of Root-Mean Squared Error (CVRMSE) could be used to evaluate accuracy of predictive model in regression and its uncertainty. It assesses the deviation between predicted values and actual values in percentage. In the sample case above, the CVRMSE is 19.9%, which is considered reliable for energy modelling according to ASHRAE Guideline 14 (<20%) [44].

The other evaluation method is by employing **F-test** on the regression model. It is used to evaluate overall statistical significance of the model, whether the independent variables have significant impact on the dependent variables, by comparing two variances from actual values and regression model. If the result of **P-value < 0.05 significance level, the model is considered fit** as it rejects the null hypothesis. The model shows p-value 0.000288 < 0.05 which is statistically significant, where cement production impacts electricity consumption.

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3.59E+12	3.59E+12	29.49219	0.000288622
Residual	10	1.22E+12	1.22E+11		
Total	11	4.8E+12			

Figure 19. F-Test of the Sample Case
Source: ACE, own analysis

The other measure to ensure regression model stability is by checking multicollinearity of the model when two or more independent variables are highly correlated. This can be done by calculating **Variance Inflation Factor (VIF)** obtained from 1 / (1 – R^2). If **VIF > 5,** there is a moderate multicollinearity relationship between independent variables. In this case, redundant variables may need to be detected and removed from the regression model.

- **Interpret the Results**:
  - Energy Performance Indicator: **Y = 135.26x + 25,438**
  - Y is electricity consumption (kWh), and X is the cement production (ton)
  - All values are positive
  - **Baseload electricity consumption is 25,438 kWh**. This indicates the energy consumed where production of cement is zero

  This regression equation could be **established as the Energy Baseline (EnB) to monitor its efficiency improvement over time** or identify any anomalies in production (equipment malfunctions, downtime, production cycles, and other factors) that requires investigation.

- **Validate the result with experts**: Consult the result with the experts in operation or production of cement industry to justify whether the phenomena found in the analysis actually happen in cement industry. If some phenomenon is found to be misleading, we may refine the formulation of setting up the regression model.

5.3.3 Energy Efficiency Index (EEI)

This metric is useful to evaluate where a company stands compared to theoretical or average performance and among other similar plants in the region. The index is calculated to yield a score by dividing the SEC observed in a plant with SEC reference.

EEI = [SEC plant observed / SEC reference] x 100

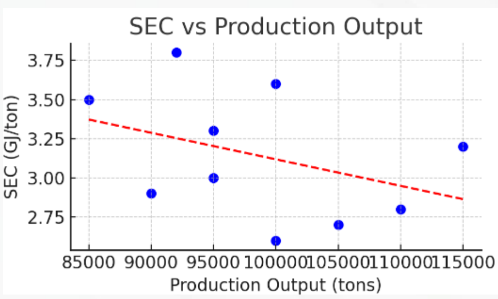
A lower EEI indicates better energy efficiency, suggesting that a facility is utilising less energy to produce the same amount of cement compared to its competitors. In contrast, an EEI exceeding 100 implies that the plant operates in a less efficient manner than standard normal operating condition, necessitating greater energy consumption than typical cement plant.

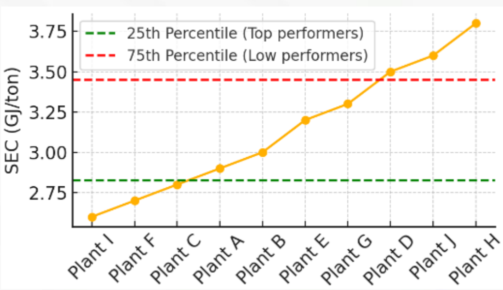
For this calculation, an SEC reference shall be set in the first place. This value can be obtained from a normal common practice in cement production worldwide as explained in section 4.2. This SEC reference is given an EEI value of 100, acting as the baseline.

This method can be performed in overall energy consumption and in each process to understand different energy efficiency potential that we can capture.

