The Danish Energy Agency

Anonymous Audit Report
from a cement manufacturing company

Vietnam Technology Solutions Joint Stock Company, May 2026

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Introduction to the context

On March 13, 2019, the Prime Minister issued Decision No. 280/QD-TTg approving the National Program on Energy Saving and Efficiency (VNEEP) for the period 2019–2030.

The VNEEP program implements a comprehensive range of activities in the field of energy conservation and efficiency, demonstrating the commitment of all levels of government, associations, businesses, organizations, and individuals to energy conservation and efficiency in particular, and to responding to climate change and protecting the environment in general.

The Vietnam-Denmark Energy Cooperation Program Phase 3 (DEPP3), implemented during the 2020-2025 period, has carried out many practical and effective activities, making a significant contribution to Vietnam's energy transition towards green growth and carbon emission reduction through the development of green energy systems, flexible power system operation, and effective implementation of policies and solutions to promote energy saving and efficiency.

One of the key activities to promote energy efficiency is conducting energy audits in many industries in Vietnam.

This document is an anonymous summary of a specific energy audit report, conducted within the framework of the DEPP3 Program, carried out by Vietnam Technology Solutions Joint Stock Company (VETS), in collaboration with international experts from Viegand Maagøe.

This report summarizes the results of an in-depth energy assessment and audit at a large-scale cement manufacturing enterprise in Vietnam. The assessed industrial facility is classified as a national key energy consumer and currently operates a configuration of four rotary kiln lines using the dry process, incorporating a waste heat recovery (WHR) system. The audit process strictly adhered to international standard audit guidelines, combining analysis of operational data series over a five-year period (2021–2025) with in-depth field measurement techniques.

The core objective of the report is to quantify energy flow, identify performance bottlenecks, and propose energy efficiency (EE) projects that are both technically and financially feasible. The analysis results indicate that the facility's energy structure relies primarily on thermal energy from coal (accounting for 86–93% of total energy), while grid electricity and self-generated power (WHR) provide power for mechanical loads.

The approach delves into surveying the current energy consumption status of the entire core production line and auxiliary utility systems, thereby identifying technological bottlenecks, thermodynamic leaks, and gaps in operational management. Through modern analytical tools such as Energy Mapping, the report identifies significant energy saving potential. By quantifying savings potential in detail (in kWh, tons of coal, and percentage) and analyzing the lifecycle cost-benefit (LCC), the report provides a portfolio of the most feasible Energy Efficiency (EE) projects. Therefore, this document serves as a strategic compass, equipping business leaders with a scientific data foundation to make accurate investment decisions, aiming to realize a circular production model and sustainable development in the context of a green economy.

Summary

The main subject is a large-scale integrated cement plant in northern Vietnam, with four synchronized production lines. The business operates as a multi-member limited liability company, primarily engaged in the production of cement, lime, and gypsum, operating continuously 24/7 with three shifts per day for the production unit.

The organizational structure is divided into three main blocks: Production Block (mechanical, electrical, line operation and central control room), Business Block (materials, accounting, sales) and Internal Affairs Block (administration, safety, QC), under the direct supervision of the Factory Director. The enterprise has implemented several international standard management systems such as ISO 9001, ISO 14001, ISO 14064-1, ISO 14067, creating a favorable foundation for building an energy management system according to ISO 50001.

The facility boasts a large-scale production infrastructure with four modern technological lines, increasing the total designed capacity to 10.5 million tons per year. To meet this scale, the input material supply chain must process a huge volume of materials, including limestone, clay, clean limestone, coal, and adjusting additives (iron ore, gin, silica), artificial gypsum, and mineral additives (fly ash, steel slag, black clay). The total amount of raw materials consumed in 2024 is recorded at 145,513.49 tons per year.

The production characteristics of Lines 3 and 4 focus entirely on the clinker burning process, while Lines 1 and 2 handle the grinding of the raw materials into commercial cement. This production volume is accompanied by a very high intensity of carbon emissions. Statistics from 2024 show that the consumption of 433,979,656 kWh of electricity and 1,224,438 tons of coal generated a total greenhouse gas emission equivalent to 3,310,441 tons of CO_2 (equivalent to an energy level of 801,626 TOE).1 This context places the enterprise under immense pressure to optimize its operations rigorously.

Energy consumption in the production line is primarily for clinker production. The energy conversion structure shows that thermal energy from coal accounts for approximately 86–93% of total energy, while grid electricity, WHR electricity, and diesel oil account for smaller proportions. Total energy consumption surged in 2022, then decreased and gradually stabilized during the 2023–2025 period, reflecting the process of operational stabilization and/or production optimization.

Overall energy consumption situation at the factory:

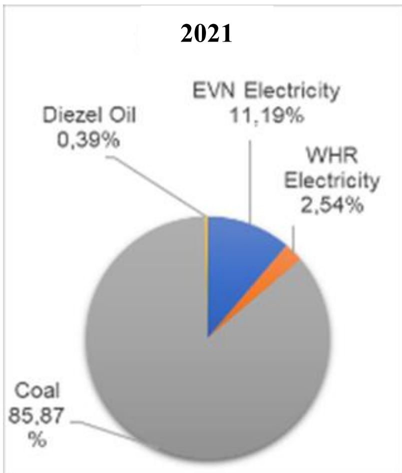
- Below is a detailed analysis of the Company's energy consumption patterns over the 5-year period (2021 – 2025):

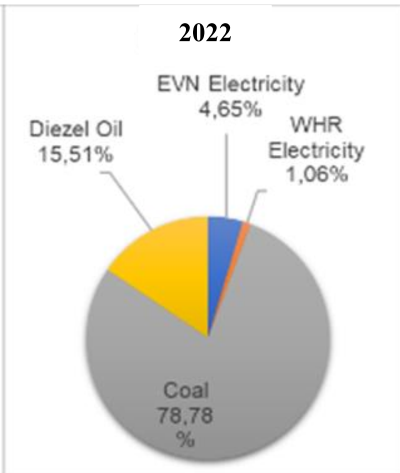
Table 1.1. The company's energy consumption structure during the period 2021–2025

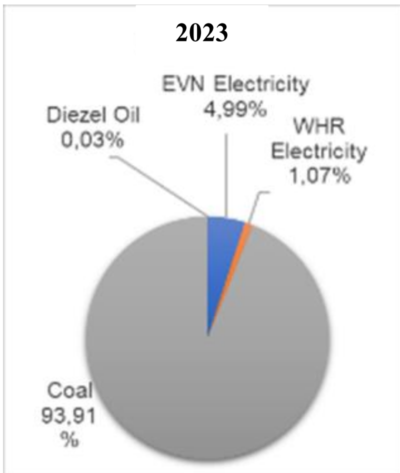
No.	Type of energy	Unit	Energy consumption	Conversion (kWh)	Percentage (%)
2021					
1	EVN Electricity	MWh	537,250,010	537,250,010	11.19%
2	WHR electricity	MWh	122,184,540	122,184,540	2.54%
3	Charcoal	Ton	590,853	4,122,972,234	85.87%
4	DO oil	Liter	1,834,231	18,773,150	0.39%
5	Water	M^3	-	-	0.00%
Total				**4,801,179,934**	**100.00%**
2022					
1	EVN Electricity	MWh	476,416,710	476,416,710	5.50%
2	WHR electricity	MWh	108,771,532	108,771,532	1.26%
3	Charcoal	Ton	1,157,729	8,078,632,962	93.23%
4	DO oil	1000 Liters	155,411	1,590,614	0.02%
5	Water	M^3	2,092,467	-	0.00%
Total				**8,665,411,818**	**100.00%**
2023					
1	EVN Electricity	MWh	471,190,566	471,190,566	4.99%
2	WHR electricity	MWh	101,156,220	101,156,220	1.07%
3	Charcoal	Ton	1,270,207	8,863,504,446	93.93%
4	DO oil	1000 Liters	254	2,601	0.00%
5	Water	M^3	3,318,844	-	0.00%
Total				**9,435,853,833**	**100.00%**
2024					
1	EVN Electricity	MWh	433,979,656	433,979,656	4.72%

No.	Type of energy	Unit	Energy consumption	Conversion (kWh)	Percentage (%)
2	WHR electricity	MWh	214,522,803	214,522,803	2.33%
3	Charcoal	Ton	1,224,438	8,544,128,364	92.95%
4	DO oil	1000 Liters		-	0.00%
5	Water	M^3		-	0.00%
Total				**9,192,630,823**	**100.00%**
2025					
1	EVN Electricity	MWh	440,176,418	440,176,418	5.14%
2	WHR electricity	MWh	195,199,469	195,199,469	2.28%
3	Charcoal	Ton	1137336	7,936,330,608	92.59%
4	DO oil	1000 Liters		-	0.00%
5	Water	M^3		-	0.00%
Total				**8,571,706,495**	**100.00%**

(*) Note: Energy consumption data for 2025 is compiled for the period from January to October 2025.







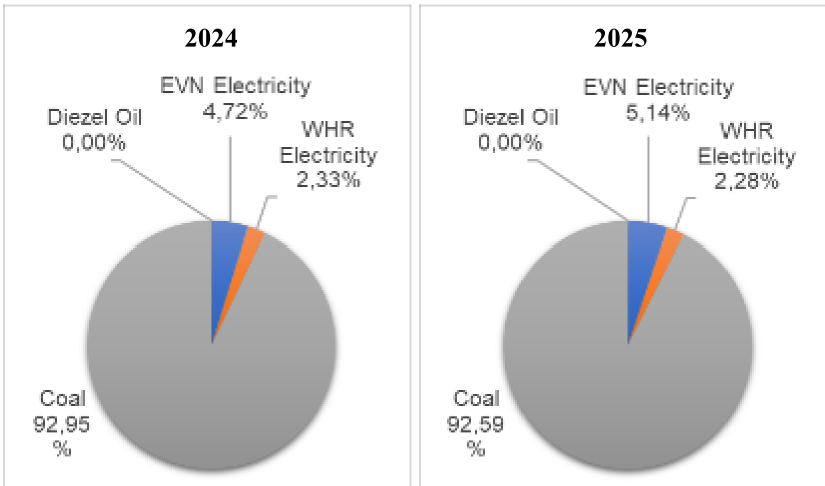


Figure 1.1. Energy consumption structure chart for the entire company, 2021-2025

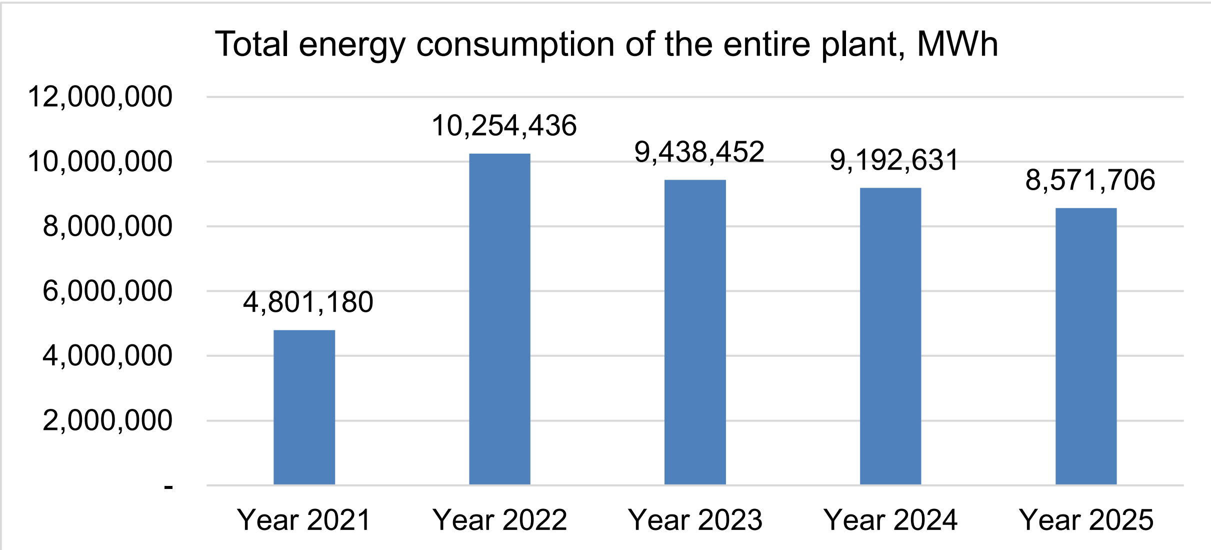


Figure 1.2. Energy consumption chart for the entire company from 2021 to 2025

Energy saving potential

After surveying and assessing the current state of energy use and management at the company, the audit team found that the factory has potential for energy savings in the following systems: production machinery, power supply and distribution systems, air compressor systems, furnace systems, etc. Based on detailed analysis and calculations, the potential savings at the company are determined as follows:

Based on detailed analyses, the plant's total energy saving potential is estimated at approximately 34,581,192.4 kWh of electricity per year and 20,815.4 tons of coal per year, with a savings value of approximately VND 122,813.40 million per year. To exploit this potential, an investment of approximately VND 316,001 million is needed for the proposed technical solutions.

Implementing appropriate energy-saving solutions will contribute to helping the plant achieve its strategic objectives, including:

- Reduce energy costs in the production cost;
- Improve the operational efficiency and reliability of equipment;
- Reducing greenhouse gas emissions is in line with the green production approach;
- Gradually implement energy management systems (e.g., ISO 50001) and advanced energy management practices.

A detailed list of energy saving opportunities is presented in the following sections.

1 About the enterprise

1.1 Description of the company

- Sector: Cement production
- The audited entity is an integrated cement plant (clinker and cement) operating four modern production lines, using dry-process rotary kiln technology, and equipped with a WHR system for generating electricity from hot exhaust gases. The plant is a multi-member limited liability company, operating since 2016, with its main business being the production of cement, lime, and gypsum.
- Organizationally, the management structure is divided into three main blocks: Production Block (mechanical, electrical, manufacturing, central operations), Business Block (materials, accounting, sales), and Internal Affairs Block (administration and QC), under the direct supervision of the Plant Director. This model ensures clear functional allocation, but the current energy management system is mainly integrated within departments and does not fully operate according to ISO 50001 standards.
- Main ingredients: Limestone, clay, purified limestone, coal, adjusting additives (iron ore, gin, silica), artificial gypsum and mineral additives (such as fly ash, steel slag, slag, black clay, etc.).

  + Total raw material consumption in 2024: 145,513.49 tons/year

- Line 1: 4,275,086.4 tons/year;
- Line 2: 4,044,921 tons/year;
- Line 3: 3,343,749 tons/year;
- Line 4: 3,923,441 tons/year.