5.3.4 Visualisation Methods

A good visualisation is essential to transform complex numerical datasets into easily interpretable visual formats. Given the industry's high energy intensity and the significant variation in energy performance between plants, visual representations such as charts, graphs, and curve are useful for identifying patterns, trends, and outliers. Effective visualisation allows decision-makers to quickly assess how plants perform in terms of Specific Energy Consumption (SEC), compare the efficiency of processes, and pinpoint areas for improvement. Below are some methods of visualisation that can be utilised in illustrating the result.





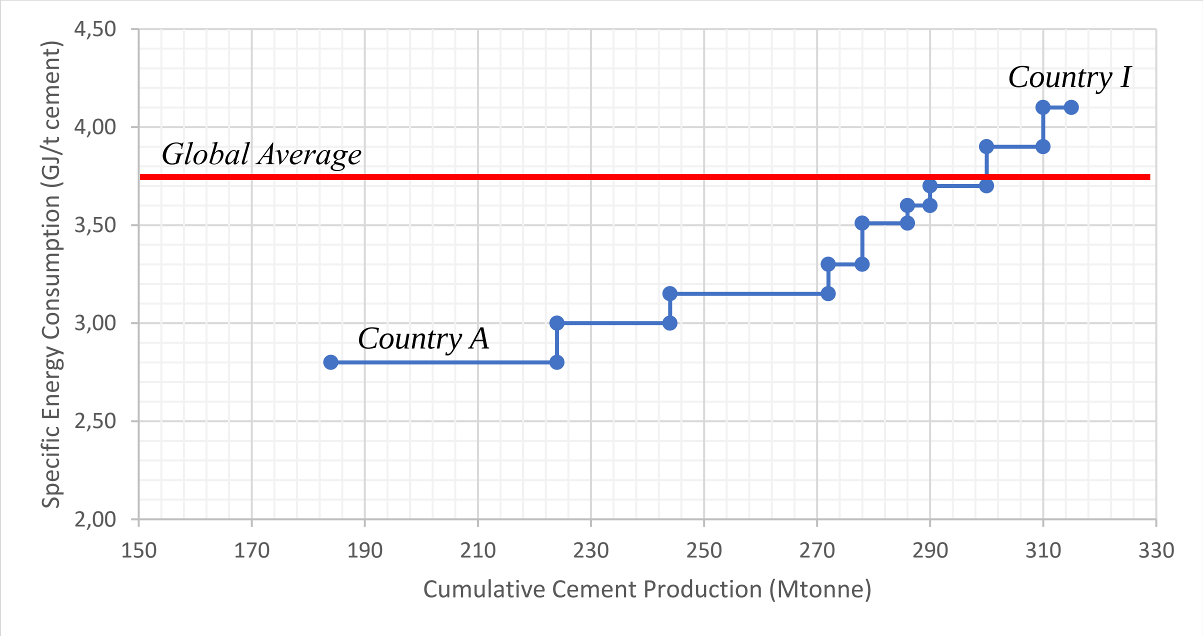


Figure 20. Example of Benchmarking Visualisations
Source: ACE, own analysis with reference to UNIDO [45]

By adopting reference from Global Energy Efficiency Benchmarking Working Paper (2010), in the Figure 20, a line graph is drawn, starting from the most efficient entity with the lowest Specific Energy Consumption along with X-axis to indicate the production from each entity. For example, Country A is the most efficient with SEC around 2.7 GJ/t and produces around 40 million ton annually. Meanwhile, Country I is the least efficient with SEC above 4 GJ/t and it produces less than 10 million ton per year. The indicative graph and numbers above show that more production leads to more efficient operation.

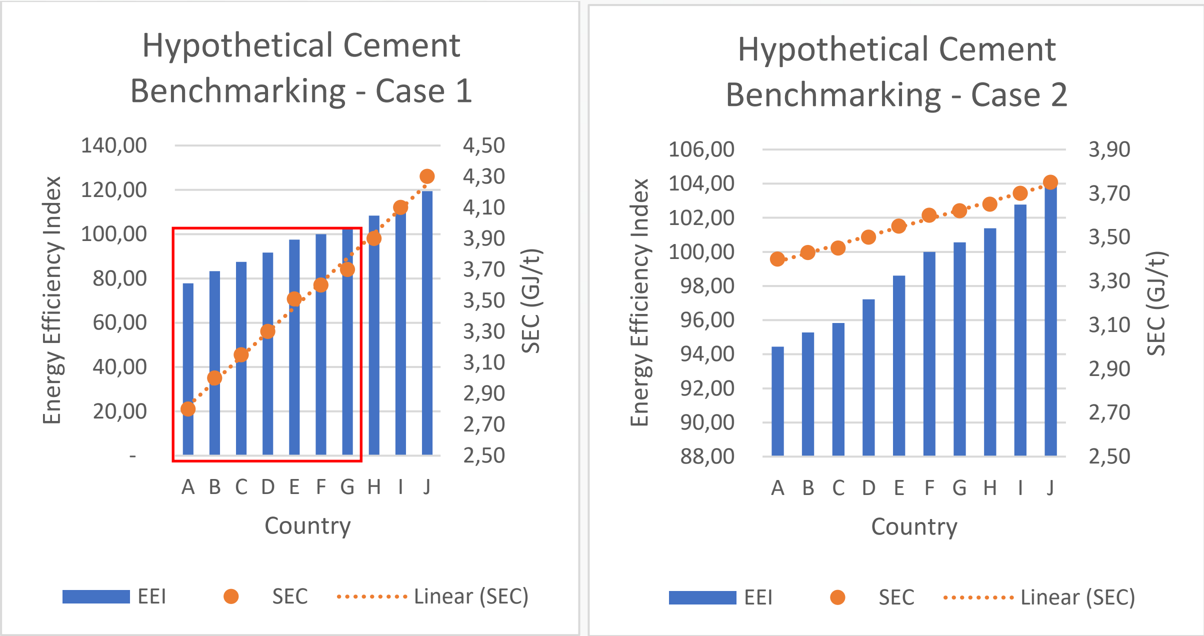


Figure 21. Hypothetical Benchmarking Cement EEI
Source: ACE, own analysis with reference to UNIDO [45]

Two graphs shown above aim to illustrate some hypothetical results of cement benchmarking. In case one, the top performer country A has EEI 80, meaning that it is 20% more efficient than normal practice. Moreover, there is a **considerable gap between top performer and low performer shown by steeper SEC line**, **indicating that there are plenty of low-cost and proven measures that could be implemented** to narrow the gap.

Conversely, in case two on the right side, the most efficient country has EEI 94, signifying that it is only slightly better than global average. This case also shows that all countries have **fairly comparable performance, highlighting that the industry's technology is established and requires a significant upgrade and a breakthrough in innovation**.

The graph can be made more detail to differentiate between thermal and electricity SEC. We may also explore other ways to present the findings by comparing SEC with clinker-to-cement ratio to learn about the relationship between SEC and clinker factor.

After drawing the graphs, the analysis should also focus on identifying barriers between top and low performers, such as differences in equipment technology, maintenance practices, fuel types, and even policy in each country. Hypotheses can be formulated to explain these gaps, such as outdated equipment, operational inefficiencies or differing levels of staff expertise.

5.4 Conclusion

The final stage involves drawing conclusions from the benchmarking exercise and providing actionable recommendations. Key considerations for concluding include:

- **Identifying key takeaways**: Highlight the main findings from the benchmarking analysis, such as which plants are the most and least energy efficient. These insights can help derive lessons learned from successful technology implementations or best practice management approaches.
- **Recommendations for improvement**: Offer general recommendations to enhance energy performance in cement industry, from policy and industry practice perspectives. This may necessitate a more detailed benchmarking study focused on specific processes or equipment to precisely identify areas for optimisation. This could involve upgrading equipment, optimising process flows, or increasing the use of alternative fuels. Potential savings can also be calculated by comparing the result with SEC reference value in each system.
- **Benchmarking refinement**: Suggest improvements for future benchmarking exercises, such as refining data collection methods or expanding the scope of the study that may improve the accuracy of the benchmarking.
- **Efficiency targets**: Establish realistic energy efficiency targets based on the benchmarking results, helping companies align with global or regional standards.