  + Main products: Clinker, Cement

Table 1.1. Total production output data for 2024

No.	Production line		Unit	2024
1	Line 1	Clinker	Ton	620,000
2		Cement	Ton	2,636,201
3	Line 2	Clinker	Ton	570,000
4		Cement	Ton	2,465,184
5	Line 3	Clinker	Ton	2,153,563
6		Cement	Ton	-
7	Line 4	Clinker	Ton	2,558,356

No.	Production line		Unit	2024
8		Cement	Ton	-

Table 1.2. Total energy consumption in 2024 (Electricity, coal)

Energy type	Unit	Line 1	Line 2	Line 3	Line 4
Total electricity used	kWh	221,049,989	190.123.028	175,698,090	188,884,080
Electricity (EVN)	kWh	166,154,736	143,920,128	123,904,792	-
Electricity from production	kWh	46,347,213	44,768,440	55,686,202	67,720,948
Coal	ton	321,601	304,357	301,772	357,740

Table 1.3. Carbon emissions in 2024

No	Type of energy	Unit	Energy consumption	CO2 emissions (Tons of CO2)	TOE Conversion (TOE)
1	Electricity (EVN)	kWh	433,979,656	286,079	66,963
2	Charcoal	Ton	1,224,438	3,024,362	734,663
Total				**3,310,441**	**801,626**

1.2 Process description

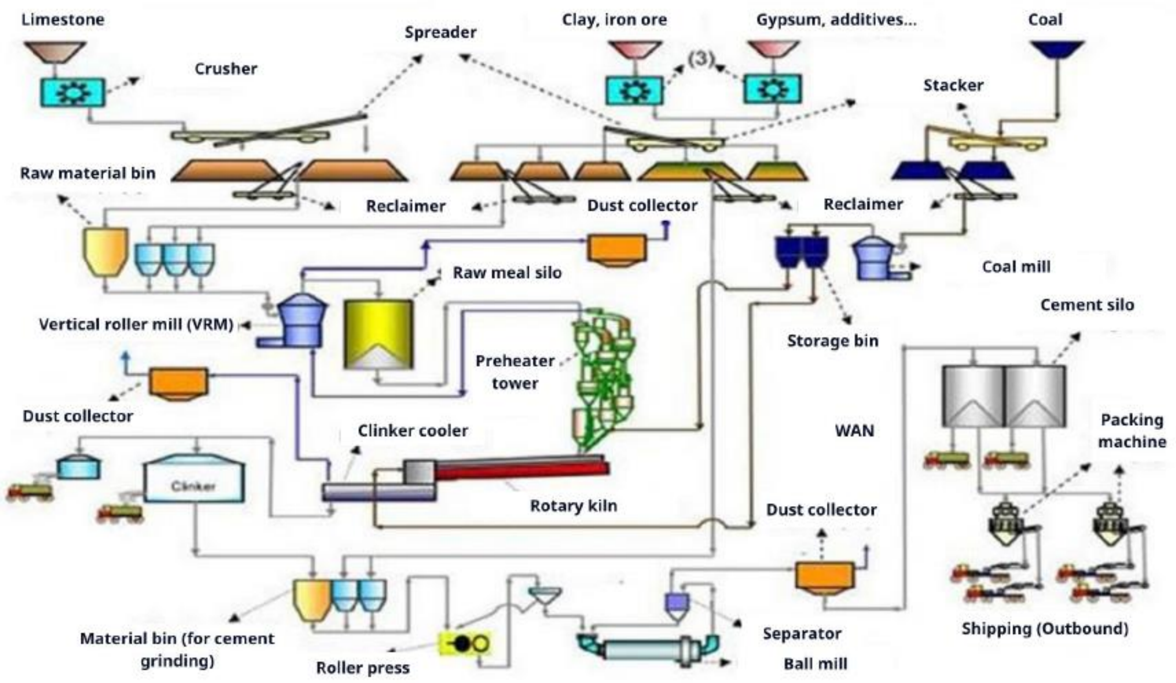


Figure 1.3. Process flow diagram

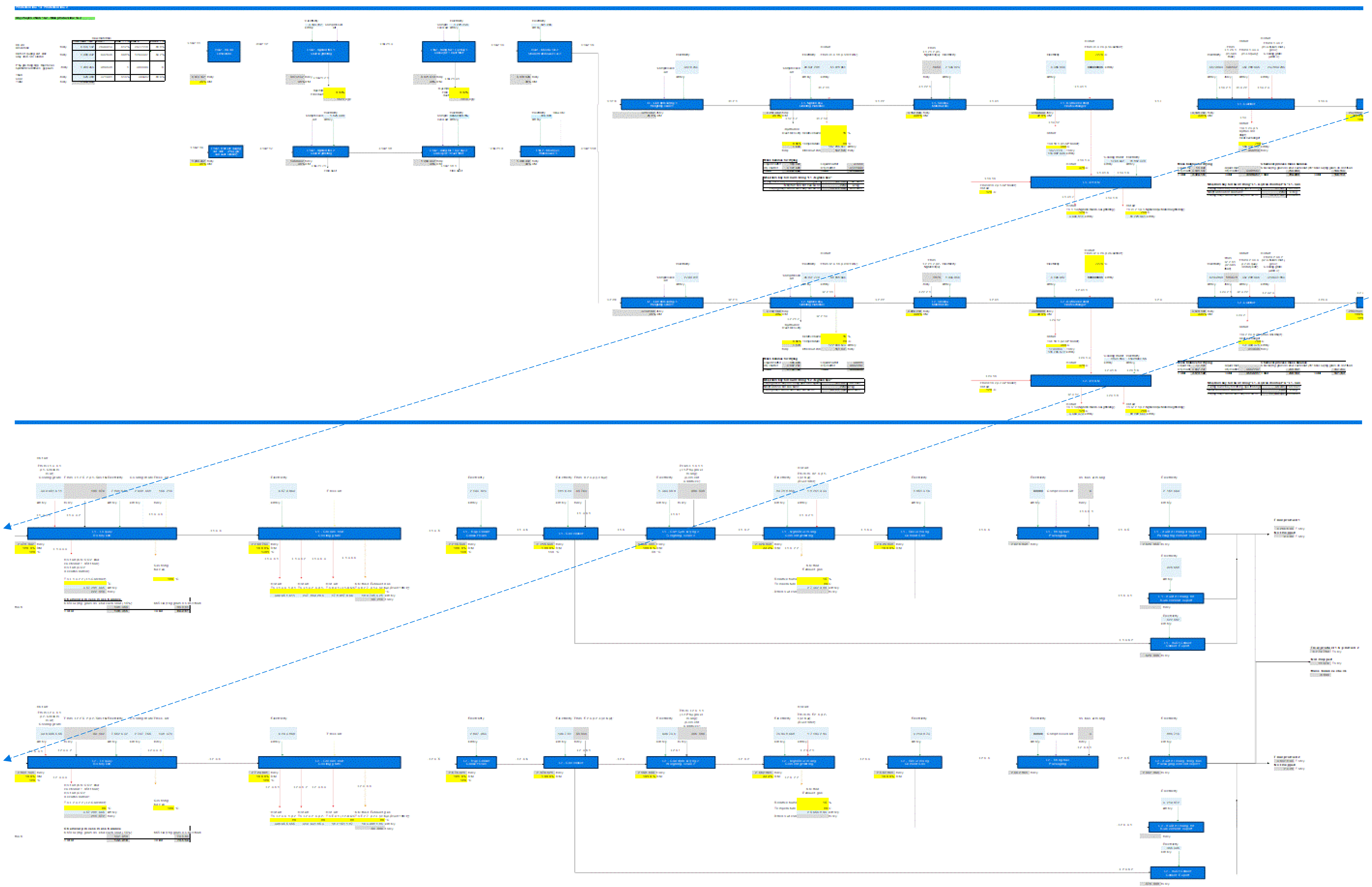


Figure 1.4. Production process flow diagrams for lines 1 and 2

<u>Describe the steps in the technological process:</u>

The cement production process at Line 1 and Line 2 of the Cement Plant includes all stages from raw material preparation to finished cement production. The main steps are as follows:

(1) Preparation and processing of raw materials:

- The main raw materials, including limestone, clay, and adjusting additives, are either mined or sourced from outside. The materials are pre-crushed, then transported and stored in a homogenization warehouse to ensure chemical stability before being fed into the grinding process.

(2) Grinding and homogenizing the raw material powder:

- After being measured according to the mixing ratio, the raw materials are fed into a vertical mill to be ground into a fine powder. During the grinding process, the material is dried with hot air from the kiln system to reduce moisture content. The ground powder is then transferred to a homogenization silo to ensure stability before being fed into the clinker burning system.

(3) Clinker burning:

- Homogenized raw material from the silo is fed into a heat exchange tower (preheater), where the material is heated by a countercurrent flow of hot air. Then, the material enters a calciner, where most of the $CaCO_3$ decomposition reaction takes place. The material is then transferred to a rotary kiln to complete the clinker mineralization reactions at high temperatures (approximately 1,450°C).

(4) Cooling the clinker:

- After exiting the rotary kiln, the clinker is rapidly cooled in a forced-air cooling grate. This process helps stabilize the mineral structure of the clinker and simultaneously recovers heat for reuse in the kiln system.

(5) Grinding cement:

- After cooling, the clinker is mixed with gypsum and mineral additives in specific proportions, then ground in a cement grinding system to achieve the required fineness. The ground cement is then transported to storage silos.

(6) Product storage and export:

- Finished cement is stored in silos and released to the market as bulk cement or bagged cement via an automated bagging system. Additionally, a portion of the clinker may also be exported directly depending on market demand.

1.3 Description of the utility system

- ❖ **Power supply system:**

The plant is supplied with electricity from the national grid via a 110 kV voltage level, distributed to medium/low voltage transformers. The transformer substation system is designed to meet the starting current of the grinding mill motors: at Lines 1 & 2, there are 9 transformers of 2000 kVA-6.3/0.4 KV and 2 transformers of 1800 kVA-6.3/0.6 KV operating 24/7.

The facility's technological highlight is its waste heat recovery (WHR) generator set. Heat recovery steam generators (HRSG) are located at the top of the preheater tower (AQC) and the cooler outlet (SP) to heat water into superheated steam, which then drives a turbine to generate electricity.

Specifically:

- Lines 1 and 2 are equipped with WHR systems with a capacity of 7 MW/line;
- Lines 3 and 4 are equipped with a WHR system with a capacity of 9 MW/line.

Electricity generated from the WHR is directly fed into the internal grid, prioritizing power for loads such as ID fans and air compressors, acting as a buffer to minimize the amount of electricity purchased from EVN.

In addition, to ensure reliable power supply, the plant is equipped with backup diesel generators to maintain the operation of critical loads in the event of grid failures or outages.

Table 1.4. Substation specifications

No	**Device Name**	**Quantity**	**Total power capacity (KVA)**	**Operating hours (hours/day)**
I	**Lines 1 & 2**			
1	1250KVA-6.3/0.4KV transformer	5	6,250	24
2	1000KVA-6.3/0.4KV transformer	1	1,000	24
3	1800KVA-6.3/0.6KV transformer	2	3,600	24
4	1600KVA-6.3/0.4KV transformer	4	6,400	24
5	2000KVA-6.3/0.4KV transformer	9	18,000	24
6	1400KVA-6.3/0.4KV transformer	1	1,400	24
II	**Chain 3&4**			
1	1000KVA-6.3/0.4KV transformer	2	2,000	24
2	1600KVA-6.3/0.4KV transformer	1	1,600	24
3	NL 2000KVA-6.3/0.4KV transformer	9	18,000	24
4	1800KVA-6.3/0.6KV transformer	2	3,600	24

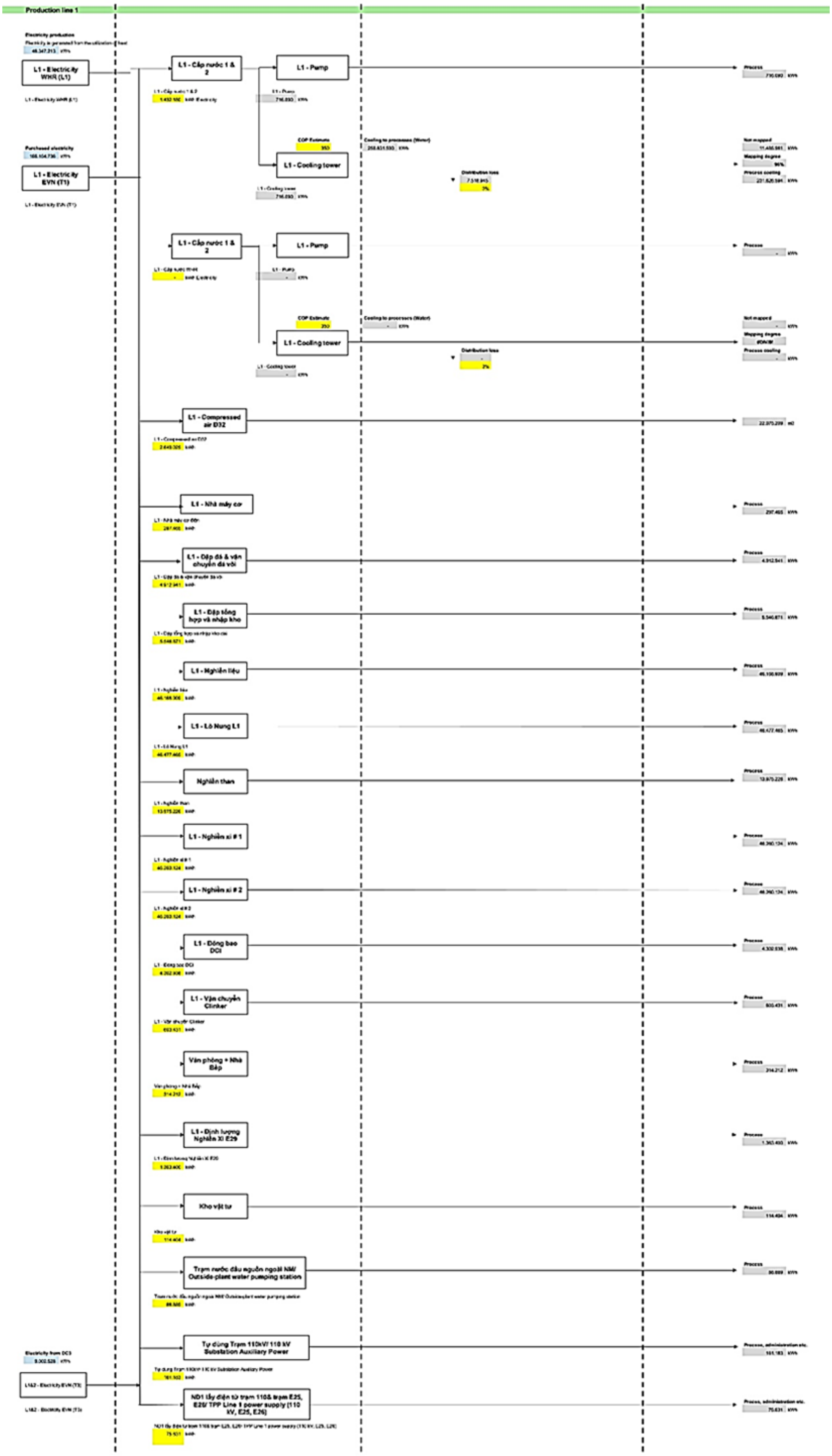


Figure 1.5. Power supply diagram and related auxiliary systems

❖ Coal supply system:

The plant's coal supply system is organized in a continuous chain, ensuring a stable and continuous fuel supply for the clinker burning processes.

The coal consumption structure operates in a closed loop. Imported/domestic pulverized coal is finely ground into pulverized coal, dried with excess hot air, and stored in an intermediate silo. A pneumatic conveying system uses a high-pressure air stream from a Roots blower to "bomb" the pulverized coal through a metering pipe directly into the calciner and furnace burner. The uniformity of the pulverized coal flow and the air pressure directly determine the flame shape and heat transfer intensity in the rotary kiln.

Overall, the plant's coal supply system is designed to be a closed, highly automated system, effectively meeting the requirements for stable feed supply and operational safety, contributing to the efficiency of the clinker burning process.

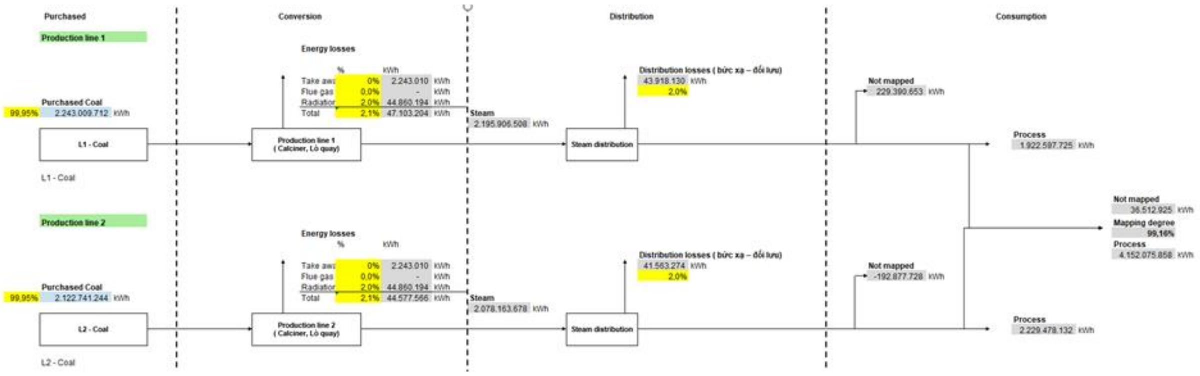


Figure 1.6. Diagram illustrating the energy flow for coal supply and consumption in the plant (Lines 1 & 2)

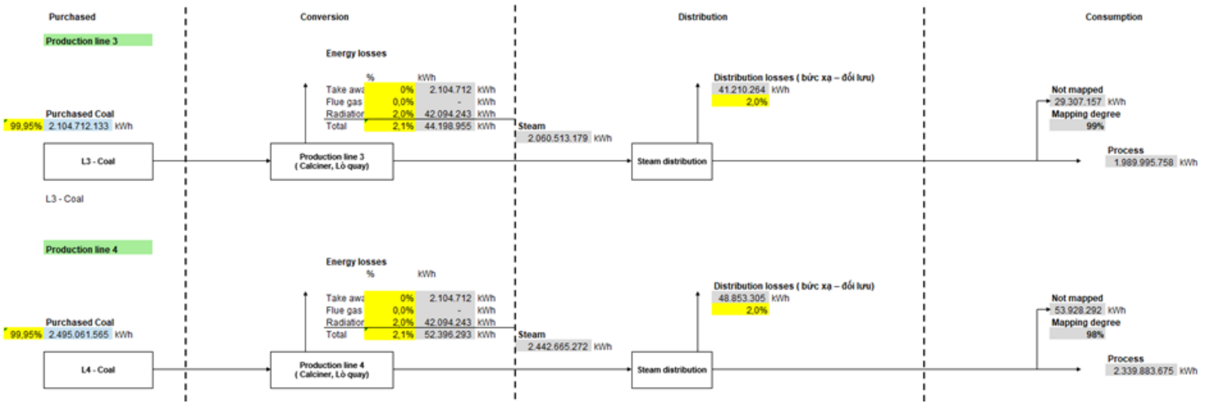


Figure 1.7. Diagram illustrating the energy flow for coal supply and consumption in the plant (Lines 3 & 4)

1.4 Energy Consumption Structure (2021-2025):

Analysis of energy records over the past five years reveals a clear dominance of fossil fuels, while also reflecting the cyclical nature of production operations. Below is a summary table of energy shifts from internal operational data:

Table 1.5. Overall statistics table of energy shifts

Type of energy	Unit	2021	2022	2023	2024	2025 (*)
EVN Electricity	MWh	537,250	476,416	471,190	433,979	440,176
WHR electricity	MWh	122,184	108,771	101,156	214,522	195,199
EVN's electricity share	%	11.19%	5.50%	4.99%	4.72%	5.14%
WHR Electricity Ratio	%	2.54%	1.26%	1.07%	2.33%	2.28%
Coal (Thermal energy)	Ton	590,853	1,157,729	1,270,207	1,224,438	1,137,336
Coal proportion	%	85.87%	93.23%	93.93%	92.95%	92.59%
DO oil	1000 Liters	1,834	155	0.25	But	But
Water	M3	But	2,092,467	3,318,844	But	But

Note: The 2025 data only includes data up to October.

The sharp increase in coal production in 2022 and the gradual stabilization from 2023-2025 suggest profound adjustments to production strategies or changes in the calorific value of the input coal. The 93% energy reliance on coal confirms that any micro-level solutions related to the coal utilization system (such as limiting shell radiation losses or optimizing feedstock) will yield macro-level financial value.

In terms of internal consumption between the lines in 2024, the total electricity consumed by EVN was mainly at Line 1 (166 million kWh) and Line 2 (143 million kWh), while Lines 3 and 4 utilized a large proportion from WHR and optimal load coordination. WHR electricity production in 2024 peaked at Line 4 (67.7 million kWh) and Line 3 (55.6 million kWh).

2 Methodology used to identify EE projects

2.1 How EE projects have been identified and developed

The success of energy audit depends entirely on the methodology applied. To ensure the accuracy of the data and the feasibility of the recommendations, the expert team strictly adhered to the multi-tiered methodology based on DEPP3 standard of Danish, complying with current regulations (Circular 25/2020/TT-BCT) and combining the technical guidelines of the DEPP3 program and the international standard ISO 50002 (Standard on Energy Auditing) recommended by UNIDO.

This method requires viewing the entire system holistically (Systems Approach), rather than examining individual components. Specifically, it involves analyzing the thermodynamic relationships between material and energy flows throughout the entire plant, based on a systems approach and using energy mapping.

The main steps include: defining the scope, forming an audit team, collecting historical data for 3–5 years, conducting on-site surveys and measurements, building a material-energy balance map by process and production line, analyzing KPIs and comparing them with industry standards, and thereby identifying and classifying energy efficiency opportunities.

The energy consumption structure is analyzed in detail by energy type (grid electricity, WHR electricity, coal, auxiliary fuels) and by main consumption areas (grinding, transportation, furnace – grate, compressed air, lighting, auxiliary). Key energy-consuming areas (SEUs) are identified for prioritized in-depth analysis and proposed solutions.

- ❖ **Detailed procedure for conducting an energy audit:**

The energy audit process in the project is conducted in compliance with current Vietnamese regulations, while also integrating advanced approaches from international programs.

The energy audit process is carried out according to the guidelines of Circular 25/2020/TT-BCT dated September 29, 2020. Specifically, as shown in the image below:

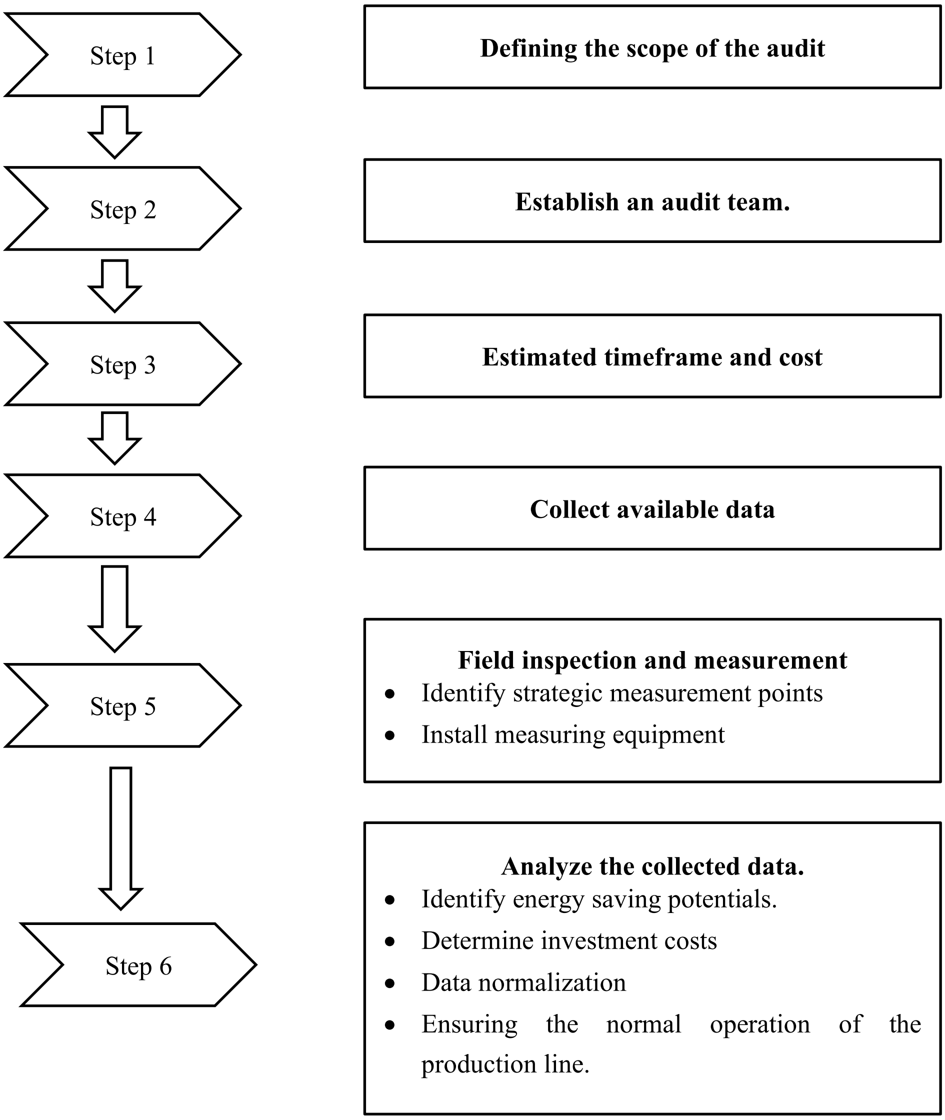


Figure 2.1. Energy audits procedure according to Circular 25

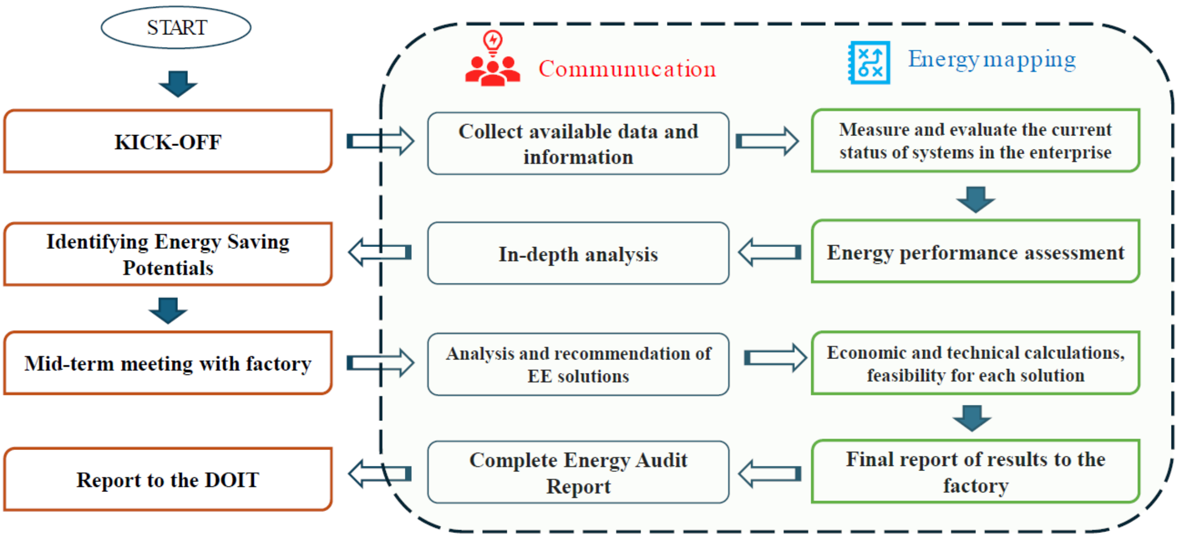


Figure 2.2. Energy audit procedure according to DE3 program

In addition to complying with the energy audit procedures under Circular 25/2020/TT-BCT, the methodology applied in this project is also adapted in line with the technical guidelines of DEPP3, with the main contents including:

- A system-based approach, focusing on key energy-consuming areas;
- Development of energy mapping to assess energy flows and identify loss points;
- Analysis of energy performance indicators (KPIs) for each process and production line;
- Identification and classification of energy-saving opportunities by priority levels (Level A, Level B);
- Evaluation of solutions not only based on energy-saving potential but also considering technical feasibility and operational impacts.

The integration of national guidelines with the DEPP3 program's approach ensures regulatory compliance while enhancing the depth of analysis and the practical applicability of the proposed solutions.

❖ **Energy mapping**

Energy Mapping is the central analytical method in this report. This tool transforms discrete data into a digitized diagram of the plant's overall energy flow. The consulting team developed a comprehensive energy diagram for the plant to visualize the energy flow from input to key consumption points, including:

- Energy balance between processes (material grinding, kiln, clinker cooling, cement grinding, auxiliary).
- Evaluate the energy efficiency of each system.
- Identify energy loss points and opportunities for improvement.

This method splits the energy flow into two main branches:

- Thermal Energy Flow: Measurement surveys indicate that heat flow (from coal) is mainly lost in 3 areas: (1) Radiation and convection through the rotary kiln shell and pre-firing tower due to the degradation of the quality of the insulating refractory bricks; (2) Heat carried away by chimney flue gas not fully recovered by the WHR system; (3) Heat loss carried away by hot clinker when leaving the cooler due to suboptimal heat exchange with secondary air.
- Electrical Energy Flow: The hotspots of electricity consumption are concentrated at the raw mill and finish mill systems due to the extremely high energy loss from mechanical friction; the multi-megawatt (MDR) Induced Draft Fan (ID) system for aerodynamic

control of the kiln; and auxiliary systems (compressed air, cooling water pumps). The mapping diagram clearly shows the gap between input energy and useful work produced, thereby accurately quantifying the potential savings.