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APPENDIX A

Focus Group Discussion (FGD) Report

Energy Performance Benchmark and Guideline for Industry-Specific Sector in ASEAN

Vientiane, Lao PDR, 15th May 2024

Objective

The Focus Group Discussion aims to gather preliminary inputs qualitatively for conducting energy performance benchmarks in this study. Upon the completion of the focus group discussion, the expected outcomes are to:

- Understand the main industrial sub-sector and potential growth in each AMS
- Reach agreement on which industrial sub-sector to be benchmarked for this study
- Determine level of depth and method for this benchmarking study

Format and Participants

FGD was mainly intended to gather inputs from ASEAN Member States. Dialogue Partners and International Organisations present at the meeting is allowed to participate in the discussion.

Discussion was held into two groups, each accompanied by a facilitator and a note-taker from ASEAN Centre for Energy.

Group 1: Philippines, Singapore, Thailand, USAID representative.

Group 2: Brunei, Cambodia, Indonesia, Lao PDR.

The result of the FGD is not the final stance of the AMS. Instead, this is a preliminary input from representatives that will build upon by ACE.

ACE will propose officially to AMS focal points regarding which sub-sector to be observed and seek for the approval.

Discussion Results

Which industrial sub-sectors should be prioritised in the energy benchmarking study? What scope do you think the study should encompass? Should it focus on country-level data or compare company-to-company data?

Group 1:

From the discussion, the group **suggests conducting energy benchmark in food and beverage industry** since it would work across several countries in ASEAN. Even so, we have to be careful in evaluating energy benchmarks because same products can be produced with different grades / different technologies that may affect energy profile. **We need to further define / narrow down the study and products.**

Group 2:

In some countries in this group, **cement industry accounts for high energy consumption**. However, there would be a challenge in countries where there is only a few cement companies/factories, therefore it will expose the situation of one single company.

This group suggests performing an **energy benchmark study for the cement industry**, focusing on **the company-to-company survey**.

What are the main barriers to implementing energy efficiency measures in industrial sub-sectors?

Group 1:

Small and medium-sized industry may would rather opt **to accelerate their growth** as much as possible by improving their production, instead of investing in energy efficiency. Investing in energy efficiency sometimes requires large amounts of **upfront cost** that is not appealing to investors.

Lack of information and awareness also play part in the seemingly inaction of energy efficiency implementation in industry sector. **Company's sustainability goals** are often designed as a whole, covering pollution, climate change mitigation, and waste management, lack focus on energy efficiency.

Group 2:

Main challenges mentioned in this group include the **limited funding for energy efficiency projects** and **the lack of technology advancement** of energy-efficient equipment. The other significant barriers would be **limited data availability, low public awareness, lack of policy enforcement** to encourage energy-efficient projects, **no fiscal incentives** for energy efficiency measures, and minimal pressure from global supply chain.

What experiences has your country had with energy-related benchmarking studies? What would be the biggest challenges for your country to support for data collection for energy performance benchmark in the selected industry?

Group 1:

A representative in this group said that their country has conducted feasibility project on energy benchmarks for industrial sector called Energy Performance Indicators, targeting food and beverage as well. The challenges were to group products based on grades, technology, or process. There were multiple factors to consider when benchmarking energy profile, which sometimes are not provided by the factories for the confidentiality reasons. One way to do it is to **self-benchmark against past data**.

Another way is to benchmark for **specific equipment that is common to be used in industrial** sector, like electric furnace or motors.

Group 2:

One country is currently conducting energy audits in downstream companies, but they do not have local energy auditors. There is a challenge to **verify data** submitted by the industry.

In another country, there is a **challenge to ensure the data accuracy** and to generate detailed indicators in assessing energy efficiency performance. Although one country has developed guidelines to develop indicators for energy performance for industry sectors, not all companies comply with government's regulation regarding energy efficiency data.

In some other countries, there is no regulation on energy efficiency, so the companies **do not have the obligation to report their data**.

Conclusion

- To initiate an energy benchmark study in industry sector, **Food and Beverage** and **Cement** industry can be selected as the object of the study. This would be a pilot project that can be replicated in other sub-sectors in the ASEAN.
- When benchmarking, it is important to **consider several factors like product's grade, technology, process**, and so forth that affect energy consumption profile.
- Alternatively, benchmark can also be done by **observing specific equipment** that is commonly used in industrial sector or performing **self-benchmark against its past performance**.

APPENDIX B

AMS' Responses to ACE's Questionnaire

Energy Performance Benchmark and Guideline for Industry-specific in ASEAN

June 2024

1. RANK INDUSTRIAL SECTORS BY REVENUE

The top industrial sector by revenue varies across countries.

Food, Beverage, and Tobacco appears to be the sector that generates the highest revenues in several countries in Southeast Asia. It tops the chart in Lao PDR and Myanmar, while this sector sits at the second highest revenue-generating industry in Indonesia and in Thailand. In addition, this sector is regarded among the fastest growing industry in both Indonesia and Thailand if compared to other sectors listed.

Mining Industry is the other industry included on the top list. Mining, along with upstream oil and gas, is Brunei Darussalam's primary source of revenue. Indonesia and the Lao PDR have also stated that this sector ranks among the top five in annual sales.

The other sectors mentioned in the responses are Construction, Non-Metallic Mineral, Pulp and Paper, Metal Products, Upstream and Downstream Industry, and Chemicals

Summary in **ANNEX 1**

2. RANK INDUSTRIAL SECTORS BY ENERGY CONSUMPTION

Non-Metallic Mineral (Cement, glass, ceramic, lime) belongs to the top 5 of the highest energy consuming sector in five countries: Indonesia, Lao PDR, Malaysia, Myanmar, and Thailand. This is consistent with the findings from ASEAN Energy Outlook 7th (2022), highlighting this sector as the biggest contributor of energy consumption from Industrial sector.

Food, Beverage and Tobacco is also mentioned by five countries: Indonesia, Lao PDR, Malaysia, Philippines, and Thailand, as the sector that demands plenty of energy in ASEAN. In the ASEAN Energy Outlook 7th (2022), this sector's energy consumption is expected to grow nearly 4 times in the next 30 years.

The other sectors on the list include Chemicals, Metal Products, Pulp and Paper, Textile.

Refer to **ANNEX 2**

3. SUGGESTION FROM AMS ON WHICH INDUSTRIAL SUB-SECTOR TO OBSERVE IN THIS ENERGY BENCHMARKING STUDY

One essential point that AMS advocates is to select an industrial sub-sector that is the most **prevalent industry** across ASEAN and will **promote strong engagement** from member states. Although, this is quite challenging since different countries have different characteristics and priorities.

Benchmarking in industry sub-sector should also be **easy to define** with similar products, common metrics, and technology that is being used.

This benchmarking study is also expected to **promote standardized methodology/framework and key performance index** for simplifying the comparison across countries.

Another suggestion is to **focus on one sub-sector** to generate the best, in-depth, and optimal output of this study. This could b**e a good starting point going forward for replicating the benchmark in other sub-sector** in the future.

The sectors that are mostly suggested by AMS are **Food Beverage and Cement.**

Food and Beverage is one good option since most of the AMS have this sector in place, which suits replicability criteria, and has room to grow in the future. Yet, the **challenge is to further narrow down the specific type of food product** or production process to observe, which is fairly diverse.

Cement is another sector suggested to observe due to its common features, energy-intensive, and standardized measurement.

Original Responses refer to **ANNEX 3**

4. CHALLENGES IN ENERGY BENCHMARK ACTIVITIES

Data Gathering. This may include lack of tools to assess, support mechanism, technical knowledge, availability of the data, less awareness of energy usage, multiple sources of data.

Data Reliability (Validation) Some companies just submitted some figures they have without checking its validity and relevance to the requirements. Geographical challenges are one of the barriers for data validation

Consolidated Market. One or two companies dominating large part of the market, making benchmarking activities directly expose those companies' performance.

Confidentiality of the Data. Sensitive data related to production, processes, and revenues may impede the accuracy of the benchmarking assessment.

No Obligation. Some companies are reluctant to involve since it is not mandatory, minimum compliance with regulation, and does not yield immediate / tangible benefits for companies to participate.

Interpretation of the Data. System boundaries (capacity, production volume, metrics, etc) should be clearly defined so that companies could understand well the results that may be applicable to improve their performance.