Thanks to Energy Mapping, the team of experts clearly separated the Electricity Consumption Rate (kWh/ton) and Heat Consumption Rate (kcal/kg) (EnPIs) for each equipment cluster. The energy diagram also helps the Plant's Energy Management Board gain an overall view of the energy flow throughout the entire production line, thereby supporting decision-making and building a long-term energy optimization roadmap.

Energy performance assessment at the factory is carried out by comparing actual energy consumption with domestic and international benchmark values, and calculating key performance indicators (KPIs) for each production stage.

Specifically, the advisory group focused its assessment on:

- Electricity and heat consumption rates of clinker and cement production lines.
- Performance of key energy-consuming systems such as furnaces, grinding mills, cement mills, compressed air systems, fans, and pumps.
- Energy recovery and utilization efficiency from WHR systems
- Based on this, areas with low or suboptimal efficiency are identified, providing a basis for proposing energy-saving solutions.

Benchmarking results using industry data (Vietnam Cement Industry Average) show a mixed picture of positive and negative outcomes:

- Clinker firing electricity consumption rate: The facility achieves excellent efficiency, 8–17% lower than the industry average, and operates extremely stably over 5 years.
- Cement grinding power consumption: Reached the industry average. However, standard deviation analysis showed that Line 1 consumed more electricity than designed, which is a warning sign of mechanical wear at the grinding mill or reduced centrifugal force at the separator.
- Clinker firing heat loss: Although the WHR system has helped recover significant heat, energy mapping revealed a notable area: radiant heat loss through the kiln shell and wasteful medium-temperature (65°C - 150°C) flue gas streams escaping at the dust collector, silo, and grinding areas. The thermodynamic optimization space here is very large.

The detailed analysis and evaluation process is based on the synthesis of measurement data, operational data, and field survey results, aiming to build a technical basis for energy-saving solutions.

The main points of analysis include:

- Analyze the energy consumption structure by production stage (raw material grinding, kiln, clinker cooling, cement grinding, and auxiliary systems).
- Evaluate key performance indicators (KPIs) and compare them to benchmark values.
- Develop detailed energy flow diagrams for each area and system.

In addition, the energy consumption of key equipment and systems is also analyzed, including:

- Clinker production line: kiln, calciner, clinker cooling system
- Cement grinding line: grinding, separation, and conveying
- Compressed air systems, cooling systems, fan and pump systems
- Heat recovery system (WHR) and main electrical loads

The report analyzed data series and energy consumption patterns over the years, yielding key insights. Firstly, there was a surge in coal consumption after 2021 (almost doubling from over 590,000 tons to a sustained level of 1.1 to 1.2 million tons per year). This increase pushed thermal energy to over 92% of the total energy mix. Secondly, the near-total reliance on pulverized coal (a fossil fuel with an extremely high emission factor) directly generated over 3 million tons of CO2 in 2024, creating a significant financial risk if international carbon taxes (CBAMs) are implemented. However, the amount of electricity purchased from EVN (Vietnam Electricity) showed a slight downward trend and was offset by the internal WHR system, demonstrating the improving self-sufficiency of the enterprise in electricity generation.

This analysis process helps identify the causes of energy loss, assess the extent of its impact, and clarify the potential for improvement in each system.

Identifying energy saving opportunities is based on performance assessments and detailed analyses of the plant's systems.

The consulting team conducted the following:

- Identify opportunities for optimizing operations and improving technology.
- Propose energy-saving solutions tailored to each system and specific conditions.

The solutions focus on:

- Optimizing production line operations

- Improve device performance
- Applying advanced technologies (e.g., Machine Learning, automation)
- Utilize surplus energy and renewable energy.

For each solution, the consulting team performs the following:

- Estimate potential energy and cost savings.
- Preliminary assessment of investment costs
- Analyze the economic efficiency (payback period, IRR, NPV if needed).

Finally, the solutions were ranked based on the following criteria:

- Energy saving level
- Technical feasibility
- Investment costs
- Payback period

This will help to build a list of highly feasible energy-saving projects, serving as a basis for implementation in the next phase.

Energy consumption rate:

Due to the specific nature of cement production, which consists of two main product groups—clinker and cement—electricity is separated into two parts for separate evaluation:

a) Electricity consumption rate for clinker production

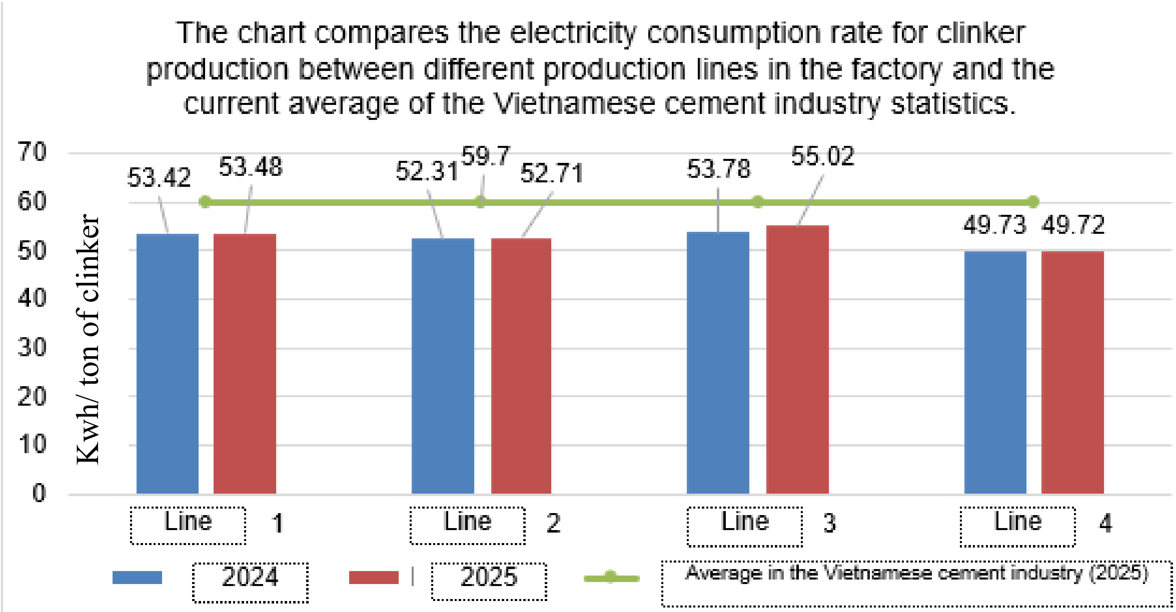


Figure 2.3. The chart compares the electricity consumption rate for clinker production between different production lines in the factory and the current average of the Vietnamese cement industry statistics.

b) Electricity consumption rate for cement grinding

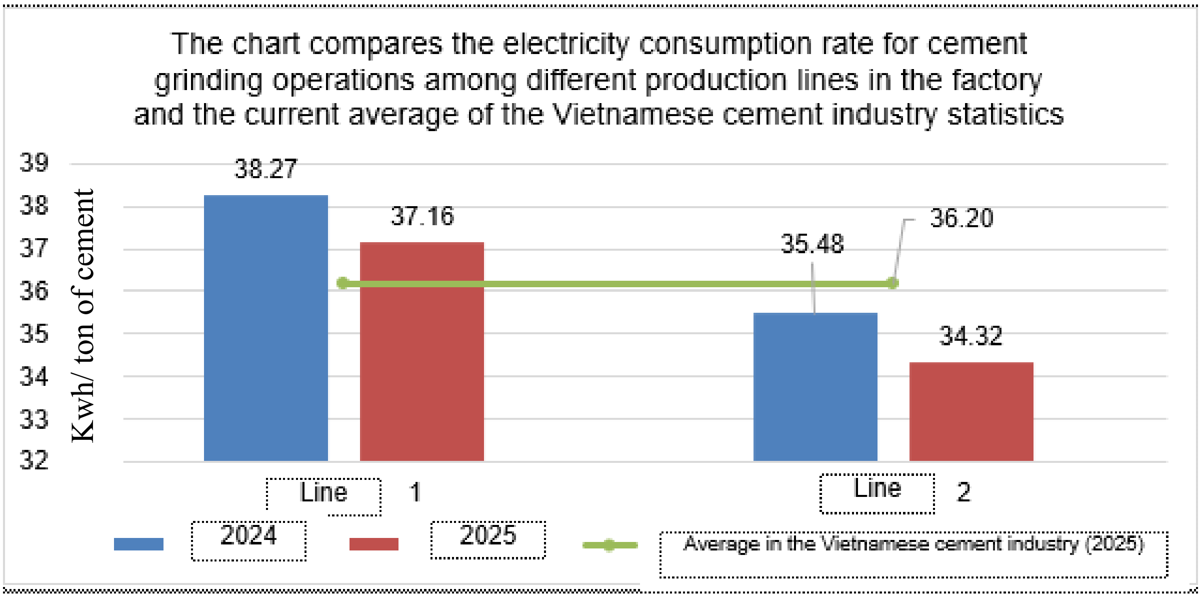


Figure 2.4. The chart compares the electricity consumption rate for cement grinding operations among different production lines in the factory and the current average of the Vietnamese cement industry statistics.

c) Thermal energy consumption rate for clinker production

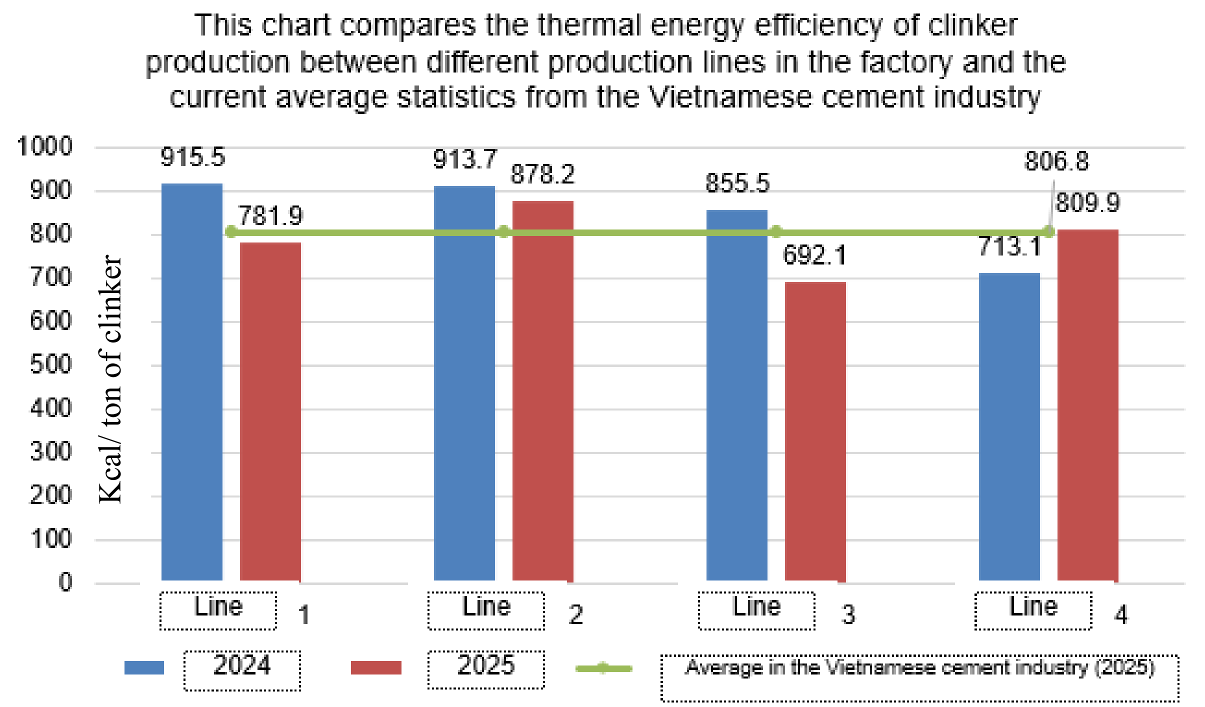


Figure 2.5. This chart compares the thermal energy consumption rate for clinker production between different lines in the factory and the current average of the Vietnamese cement industry statistics.

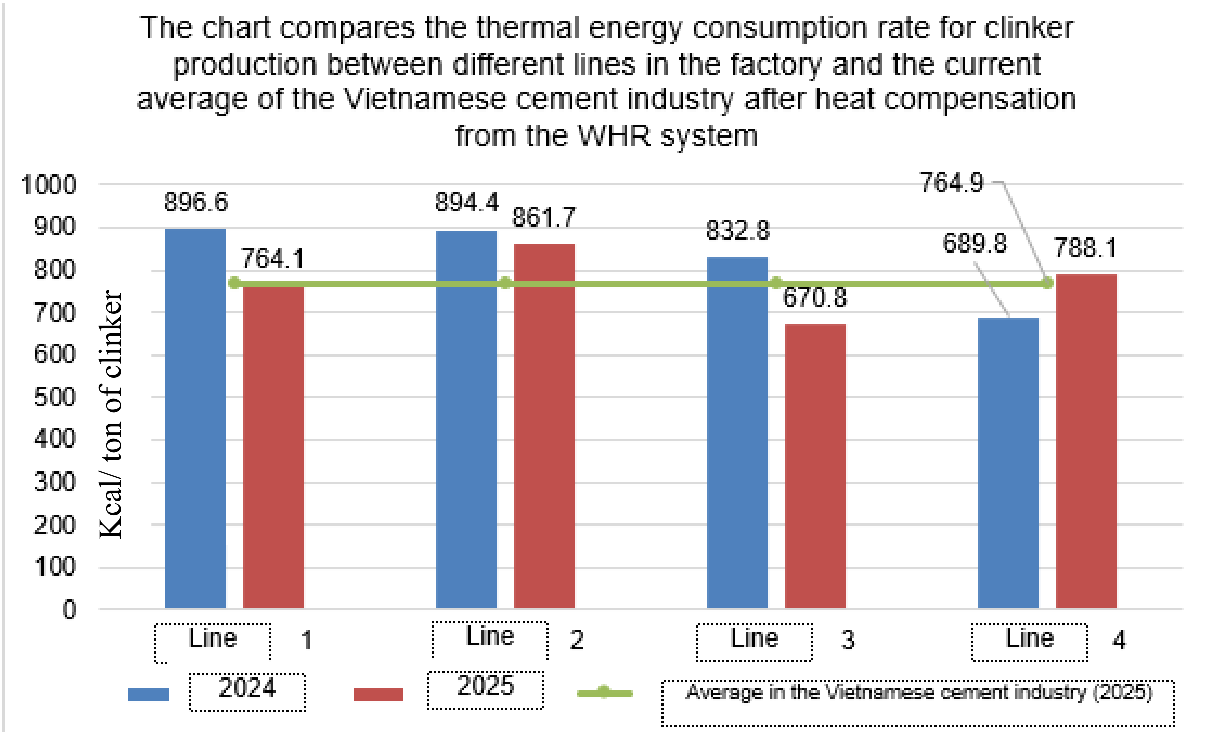


Figure 2.6. The chart compares the thermal energy consumption rate for clinker production between different lines in the factory and the current average of the Vietnamese cement industry after heat compensation from the WHR system.