5. OVERCOMING CHALLENGES FOR ENERGY BENCHMARK ACTIVITIES

Establish energy management system, capacity building, in-kind assistance for energy audit, enaction of regulation for reporting energy usage.

6. OTHER INPUTS TO CONSIDER

Technology Roadmap would help industry players in the region in developing their energy efficiency measures.

Specific Energy Consumption (SEC)shows a total energy consumption per unit of output can be used, but it could mislead the conclusions since there are varying numbers of technology, production size, and other factors affecting energy consumption. Should also consider another factors/index to measures.

Energy Performance Indicators (EnPI) could help to normalise the energy consumption measures and its influencing factors but still quite challenging to use.

Compare common industrial system like boilers, refrigeration, heating, drying could be another option to benchmark.

Company's size matters since smaller company will prioritise for production improvement / growth rather than energy consumption reduction.

ANNEX 1 – RANK SECTOR PER COUNTRY BY REVENUE

Sub-Sector	Brunei Darussalam	Cambodia	Indonesia	Lao DPR	Malaysia	Myanmar	Philippines	Singapore	Thailand	Vietnam
Chemicals			6						1	
Construction	3		1							
Downstream Oil and Gas, Coal Products	2		5							
Food, Beverage and Tobacco			2	1		1			2	
Metal Product						2			5	
Mining	1		3	4						
Non-Metallic Mineral						4			3	
Pulp and Paper				3					4	
Textile				2						
Upstream Oil and Gas	1		4							
Wood						3				

ANNEX 2 – RANK SECTOR PER COUNTRY BY ENERGY CONSUMPTION

Sub-Sector	Brunei Darussalam	Cambodia	Indonesia	Lao DPR	Malaysia	Myanmar	Philippines	Singapore	Thailand	Vietnam
Chemicals			2		2	4			1	
Food, Beverage and Tobacco			5	3	5		1		2	
Manufacture of Electronic Products					1					
Metal Product			4		4	2			5	
Mining										
Non-Metallic Mineral			3	1	3	1			3	
Pulp and Paper			1	4					4	
Textile				2		3				

ANNEX 3 – Sample of AMS Responses

Which industrial sub-sector do you think ASEAN has to prioritise for benchmarking energy performance that would be beneficial for ASEAN region? Please give reasons.

Brunei Darussalam:
*Brunei Darussalam's economy is unique within the region as the **oil and gas sector** is the primary industry that may be utilized for benchmarking energy performance.*

Cambodia:
*For my perspective, **cement factories** and heavy industries are the prioritized to have benchmarking energy performance since they would consume much energy among the other.*

Indonesia:
*Benchmarking could be conducted for industries such as **cement**, glass, ceramics, fertilizer, pulp and paper, tire manufacturing, as well as specific food and beverage products. This is because their industrial processes are relatively similar.*

Lao PDR:

- ***Cement Industrial,** As the AMS majority have cement factory in place. Which consumes huge energy. Especially, coal, electricity and other.*
- *Garment, I think, this sector has high potential in this sector for AMS, beside that we have challenge for section the specific type of garment for benchmarking energy performance.*
- *Beverage, Due to AMS may has Beverage factory in place.*

Malaysia:
*Should prioritize energy-intensive industries with common unit of measurement in term of production value such as Manufacture of Non-Metallic Mineral Products, Manufacture of Basic Metals or Manufacture of Chemicals and Chemical Products. Generally, these **subsectors are usually measured in Metric Tonne (MT) in terms of production data**. The energy performance of manufacturing processes can be more **readily measured and standardized compared to some other sectors**. These manufacturing sub-sector is also prevalent across all ASEAN member states, making it a common area for collaborative benchmarking efforts.*

Myanmar:
*Food and beverage sector is included in top 5 lists of ASEAN countries. However, **it can be difficult to define benchmarking energy performance because the types of food product** and production processes are different. We should choose energy intensive industries and common products. **Therefore, Cement and Iron and Steel sub-sectors should be prioritized**.*