Overall, the plant has better-than-average energy efficiency, particularly in the clinker production stage, with electricity consumption 8–17% lower and stable operation over the years. The cement grinding stage also achieves a level equivalent to or better than the industry average; however, discrepancies still exist between the production lines, with line 1 having further potential for optimization.

Regarding heat consumption, operational efficiency across production lines is uneven but has shown significant improvement in 2025, particularly in lines 1 and 3. Utilizing waste heat through the WHR system has significantly contributed to reducing overall energy consumption, bringing the plant closer to good efficiency. However, there is still room for improvement, mainly in optimizing kiln operation and cement grinding processes. Therefore, the synchronized implementation of energy-saving solutions, combined with the application of an energy management system according to ISO 50001:2018 standards, will enhance control, reduce variability, and optimize energy consumption across the entire plant.

To determine energy saving potential, the consulting team combined system analysis using Energy Mapping tools with expert assessments.

Key findings from the energy scheme analysis include:

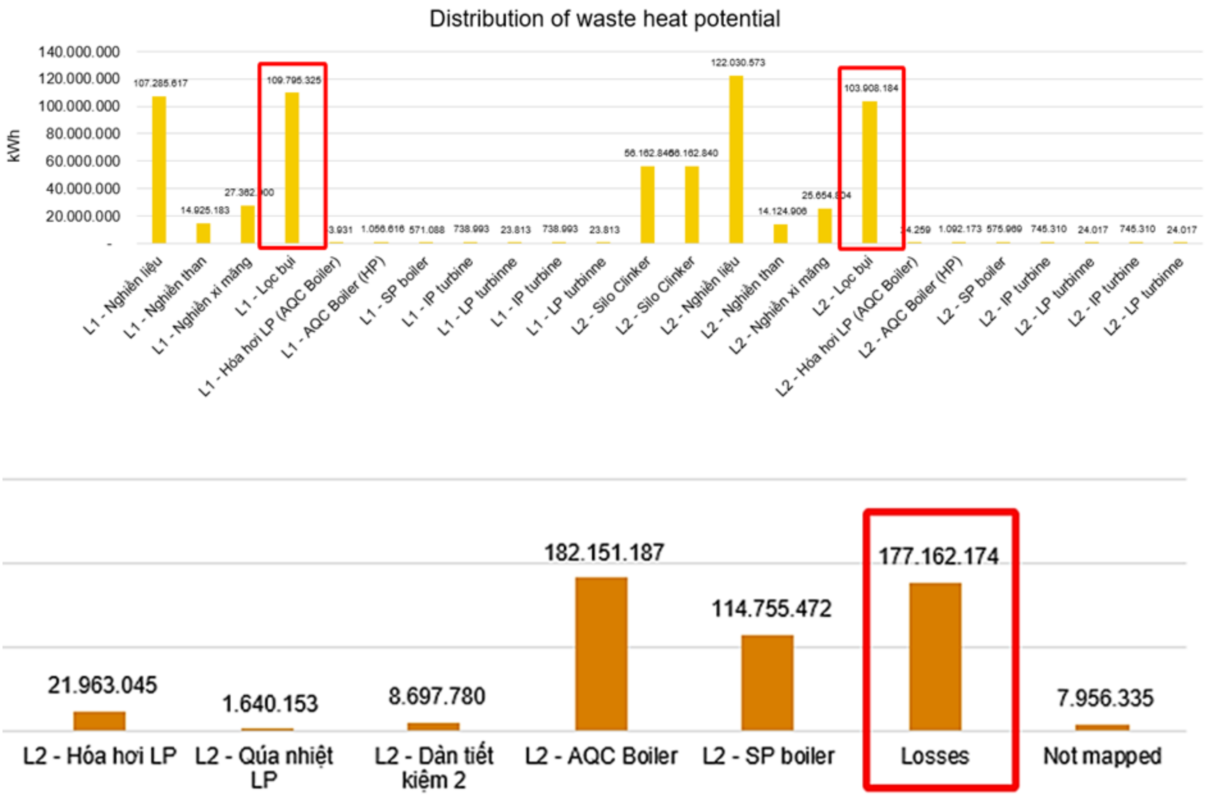


Figure 2.7. Identifying energy saving potential through mapping.

The results of the energy diagram analysis show that large electrical loads are mainly concentrated in systems such as material grinding, cement grinding, high-power fans, and compressed air systems. Among these, the compressed air system and continuously operating equipment (fans, pumps) account for a significant proportion of electricity consumption, indicating potential for optimization through improved operating modes and enhanced equipment efficiency.

Regarding thermal energy, most of the heat is supplied to the clinker burning process in the rotary kiln and calciner. However, significant heat losses still occur through exhaust gases, radiation, and clinker cooling processes. Although the plant is equipped with a waste heat recovery (WHR) system, some of the residual heat remains unutilized, particularly in the exhaust gas streams and cooling areas.

Furthermore, because the plant simultaneously employs heating and cooling processes, along with various waste heat sources, the potential for optimization through heat recovery and reuse is significant. Developing an energy flow diagram helps visualize the energy flow throughout the entire process, thereby supporting management, control, and the proposal of energy-saving solutions such as operational optimization, technological improvements, and system efficiency enhancement.

The energy mapping process also uncovered a certain percentage of 'Not Mapped' energy, indicating that the business needs to upgrade its workshop metering system for more accurate loss control.

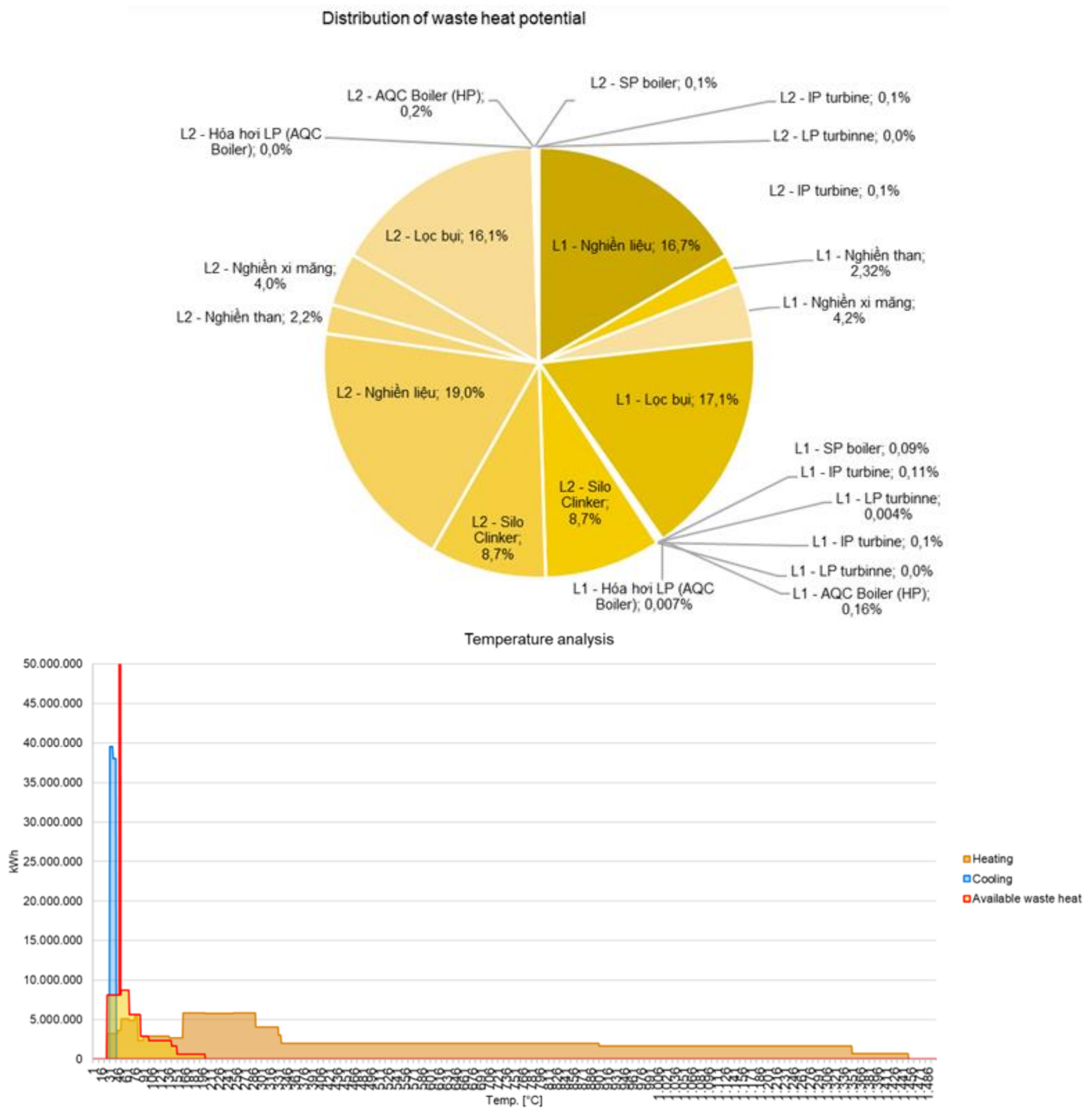


Figure 2.8. Identifying the potential for waste heat recovery and optimizing heat transfer between processes (red circled area).

Through the systems analysis methods described above, the consulting team proposed a list of potential energy-saving solutions (Level B list) as presented in Chapter 3 of the report.

The energy saving potential proposed by the consulting team is enormous. Implementing these solutions will significantly reduce energy costs. The proposed solutions are considered highly feasible both technically and economically. Based on the proposed list, the consulting team will collaborate with the factory to select the solutions requiring further investment research (Level A list). Investment costs will be estimated and calculated in detail during the investment phase.

Table 2.1 Level A list – Energy Saving Solutions Requiring Investment

No.	Describe	Coal energy savings (tons)	Potential savings (kWh)	Estimated cost savings (Million VND)	Investment cost (Million VND)	Return on investment (years)
1	Establish, implement, and certify an Energy Management System according to ISO 50001:2018 standards.	2,448.88	1,296,654	8,648	3,000	0.35
2	Solar power system installation solutions		14,134,437	30,945	172,250	5.57
3	Install a variable frequency drive (VFD) for the air compressor system combined with a central controller for the compressed air system		590,358	1,150.02	3,600.00	3.13
4	Pipeline renovation: "Installation of pressure distribution piping for the compressed air system"		836,437.63	1,629.38	4,500.00	2.76
5	Install a HydroBall automatic cleaning system, electronic descaling device, and automatic controller for the circulating water pump and cooling tower fan based on condenser vacuum pressure.		2,447,672	4,768.07	3,000	0.63
6	Waste heat recovery solution (>100°C) using absorption chiller technology to serve the air-conditioning system for loads in the control room and electrical substation areas (L1–L4).		1,296,480.00	2,525.54	9,000.00	3.56
7	Machine Learning solutions for optimizing manufacturing operations.	18,366.6	12,966,543.13	71,175.25	116,600.00	1.64

No.	Describe	Coal energy savings (tons)	Potential savings (kWh)	Estimated cost savings (Million VND)	Investment cost (Million VND)	Return on investment (years)
Total		**20,815.45**	**33,568,582**	**120,841**	**311,950**	**2.58**

2.2 EE Project evaluation

The evaluation of each energy-saving solution is conducted based on a clearly structured evaluation framework. This evaluation considers multiple factors, including energy savings, financial efficiency, and environmental impact, to ensure a comprehensive analysis of each proposed solution.

For each solution, energy savings are estimated by comparing baseline energy consumption with the projected performance after the improvement. Financial feasibility is assessed through key indicators such as payback period, Internal Rate of Return (IRR), and Net Present Value (NPV), considering both initial investment costs and long-term savings. In addition, environmental benefits are quantified through CO_2 emission reductions, converted to TOE (tons of oil equivalent), ensuring alignment with sustainable development goals.

Detailed calculations for each HQNL solution are presented in the appendix.

Part 1: Technical solutions for energy saving:

2.2.1 Power supply system

2.2.2 Installing a ground-mounted solar power system

Input data:

- Expected installed capacity: 10,000 kWp;
- Average annual electricity production: 14,134,437 kWh;
- Installation costs: based on 3 options (no storage, 10MWh storage, and 20MWh storage);
- Solution lifespan: 20 years.

Summary of economic efficiency calculation results:

- Energy savings: 14,134,437 kWh/year;
- Annual cost savings: VND 30,945 million/year;
- Project investment cost: 172,250 million VND;
- Payback period: 5.6 years.

Conclusion: The solution has significant potential to save energy and reduce the Company's operating costs, while also contributing to greenhouse gas emission reductions. However, as this is a large-scale solution, the Company should develop an appropriate implementation roadmap based on the findings of this energy audit. To improve investment efficiency, the company can seek funding from the Ministry of Industry and Trade's energy efficiency investment support program, financial support programs from non-governmental organizations, or invest through profit-sharing arrangements based on energy efficiency savings via energy service companies (ESCOs).

2.2.3 Lighting system

- **Replace the 70W and 150W halogen bulbs with high-efficiency LED bulbs.**

Input data:

- Lamp power:
  + Halogen 70W (actually 85W) → LED 30W
  + Halogen 150W (actually 170W) → LED 70W
- Quantity:
  + 4,362 bulbs (70W)
  + 149 bulbs (150W)
- Operating time: 3,650 hours/year
- Simultaneous usage rate: 80%
- Average electricity price: 1,948 VND/kWh.

Summary of economic efficiency calculation results:

- Total electricity savings: 744,045 kWh/year
- Total cost savings: 1,449 million VND/year
- Total investment cost: 2,841 million VND
- Payback period: 1.96 years.

Conclusion: The solution is highly feasible, the technology is simple, easy to implement, and delivers significant electricity savings. It is a medium-cost solution with a quick return on investment and low risk, making it suitable for simultaneous implementation throughout the entire factory.

2.2.4 Compressed air system

- **Solution 1: Install a variable frequency drive (VFD) for the air compressor system combined with a central controller for the compressed air system.**

Input data:

- Number of compressed air systems surveyed: 6 systems (D31 – D36)
- Total installed capacity: 480 – 720 kW/system

- Current operating pressure: ~0.65 – 0.68 MPa
- Pressure after renovation: ~0.62 MPa
- Operating time: continuous (~85 – 99% load)
- Idle run rate (unload): ~30%
- Average electricity price: 1,948 VND/kWh.

Summary of economic efficiency calculation results:

- Energy savings per year: 590,358 kWh/year;
- Annual cost savings: VND 1,150 million/year;
- Project investment cost: 3,600 million VND;
- Payback period: 3.13 years.

Conclusion: The solution has the potential for significant energy savings and is suitable for deployment, particularly effective in systems with high load and long operating hours (such as D35, D34). However, priority should be given to regional investments to optimize financial efficiency, as some systems have longer payback periods.

- **Solution 2: Regularly inspect and repair any compressed air leaks.**

Input data:

- Number of compressed air systems: 6 systems (D31 – D36)
- Number of air compressors: 4 – 6 units/system
- Total installed capacity: 480 – 720 kW/system
- Annual electricity consumption: ~2.1 – 4.6 million kWh/year/system
- Estimated loss rate due to leakage: ~1%
- Average electricity price: 1,948 VND/kWh.

Summary of economic efficiency calculation results:

- Total electricity savings: 182,732 kWh/year
- Total cost savings: 356 million VND/year
- Total investment cost: 120 million VND;
- Payback period: 0.34 years.

Additional benefits:

- Reduce the load on the air compressor system;
- Reduce compressed air losses and improve pressure stability;

- Reduce emissions by approximately 120 tons of CO_2 per year.

Conclusion: This is a low-cost, high-efficiency solution with a very quick return on investment, and should be prioritized for immediate implementation. Controlling and rectifying leaks not only saves energy but also improves the reliability and lifespan of the entire compressed air system.

- **Solution 3: Install pressure distribution piping for the compressed air system.**

Input data:

- Number of compressed air systems: 6 systems (D31 – D36)
- Number of air compressors: 4 – 6 units/system
- Total installed capacity: 480 – 720 kW/system
- Annual electricity consumption: ~2.1 – 4.6 million kWh/year/system
- Current operating pressure: ~0.65 – 0.68 MPa
- Low load ratio: ~45 – 60%
- Pressure after renovation (low pressure group): ~0.50 MPa.

Summary of economic efficiency calculation results:

- Total electricity savings: 836,438 kWh/year
- Total cost savings: 1,629 million VND/year
- Total investment cost: 4,500 million VND
- Payback period: 2.14 – 4.82 years.

Additional benefits:

- Reduces the operating load on the high-pressure air compressor group;
- Reduces throttling losses and limits the generation of excess-pressure compressed air;
- Reduces compressed air leakage by lowering pressure across most of the distribution network;
- Improves pressure stability for each load group based on actual demand;
- Reduces equipment wear and extends the service life of air compressors and compressed-air end-use equipment;
- Facilitates the management, monitoring, and optimization of the compressed air system by pressure level;
- Reduces emissions by approximately 551.38 tonnes of CO_2/year.

Conclusion: This solution offers relatively high energy efficiency, suitable for the distributed load characteristics across multiple pressure levels in a cement plant. Pressure stratification optimizes the operation of the entire compressed air system and provides sustainable efficiency.

2.2.5 Heat recovery power generation (WHR) system

- **Install a HydroBall automatic cleaning system, electronic descaling device, and automatic controller for the circulating water pump and cooling tower fan based on condenser vacuum pressure.**

Input data:

- Current operating conditions: High heat loss (>50%) in the heat recovery power generation (WHR) condenser, difficulty maintaining low vacuum pressure due to scaling, and limitations of manual pump/fan control.
- Total electricity generation of the system: 52.67 million kWh/year
- Current self-consumption of the WHR system: 2.84 million kWh/year (~5.39%)
- Potential for reducing self-consumption of electricity: 12%
- Expected system performance increase: 4%
- Average electricity price: 1,948 VND/kWh

Summary of economic efficiency calculation results:

- Energy savings (reduced self-consumption): 340,968 kWh/year
- Additional electricity consumption (due to increased efficiency): 2,106,704 kWh/year
- Total electricity benefits (converted): 2.45 million kWh/year
- Total cost savings: VND 4,768 million/year
- Emission reduction: 225 tons of CO_2/year
- Investment cost: 3,000 million VND
- Payback period: 7.5 months (~0.63 years)
- Expected CO2 emission reduction: 224.77 tons of CO2/year.

Additional benefits:

- Improves the condenser vacuum pressure from approximately -85.7 kPa to -92.5 kPa, helping increase the WHR system efficiency by around 3–5%;
- Reduces electricity consumption of the circulating water system and cooling tower by 10–15%;

- Maintains stable heat exchange efficiency, limits scaling, and reduces the frequency of equipment cleaning;
- Reduces maintenance costs, extends equipment service life, and improves system operational stability;
- Contributes to greenhouse gas emission reductions and improves the overall energy efficiency of the plant.

Conclusion: This solution offers a dual benefit: high technical and economic feasibility, strong innovation, and a very quick return on investment, providing both reduced self-consumption of electricity and increased power generation. Equipping the system with electronic descaling devices combined with automatic cleaning technology ensures the condenser's heat exchange surface remains clean, effectively preventing scale buildup. As a result, the system's vacuum pressure is maximized, increasing turbine output while minimizing the self-consumption of the cooling tower's pumps and fans. With a payback period of less than 8 months, this is a top priority solution that businesses should implement immediately.

2.2.6 Production machine system

- **Solution 1: Replace low-efficiency IE1 motors with high-efficiency motors (IE3-IE4) whenever possible**

Input data:*(Sample calculations for some typical engines in Line 1 and Line 2)*

- Line 1 (IE1 → IE4):
  - Power: 160 kW (1 motor – 221CR01 crusher)
  - Efficiency: 93.8% → 96.6%
- Line 2 (IE2 → IE4):
  - Power: 90 kW × 2 motors (conveyor belts 322BC02 & 522BC08MT01)
  - Efficiency: 93.0% → 96.1%
- Operating time: 8,640 hours/year
- Utilization rate: 70%
- Average electricity price: 1,948 VND/kWh.

Summary of economic efficiency calculation results:

- Total electricity savings: 85,833 kWh/year
  - Line 1: 52,415 kWh/year
  - Line 2: 33,418 kWh/year
- Total cost savings: 167 million VND/year

+ Line 1: 102 million VND/year
+ Line 2: 65 million VND/year

- Total investment cost: 1,090 million VND
- Payback period:
    + Line 1: 4.41 years
    + Line 2: 9.83 years
    + Average: 6.5 years.

Additional benefits:

- Reduces electricity losses and operating costs throughout the equipment life cycle;
- Reduces heat generation, improving operational stability and reliability;
- Extends motor service life by reducing mechanical wear and thermal losses;
- Reduces emissions by approximately 85.83 tonnes of CO_2/year;
- Suitable for phased implementation during major overhauls or equipment replacement due to failure, in order to optimize investment costs and minimize impacts on production.

Conclusion: This solution helps improve equipment efficiency and reduce power losses; however, the payback period is relatively long due to high investment costs. Therefore, it should be implemented as a replacement option when opportunities arise (due to malfunctions, overhauls) rather than investing in a large number of equipment at once.

- **Solution 2: Waste heat recovery solution (>100°C) using absorption chiller technology to serve the air-conditioning system for loads in the control room and electrical substation areas (L1–L4).**

(Typically applicable to air conditioning systems – Line 1)

Input data:

- Cooling capacity:
    + Previous: 580 RT
    + After: 630 RT
- Power consumption:
    + Previous: 328 kW
    + After: 180 kW
- Operating hours: 24 hours/day; 365 days/year
- Electricity consumption:
    + Previously: 2,873,280 kWh/year

+ After: 1,576,800 kWh/year

- Average electricity price: 1,948 VND/kWh.

Summary of economic efficiency calculation results:

- Electricity savings: 1,296,480 kWh/year
- Cost savings: VND 2,525.5 million/year
- Investment cost: 9,000 million VND
- Payback period: 3.2 years.

Conclusion: Utilizing waste heat for refrigeration significantly reduces HVAC system electricity consumption while improving the overall energy efficiency of the plant. With an IRR of approximately 24.65% and a positive NPV, this is a viable and economically viable solution, offering clear efficiency and suitability for production lines with a stable waste heat source.

Part 2: Management solutions for energy saving:

Energy Management and Optimization Solutions

- **Solution 1: Machine Learning solutions for optimizing manufacturing operations**

Principles, Benefits, and Novelty of Machine Learning Solutions

- AI/ML applications are used to analyze operational data in real time, thereby optimizing material mix, kiln and grinding system operations, and predicting and automatically adjusting critical parameters. This helps reduce heat and electricity consumption, minimize operational fluctuations, and improve overall system efficiency.
- The solution offers several clear benefits, such as a 3–5% reduction in energy consumption, increased operational stability, and reduced reliance on operator experience.
- This is an advanced solution that has been implemented in many large cement plants around the world (ABB, FLSmidth, Schneider, etc.), aligning with the trend of digital transformation and data-driven energy optimization (AI-driven operation).

Input data:

- Total electricity consumption in 2024:
  + Line 1: 221.5 million kWh
  + Line 2: 188.7 million kWh
  + Line 3: 117.8 million kWh

+ Line 4: 120.4 million kWh

- Total coal consumption:
  + Line 1: 321,601 tons
  + Line 2: 304,357 tons
  + Line 3: 301,772 tons
  + Line 4: 296,708 tons
- Electricity price: 1,948 VND/kWh
- Coal price: 2.5 million VND/ton
- Optimal potential:
  + Power reduction: ~2%
  + Coal reduction: ~1.5%.

Summary of economic efficiency calculation results:

- Total electricity savings: 12,966,543 kWh/year
- Total coal savings: 18,366 tons/year
- Total cost savings: VND 71.175 million/year
- Investment cost: 116,600 million VND
- Payback period: 1.55 – 1.71 years

Conclusion: This solution has the greatest impact among the proposed solutions, with high potential for savings, a quick return on investment, and long-term strategic benefits. It should be prioritized for implementation on a factory-wide scale.

- Solution 2: **Establish an energy management system according to ISO 50001:2018 standards.**

Input data:

- Total electricity consumption in 2024: 648,327,157 kWh
- Total coal consumption: 1,224,438 tons
- Electricity price: 1,948 VND/kWh
- Coal price: 2.5 million VND/ton
- Potential for improvement:
  + Power reduction: ~0.2%
  + Coal reduction: ~0.2%

Summary of economic efficiency calculation results:

- Energy savings: ~1,296,654 kWh/year
- Coal savings: ~2,449 tons/year
- Cost savings: approximately VND 8,648,000 per year
- Investment cost: ~3,000 million VND
- Payback period: 0.37 years (~4–5 months).

Conclusion: This medium-cost, high-efficiency solution offers a very quick return on investment and serves as a foundation for maintaining and optimizing the effectiveness of all other energy saving solutions. Early implementation at the factory-wide level should be prioritized.

2.3 The process of the development and implementation of the identified projects.

The main solutions selected for inclusion in the investment study proposal after conducting an energy audit are presented in the Level A list (Table 2.2). To achieve the goal of transforming the plant into an energy-efficient plant, the proposed solutions need to go through several key stages.

The process begins with an energy audit report, providing an overview of the plant's energy saving potential. This is followed by a pre-feasibility phase to identify and select two to three of the most important solutions. The feasibility phase then evaluates these options to determine the most viable solution for investment. After an investment decision is made, the process moves to the bidding or competitive quotation phase, followed by evaluation of bids or procurement.

The installation and commissioning phases require close monitoring by the plant to ensure that key design decisions made during the feasibility and bidding phases are properly executed. Once the solution is installed and operational, a comprehensive evaluation is necessary to collect and record new energy performance data. This final step aims to ensure that the solution not only performs as expected but also delivers the anticipated energy savings.

2.4 Feedback from the Enterprise

Following the presentation and discussion, the factory agreed with the energy audit results and all proposed energy-saving solutions. In addition, the factory also hopes to receive cooperation and support from the Project Management Board in the next steps to ensure the successful implementation of energy saving solutions. Accepting DEPP3's green energy proposals aligns perfectly with the company's long-term strategy to improve operational efficiency, increase equipment reliability, and achieve sustainable development goals while minimizing greenhouse gas emissions.

3 EE Projects identified

Through energy mapping analysis and field diagnostics, the expert team compiled a series of preliminary energy efficiency solutions (Level B list) aimed at comprehensive interventions ranging from operational behavior to heavy mechanical improvements. If the entire Level B project portfolio is implemented, the facility could save 34,581,192.4 kWh of electricity and 20,815.4 tons of coal annually. However, to ensure optimal allocation of investment funds, the report applied a rigorous filter of criteria including technical feasibility, positive NPV, IRR exceeding financial barriers, and carbon emission reduction levels. After the screening process, the energy efficiency projects were classified into:

- Level A: Priority solutions, which have undergone detailed technical, energy, and financial analysis, have significant savings potential, and are operationally feasible.
- Level B: A complete list of energy saving opportunities identified during the audit process requires further preliminary/detailed study in subsequent stages.

Priority criteria included: scale of energy and cost savings, payback period, technical readiness, impact on production and maintenance, compatibility with existing systems, technical and operational risks, and contribution to the company's sustainable development and emission reduction goals. As a result, 7 Level A solutions were selected for further study and investment proposals, as shown in Table 2.1.

Table 3.1. Level B list

No	Energy saving solutions	Estimated energy savings		Money savings (million VND/year)	Investment cost (million VND)	Payback period (year)
		Electricity (kWh)	Coal (tons)			
I. Management solutions group						
1	Continue to regularly and periodically implement propaganda, education, and dissemination of	**Recommendation**				

No	Energy saving solutions		Estimated energy savings		Money savings (million VND/year)	Investment cost (million VND)	Payback period (year)
			Electricity (kWh)	Coal (tons)			
	knowledge on energy saving to employees in the Company.						
2	Manage load & optimize electricity tariffs		Load shifting, peak load control, WHR coordination. Shifting 4% of peak-hour electricity consumption to other time slots resulted in savings of 3,004.3 million VND (*).				
3	Develop, apply, and certify an Energy Management System according to ISO 50001:2018 standards		1,296,654	2,449	8,648	3,000	0.35
4	Machine Learning solutions for optimizing manufacturing operations	Production Line 1	4,430,090	4,824	20,689.85	31,800	1.54
		Production Line 2	3,773,771	4,565	18,764.69	31,800	1.69
		Production Line 3	2,355,562	4,527	15,905.09	26,500	1.67
		Production Line 4	2,407,120	4,451	15,815.62	26,500	1.68
	Total energy savings of the solution		**12,966,543**	**18,367**	**71,175.25**	**116,600**	**1.64**
II. Power supply system							
5	Solar power system installation solutions - using a typical example of a 10MWp solar power system without storage		14,134,437		30,944.52	172,250	5.57
III. Compressed air system (AC)							