Philippines:
***Food processing is an energy-intensive sub-sector**, involving various stages such as refrigeration, heating, drying, and packaging, all of which consume significant amounts of energy. Benchmarking energy performance in this sub-sector can help identify inefficiencies and opportunities for substantial energy savings. By **focusing on the food processing sub-sector**, ASEAN can address a critical area with significant potential for energy savings and sustainability improvements. This strategic prioritization can lead to enhanced economic resilience, environmental benefits, and regional collaboration, driving progress towards a more sustainable and energy-efficient future for the ASEAN region.*

Singapore:
*We are of the view that the industry sub-sector profiles, regulatory frameworks and infrastructure vary from country to country in the ASEAN region. Hence, it will be **challenging to identify common industrial sub-sectors** that could be prioritized across the region.*

Thailand:
***Food and Beverage** because our region mainly producing food product*

What do you think would be the biggest challenges in collecting data in your country for energy performance benchmarking? How to overcome these challenges?

Brunei Darussalam:
- *Confidentiality and transparency in energy performance data submission.*
- *Consolidating multiple sources of data from different agencies for use in analysis and forecasting*

Cambodia:
The Challenges: Funding, public awareness and stakeholders' involvements, regulation to enforce the data submission/collection
The solutions: Finding support from DPs and Banks to conduct the data collection, public awareness rising, establish framework and regulation to enable the implementation of EE data collections

Indonesia:
*Aside from confidentiality concerns, benchmarking activities could pose challenges in standardizing the interpretation of obtained data. This is because, despite being in similar industries, differences in production scope can render benchmarking **data inaccurate**. Furthermore, some industries may feel they don't need benchmarking because they are part of a global group where they can compare themselves with other companies within the group. Additionally, there are companies within these subsectors that consist of only one or two firms, making benchmarking activities directly expose them.*

Lao PDR:
- *The most crucial issue is the reluctance of many designated facilities to share data which they consider as confidential.*
- *Financial stress.*
- *Lack of technical tools and equipment support for collection data.*
- *Data availability and quality in the line agencies.*
- *Less awareness on Energy Efficiency some industrial.*

Malaysia:
*One of the challenges is **compliance with the regulation**, in our case is EMEER 2008. There are companies that did not know they are subject to the EMEER 2008 even though notice has been issued to them. We have to regularly conduct enforcement activities for the non-compliance companies and also provide awareness programs like seminars to disseminate information about the regulatory framework. There is also a challenge with data accuracy and reliability. Sometimes, **data reported is not really accurate** and REM has a vital role to check the report thoroughly to ensure data reported is correct and verified. **Data reliability** also can be an issue where they just report any data even though the data is not affecting or related to the energy consumption or energy performance. It goes back to **the awareness** to ensure that no "garbage in, garbage out," in which the industry must know what kind of data or variables need to be reported.*

Myanmar:

Nos.	***Challenges***	***How to overcome***

1.	*Data Availability and Quality*	*Provide awareness raising program to ensure consistency and accuracy to industries.*
2.	*Human Resource and Expertise Limitations*	*Develop capacity-building initiatives to enhance the skills of the workforce*
3.	*Regulatory and Policy Barriers*	*Enact Law and regulations including mandatory energy usage report*
4.	*Financial Constraints*	*Create Financing Mechanism including loan, grant and incentive program*

Philippines:

Compliance of DEs to the Reportorial Requirements under the EEC Act. *While Department Circular No.s DC2023-12-0036, DC2023-12-0037, and DC2023-12-0038 mandates all DEs to submit their Annual Energy Efficiency and Conservation Report (AEECR), Annual Energy Utilization Report (AEUR), and Energy Audit Report (EAR) to the DE Portal, some DEs are not fully compliant due to a lack of awareness or understanding of these requirements.*

Geographical Challenges for Data Validation. *While approximately 15,000 DEs are registered in the DE Portal, around 3,600 are in the industrial sector, which are spread across the country. The main challenge lies in the monitoring, verification, enforcement, and post-evaluation of DEs that are located outside the National Capital Region (NCR), where accessibility constraints can hinder effective oversight and data validation processes.*

Data gathering of annual consumption. *Most DEs do not practice recordkeeping of their energy consumption and their continuous monitoring. Even after the implementation of the Annual Reportorial Submission in 2019, there were still some DEs at present, who struggle to comply due to a lack of data caused by either the absence of the database or the improper turning over of data.*
Ensuring comprehensive compliance with the reporting obligations is crucial for effective monitoring and evaluation of energy efficiency efforts in the industrial sector. To overcome these challenges, the EPMPD aims to do targeted studies and benchmarking activities to help improve selected DEs and their practitioners in incorporating best practices in record-keeping and monitoring of DEs that they are handling.

Singapore:

- *Some* ***companies may not be open*** *to participate since involvement in benchmarking study is not mandatory and they may not see the tangible benefits of such an exercise. In addition, best practices guide for most common Energy Consuming Systems are readily available in public domains for companies' use;*
- ***Sensitive data related*** *to production and other processes are confidential and companies do not readily share these data. This could impede the assessment for the benchmarking;*
- ***Companies' lack of incentive to participate*** *since companies under the ECA must conduct periodic Energy Efficiency Opportunities Assessments (EEOA) which would help them improve their energy performance;*

- *The outcome of benchmarking exercise **might not be applicable or useful to certain companies due to different operating conditions**, infrastructure, and/or production equipment even within the same sub sector.*
- *To overcome challenges and improve participation, ACE may want to elaborate on how the benchmarking performance indicators can help companies improve their energy efficiency.*

Thailand:
Information is coming from and going to many places, it is quite difficult to have all information in one place

COUNTRY : ...

APPENDIX C

A. OVERVIEW OF CEMENT INDUSTRY

No	Data	Unit	2020	2021	2022	2023	Remarks
1	Number of cement companies operating in your country	companies					
2	Number of cement plants operating in your country	plants					*This may include any type of plants, from integrated to partial plants*
3	Production capacity of cement	M.tonne/year					*Maximum manufacturing capacity. Country may not produce at full capacity if utilisation/demand is low*
4	Production capacity of clinker	M.tonne/year					*Maximum manufacturing capacity. Country may not produce at full capacity if utilisation/demand is low*
5	Actual cement production	M.tonne/year					*Cement products consumption. This value can indicate utilisation of cement production*
6	Actual clinker production	M.tonne/year					*Semi-finished products consumption*
7	Export Cement	M.tonne/year					
8	Import Cement	M.tonne/year					
9	Export Clinker	M.tonne/year					
10	Import Clinker	M.tonne/year					

B. TECHNICAL INFORMATION OF CEMENT INDUSTRY

No	Questions	Answers
1	What are the main cement types produced in your country?	*(Example: finsihed/semi-finished products, CEM I ~ V, Clinker, etc)*
2	What is the main cement process in your country?	*(dry/wet)*
3	How many plants are categorised as Integrated plants?	*(All stages of cement production from mining, grinding, clinker, cement)*
4	How many plants are categorised as Grinding-only plants?	*(Only grinds the purchased clinker, mention the annual production)*
5	How many plants are categorised as Clinker plants?	*(Only produce clinker, mention the annual production)*
6	Do the integrated plants also purchase clinker from other facilities?	*(If so, averagely in plant operation, how many percent of clinker they purchase and how many percent they produce on their own)*
7	In general, what is the average clinker-to-cement ratio?	*(tonne of clinker per tonne of cement)*
8	How many plants have their own power generation?	*(produce electricity to be used by themselves)*
9	How many plants have their own Waste Heat Recovery system?	*(heat is reused for pre-heating or produce electricity)*

C. ENERGY INFORMATION OF CEMENT INDUSTRY

No.	Data	Unit	2020	2021	2022	2023	Remarks
1	Thermal Energy Consumption	Gj/year					
2	Electricity Energy Consumption	kWh/year					
3	Energy Consumption by source *(if available)*						
	- Coal	Gj/year					
	- Natural Gas	Gj/year					
	- Oil	Gj/year					
	- Petroleum coke	Gj/year					
	- Biomass	Gj/year					
	- Other (Please specify)	Gj/year					
4	Energy Consumption by process *(if available)*						
	- Raw Material Processing	Gj/year					
	- Calcination	Gj/year					
	- Final Grinding and Drying	Gj/year					

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