<table>
<tr><th rowspan="2">No</th><th rowspan="2" colspan="2">Energy saving solutions</th><th colspan="2">Estimated energy savings</th><th rowspan="2">Money savings (million VND/year)</th><th rowspan="2">Investment cost (million VND)</th><th rowspan="2">Payback period (year)</th></tr>
<tr><th>Electricity (kWh)</th><th>Coal (tons)</th></tr>
<tr><td>6</td><td colspan="2">Equipped with flow measurement and monitoring systems to support data-driven analysis and operational optimization.</td><td colspan="5">Recommendation</td></tr>
<tr><td>7</td><td colspan="2">Standardize and optimize the system's operating pressure based on actual usage requirements.</td><td colspan="5">Recommendation</td></tr>
<tr><td rowspan="7">8</td><td rowspan="6">Install a variable frequency drive (VFD) for the AC system combined with a central controller for the compressed air system.</td><td>AC system L1 – D31</td><td>84,934.92</td><td></td><td>165.45</td><td>600</td><td>3.86</td></tr>
<tr><td>AC system L1 – D32</td><td>79,470.75</td><td></td><td>154.81</td><td>600</td><td>4.14</td></tr>
<tr><td>AC system L2 – D33</td><td>48,868.52</td><td></td><td>95.2</td><td>600</td><td>7.04</td></tr>
<tr><td>AC system L2 – D34</td><td>100,062.18</td><td></td><td>194.92</td><td>600</td><td>3.24</td></tr>
<tr><td>AC system L3 – D35</td><td>194,713.10</td><td></td><td>379.3</td><td>600</td><td>1.62</td></tr>
<tr><td>AC system L4 – D36</td><td>82,308.08</td><td></td><td>160.34</td><td>600</td><td>3.9</td></tr>
<tr><td colspan="2">Total energy savings of the solution</td><td>590,357.55</td><td>-</td><td>1,150.02</td><td>3,600.00</td><td>3.13</td></tr>
<tr><td rowspan="6">9</td><td rowspan="6">Regularly inspect and repair any compressed air leaks</td><td>AC system L1 – D31</td><td>23,084</td><td></td><td>44.97</td><td>20</td><td>0.44</td></tr>
<tr><td>AC system L1 – D32</td><td>26,490</td><td></td><td>51.6</td><td>20</td><td>0.39</td></tr>
<tr><td>AC system L2 – D33</td><td>20,980</td><td></td><td>40.87</td><td>20</td><td>0.49</td></tr>
<tr><td>AC system L2 – D34</td><td>33,354</td><td></td><td>64.97</td><td>20</td><td>0.31</td></tr>
<tr><td>AC system L3 – D35</td><td>33,097</td><td></td><td>64</td><td>20</td><td>0.31</td></tr>
<tr><td>AC system L4 – D36</td><td>45,727</td><td></td><td>89.07</td><td>20</td><td>0.22</td></tr>
</table>

No	Energy saving solutions		Estimated energy savings		Money savings (million VND/year)	Investment cost (million VND)	Payback period (year)
			Electricity (kWh)	Coal (tons)			
	Total energy savings of the solution		**182,732**		**356**	**120**	**0.34**
10	Pipeline renovation: "Installation of pressure distribution piping for the compressed air system"	AC system L1 – D31	109,074		212.48	750	3.7
		AC system L1 – D32	143,047		278.66	750	2.79
		AC system L2 – D33	84,967		165.52	750	4.82
		AC system L2 – D34	180,112		350.86	750	2.2
		AC system L3 – D35	134,044		261.12	750	2.99
		AC system L4 – D36	185,193		360.76	750	2.14
	Total energy savings of the solution		**836,437.60**		**1,629.40**	**4,500.00**	**2.76**
IV. Lighting system							
11	Optimize lighting control based on area and actual usage needs.		**Recommendation**				
12	Implement automated control solutions (presence sensors, light sensors).		**Recommendation**				
13	Improve operational efficiency through regular cleaning of the lighting system.		**Recommendation**				
14	Replace 70W and 150W halogen bulbs with high-efficiency LED bulbs.		744,045		1,449	2,841	1.96
V. WHR system							

No	Energy saving solutions	Estimated energy savings		Money savings (million VND/year)	Investment cost (million VND)	Payback period (year)
		Electricity (kWh)	Coal (tons)			
15	Optimizing the clinker cooling system	Reduce **1–3% of thermal energy consumption in the kiln system** through grate air distribution optimization, reduction of excess air, and improved heat recovery efficiency.(*)				
16	Installing an automatic HydroBall cleaning system, electronic descaling device, and automatic controller for the circulating water pump and cooling tower fan based on condenser vacuum pressure – Typical example for Line 1	2,447,672		4,768.07	3,000	0.63
VI. Production support						
17	Optimizing the air system & reducing false gas	Conduct leakage inspections, optimize O_2/CO levels, reduce pressure losses, and standardize fan operation to **achieve 1–3% reduction in kiln thermal consumption.**(*)				
18	Optimizing Preheater & Calciner	Reduce cyclone ΔP, improve material distribution, stabilize combustion, and optimize O_2/CO control to **achieve 2–5% reduction in thermal energy consumption.**(*)				
19	Optimizing raw material moisture & drying	Manage raw material moisture seasonally, optimize raw mix composition, and utilize hot gas recovery to **reduce 1–4% of drying and grinding energy consumption.**(*)				
20	Optimizing the fan system	Review operating points, apply VFDs and reduce system losses **to achieve 3–5% electricity savings in fan systems.**(*)				
21	Optimizing cement grinding	Optimize classification efficiency, ventilation, circulating load, and grinding aids **to reduce 2–4% electricity consumption in grinding operations.**(*)				

No	Energy saving solutions	Estimated energy savings		Money savings (million VND/year)	Investment cost (million VND)	Payback period (year)
		Electricity (kWh)	Coal (tons)			
22	Reducing furnace shell heat loss	Apply thermal scanning and hot spot monitoring/control **to reduce 0.5–2% thermal losses**(*)				
23	Fuel preparation and combustion fineness optimization	Reduce furnace heat loss **by approximately 1–3% through improved coal fineness, combustion stability, and increased heat exchange efficiency (*).**				
24	Alternative fuels readiness screening	The potential for preheating replacement is **approximately 5–15% of TSR in the initial stage(*)**				
25	Clinker factor reduction and product portfolio optimization	Potential for a reduction of **approximately 3–8% in thermal energy equivalent per ton of cement (*)**				
26	Replacing low-efficiency IE1 motors with high-efficiency motors (IE3-IE4) when possible – Typical example	85,833		167	1,090	6.52
27	Waste heat recovery solution (>100°C) using absorption chiller technology to serve the air-conditioning system for loads in the control room and electrical substation areas (L1–L4)– Typical example for Air Conditioning System Line 1	1,296,480.00		2,525.54	9,000.00	3.56
Total energy savings for the entire factory		**34,581,192.40**	**20,815.40**	**122,813.40**	**316,001**	**2.57**

(*)*Items marked with * are for reference only, estimated empirically, based on professional literature and data used for estimation through Energy Mapping analysis, process heat consumption analysis, and line-specific thermal SEC.*

4 Selected EE Projects for further supports

The approval of investment and the synchronized implementation of the 7 Level A projects in Table 2.1 have been shown to bring about an energy transformation for the plant. With an estimated potential savings of 33,568,582 kWh of electricity and 20,815.4 tons of coal per year, the enterprise will save VND 120,841 million annually, while requiring only a technical investment package worth VND 311,950 million. Below is an in-depth technical analysis of the operating principles and feasibility of each proposed project.

4.1 Establish an energy management system according to ISO 50001:2018 standards.

Project description:

- Current Status:

The Plant has already implemented various energy management and optimization activities in its actual operations and has initially established a mechanism for monitoring and controlling energy consumption in several key process areas. However, the current energy management system has not yet been fully standardized and integrated in accordance with the structure of ISO 50001:2018.

In addition, the monitoring, evaluation, and control of energy consumption across production lines and process areas remain fragmented. Energy performance indicators (EnPIs), energy baselines, and the management mechanism for significant energy uses (SEUs) have not yet been developed in a consistent and systematic manner.

Several areas still have potential for improvement, including:

+ Strengthening the mechanism for continuously and consistently monitoring and evaluating energy performance across production lines;
+ Further standardizing energy management, operation, and reporting procedures in line with ISO 50001:2018;
+ Completing the identification, monitoring, and management of significant energy uses (SEUs);
+ Developing long-term energy objectives, targets, and action plans linked to continuous improvement activities.

Therefore, further improvement of the energy management system in accordance with ISO 50001:2018 will help the Plant enhance energy efficiency in a sustainable manner, while strengthening its ability to maintain and expand energy-saving results over the long term. .

Proposed solution:

- Principles and approaches

The ISO 50001:2018 energy management system is built on a continuous improvement cycle (PLINEA), which includes the following main steps:

+ Establishing energy policy;
+ Energy Planning;
+ Deployment and operation;
+ Continuous testing, evaluation, and improvement.

Figure 4.1. Energy management model according to ISO 50001:2018 standard

- Main implementation content

(1) Commitment of senior leadership The factory's leadership plays a key role in system implementation, with the following commitments:

+ Develop energy policies and long-term energy saving targets (e.g., a 3–5% reduction over 3–5 years);
+ Allocate resources (personnel, finances) for energy management activities;
+ Strengthen monitoring of energy consumption in key areas;
+ Promote awareness of energy conservation throughout the factory.

(2) Establish an energy management organizational structure. Establish an Energy Management Board with a clear structure, including:

+ Representative of the leadership;
+ Energy manager;
+ Energy management team in each department.

The Energy Management Department is responsible for implementing, monitoring, and maintaining the energy management system throughout the plant.

(3) Energy planning

+ Establishing an energy baseline (EnB): This serves as a basis for comparison and evaluation of effectiveness before and after the implementation of solutions.

+ Develop energy efficiency index (EnPI): Examples: kWh/t clinker, kcal/kg clinker, kWh/t cement, etc.
+ Identify key energy consumption areas (SEUs):

- ID fan system;
- Coal crushing system;
- Material grinding system;
- Cement grinding system;
- Rotary kiln system.

(4) Identifying energy saving opportunities. Based on the results of the energy audit and data analysis, the Energy Management Board will:

+ Identify and update the list of energy saving solutions;
+ Evaluate the feasibility and effectiveness of each solution;
+ Prioritize implementation based on effectiveness and investment capacity.

(5) Set goals, targets and action plans

+ Set energy targets (e.g., reduce electricity consumption by ≥0.5%/year);
+ Establish specific targets for each department;
+ Develop an action plan with:

- Clearly define responsibilities;
- Timeline for implementation;
- Methods for measuring and validating results.

Expected benefits

Implementing an energy management system according to ISO 50001:2018 offers the following key benefits:

- Saving approximately 0.1–3% of total annual energy consumption;
- Reduce operating and maintenance costs for equipment;
- Improve the effectiveness of energy monitoring and control;
- Enhance system stability and optimize operational performance.
- Supports integration with other management systems (ISO 9001, ISO 14001).

Assessment and Conclusion

- Implementing an energy management system according to ISO 50001:2018 is a fundamental and long-term solution that helps factories transition from passive to proactive and systematic energy management.

- Although the direct energy savings may not be as significant as those from technological solutions, this is a highly sustainable solution that helps maintain and optimize the effectiveness of all other energy-saving solutions throughout the factory.
- Therefore, this solution is considered essential and should be prioritized for early implementation in the energy management roadmap of the Cement Plant.

4.2 Install a solar power system (with consideration for BESS integration)

❖ **Project description**

Current Status:

The factory has a very high electricity demand, with relatively stable and continuous load operation throughout the day. The main electricity-consuming areas include: material grinding, coal grinding, kilns, clinker cooling, cement grinding, and high-capacity fan systems. This load characteristic is suitable for a self-sufficient solar power generation model, as the electricity generated during the day can be directly absorbed during the production process.

Furthermore, preliminary surveys indicate that the factory has a relatively large roof area. However, most of the existing roof structure is not designed to withstand the additional load of the solar panel system, supports, and wind loads. In addition, the cement production environment is characterized by high levels of fine dust, increasing the risk of reduced solar panel efficiency and higher operating and maintenance costs.

Figure 4.2. Image showing the potential location for installing a solar power system at the Cement Plant.

Therefore, while rooftop solar power is a feasible option, it is not yet optimal when considering the overall technical aspects and lifecycle costs.

Based on that, a more suitable option is to deploy ground-mounted solar power systems, utilizing vacant land or areas left after mining operations. This solution allows for:

- Proactively plan the layout and optimize the orientation/angle of the solar panels;
- Advantages in cleaning and maintenance;
- Easy integration of energy storage systems (BESS) and operational control.

Solar radiation conditions:

Regional microclimatic data indicates average solar radiation of approximately 4.07 kWh/m²/day, a level suitable for efficient solar power generation. Months with high radiation are concentrated from April to August, favorable for power generation during periods of high production load.

	Đơn vị	Vị trí dữ liệu khí hậu	Địa điểm cơ sở	Nguồn
Vĩ độ		19.8	20.1	
Kinh độ		105.8	105.9	
Vùng khí hậu		1A - Rất nóng - Ẩm		Đất+NASA
Cao độ	m	5	12	Đất – Bản đồ
Nhiệt độ thiết kế cấp nhiệt	°C	12.1		Đất
Nhiệt độ thiết kế làm lạnh	°C	34.1		Đất
Biên độ nhiệt độ trái đất	°C	8.2		NASA

Tháng	Nhiệt độ ngoài trời	Độ ẩm tương đối	Lượng mưa	Bức xạ mặt trời hàng ngày - đường ngang	Áp suất khí quyển	Tốc độ gió	Nhiệt độ trái đất	Độ cấp nhiệt - ngày 18 °C	Độ làm lạnh - ngày 10 °C
	°C	%	mm	kWh/m²/ngày	kPa	m/Thứ nhì	°C	°C-ngày	°C-ngày
Tháng Giêng	17.8	85.5%	21.70	2.85	101.1	1.8	18.1	6	242
Tháng Hai	18.1	88.8%	18.76	3.19	100.9	1.7	19.9	0	227
Tháng Ba	20.1	90.4%	38.13	3.89	100.6	1.5	22.5	0	313
Tháng Tư	24.1	90.0%	48.50	4.60	100.2	1.7	26.0	0	421
Tháng Năm	27.2	84.9%	130.05	5.05	99.9	1.6	28.2	0	531
Tháng Sáu	29.4	79.5%	132.30	4.95	99.6	1.8	29.1	0	502
Tháng Bảy	29.2	81.8%	156.55	4.86	99.6	1.7	29.3	0	595
Tháng Tám	28.3	85.8%	234.95	4.64	99.7	1.4	28.7	0	567
Tháng Chín	26.9	86.0%	276.60	4.20	100.1	1.6	27.5	0	507
Tháng Mười	25.2	82.7%	192.51	3.60	100.6	1.7	25.0	0	471
Tháng Mười Một	22.3	80.5%	64.80	3.41	100.9	1.8	22.0	0	369
Tháng Mười Hai	18.7	81.0%	25.11	3.06	101.2	1.7	18.8	0	270
Hàng năm	**24.0**	**84.7%**	**1,349.82**	**4.07**	**100.4**	**1.7**	**24.6**	**6**	**5,099**
Nguồn	Đất	Đất	NASA	NASA	NASA	Đất	NASA	Đất	Đất
Đo tại					m	10	0		

Figure 4.3. Table of microclimatic parameters for the cement plant location.

Besides:

- Average annual temperature: ~24°C
- Average wind speed: ~1.7 m/s

These factors indicate stable operating conditions, supporting the performance of the solar power system.

Policy mechanism:

Currently, the legal environment in Vietnam is becoming increasingly favorable for the development of renewable energy, especially in line with the direction of Decree 58/2025/ND-CP, with the following key points:

- Encourage the development of renewable energy;
- Prioritize the self-production and self-consumption model;
- Encouraging the integration of energy storage systems (BESS);
- Expanding the scope of deployment for ground-mounted solar power;

- The requirement is to integrate energy monitoring, metering, and management systems.

These factors provide a favorable basis for the factory to implement the project, both technically and legally.

❖ **Proposed solution**

Solar power systems operate on the principle of converting solar radiation into electrical energy through photovoltaic panels. The generated electricity is in the form of direct current (LINE), which is then converted into alternating current (AC) through an inverter to supply power to the load.

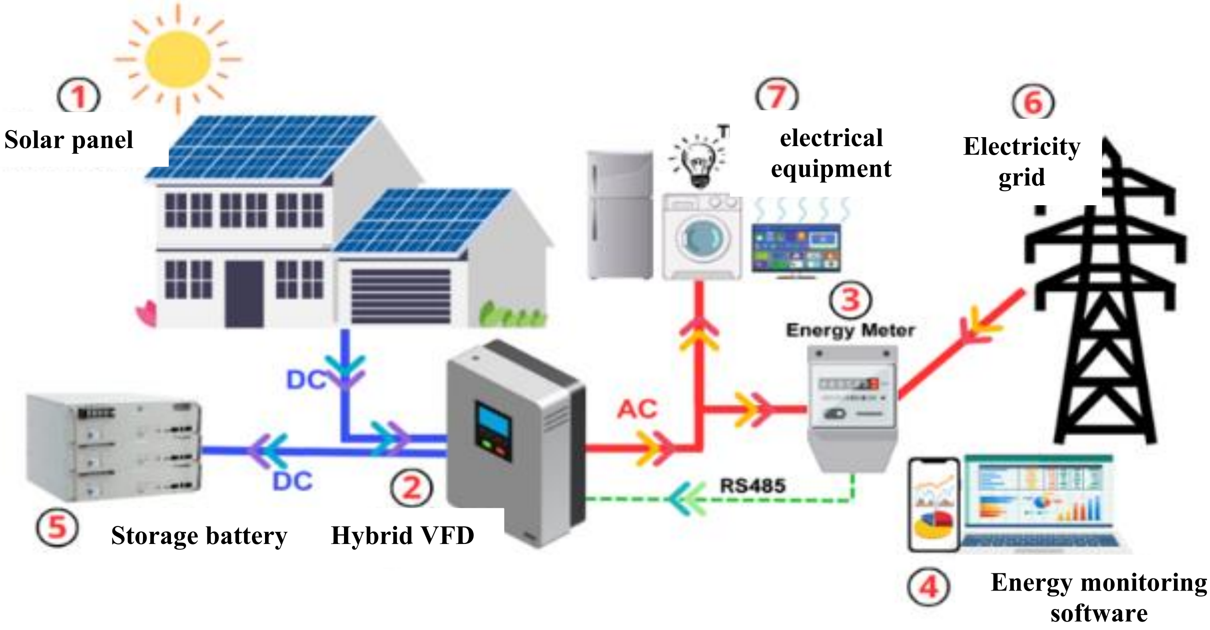


Figure 4.4. Schematic diagram of the operation of a solar power system.

Operating plan:

- Option 1 – No BESS:
  + Solar power is used directly for the load;
  + Reduce electricity purchases from the grid during the day;
  + The system is simple and has low investment costs.
- Option 2 – Includes BESS:
  + Store excess electricity in batteries;
  + Discharge electricity during peak hours or at night;
  + Increase self-consumption rate and operational flexibility.

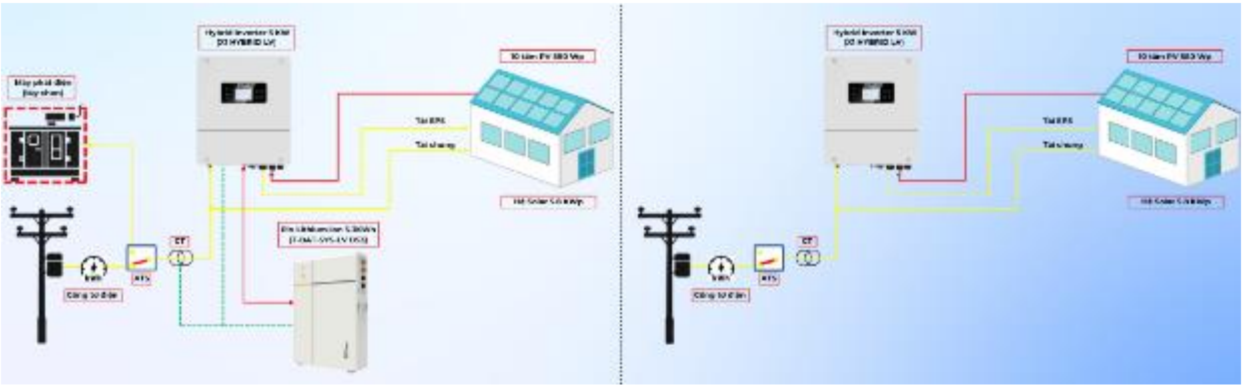


Figure 4.5. Image comparing diagrams with and without BESS

Evaluate the options:

- With the following characteristics:
  + High base load;
  + Operates 24/7;
  + There was no simultaneous stopping phenomenon;

→ The ability to absorb solar power on-site is very high.

- Therefore:
  + If the system capacity is less than the daytime load, BESS is not needed.
  + BESS is only necessary when:
    - There is surplus electricity;
    - Peak load needs to be cut off.
    - Or optimize electricity pricing.

❖ **Energy saving potential**

With a typical scale of 10 MWp, the estimated solar power output is:

- Electricity production: ~14.13 million kWh/year
- Reduce the amount of electricity purchased from the grid accordingly;
- Significant reduction in CO_2 emissions.

❖ **Challenges and issues to consider**

Despite its great potential, the solution still needs clarification:

- The ability to integrate with existing power systems;
- Connection power limit;
- Economic efficiency with/without BESS;
- The impact of dust on solar panel performance;
- Investment costs and payback period;

- Optimal operating strategy (EMS, ML…).

❖ **Conclusion and implementation plan**

Solar power is one of the solutions with great potential to help the factory:

- Reduce electricity costs in the long term;
- Take control of your energy sources;
- Reduce CO_2 emissions;
- In line with the trend toward sustainable energy transition.

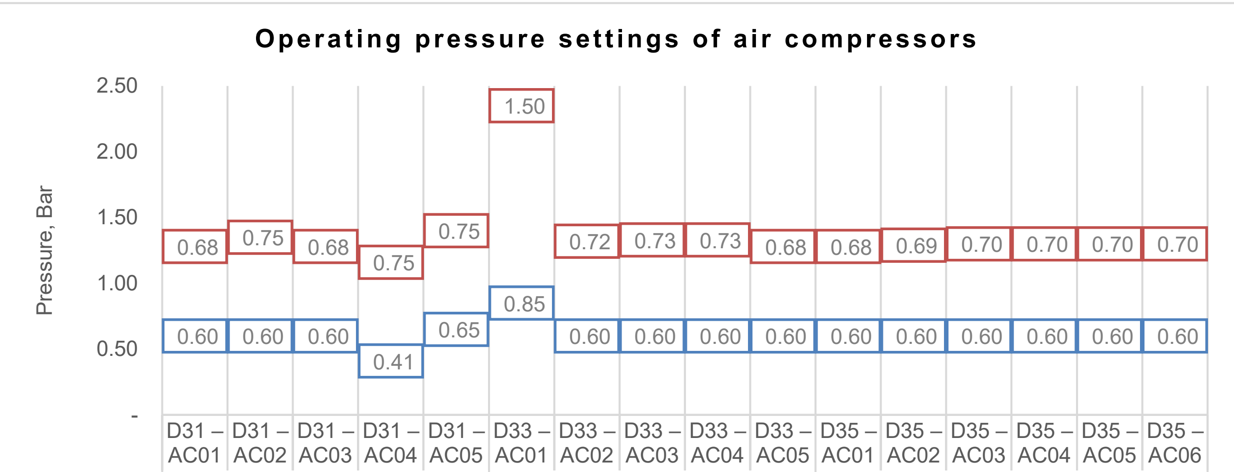
In the next phase, the following needs to be done:

- Pre-feasibility study (Pre-FS);
- Detailed site survey and connection work;
- Optimize capacity scale;
- A detailed assessment of financial performance.

4.3 Install a variable frequency drive (VFD) for the AIR COMPRESSOR system combined with a central controller for the compressed air system.

a. Current situation and problems

The factory's compressed air system currently comprises numerous air compressor stations distributed across production lines, with a large number of screw air compressors with a capacity of 110–120 kW, a working pressure of approximately 0.6–0.74 MPa, operating 24 hours a day. The equipment statistics show that most stations are equipped with multiple compressors of the same power range and capacity, serving the continuous compressed air needs of each production line.



	D31 – AC01	D31 – AC02	D31 – AC03	D31 – AC04	D31 – AC05	D33 – AC01	D33 – AC02	D33 – AC03	D33 – AC04	D33 – AC05	D35 – AC01	D35 – AC02	D35 – AC03	D35 – AC04	D35 – AC05	D35 – AC06
PUnLoad	0.68	0.75	0.68	0.75	0.75	1.50	0.72	0.73	0.73	0.68	0.68	0.69	0.70	0.70	0.70	0.70
PLoad	0.60	0.60	0.60	0.41	0.65	0.85	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60

Figure 4.6. Describe the operating pressure settings of the current air compressors at the plant.

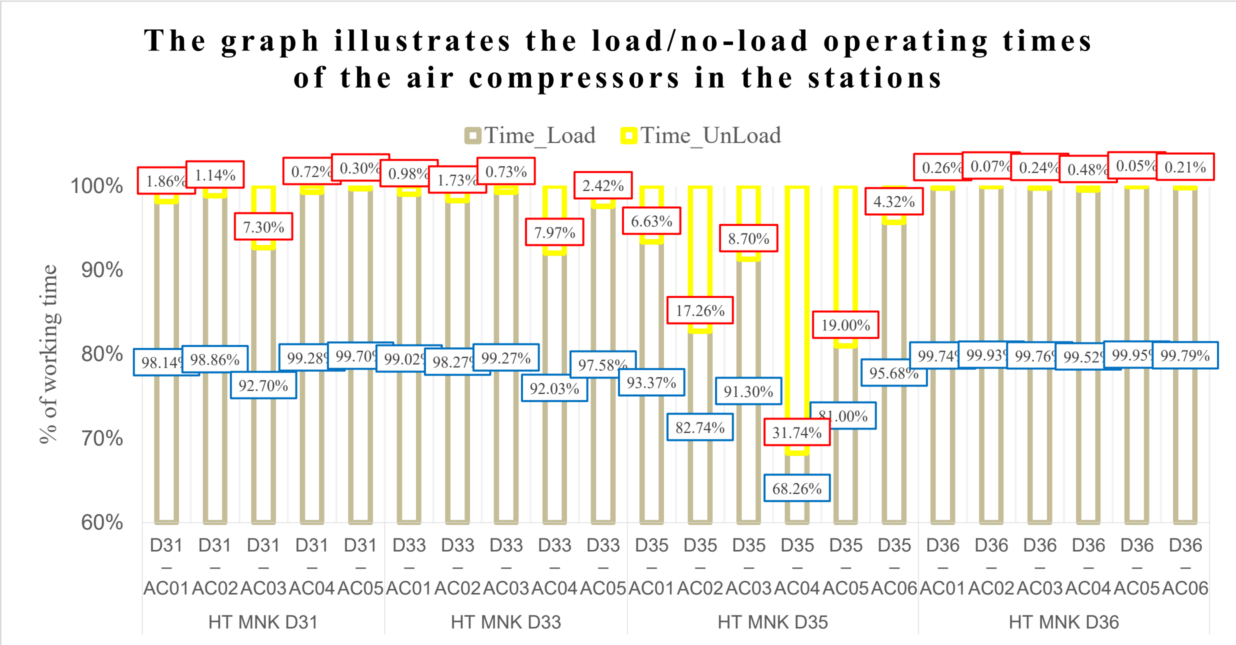


Figure 4.7. Load/Unload time of air compressors

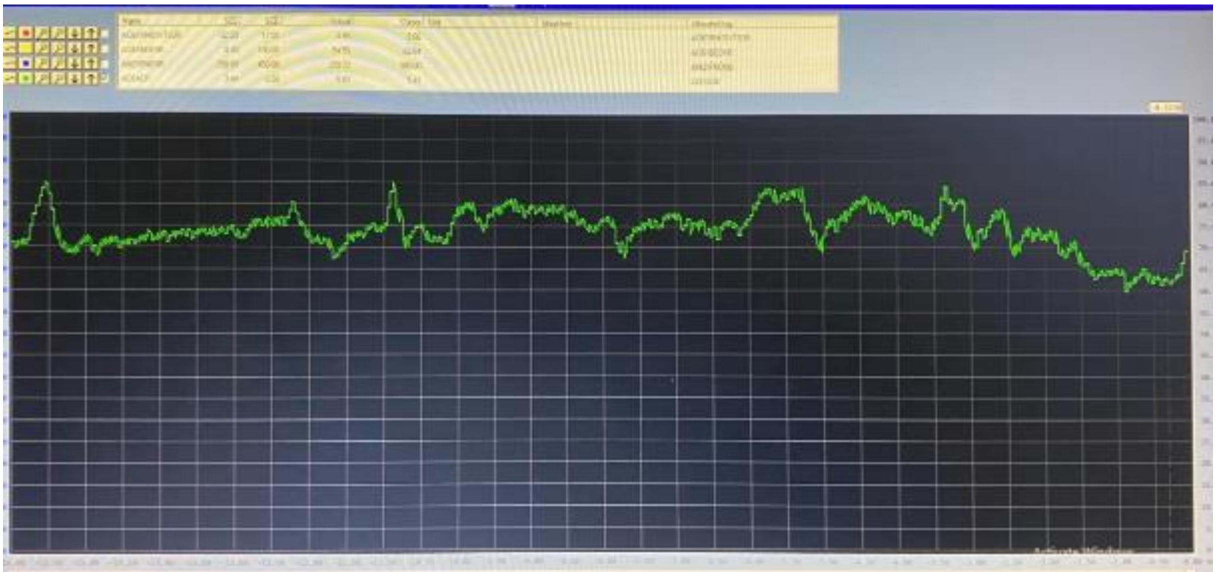


Figure 4.8. Pressure trend chart of the D31 compressed air system – Line 1

Analysis of the operating data of the air compressors at the stations reveals several positive points, such as:

- First of all, the air compressors mostly operate in high-load mode, indicating that the system is being utilized relatively efficiently and is meeting the compressed air needs of the production lines well.
- In addition, the set pressures of the machines are generally quite uniform, and the number of operating hours among machines in the same station is also relatively balanced, reflecting a certain degree of regulation in the allocation of operations.

However, the system still has some limitations that need to be considered:

- There is an inconsistency in the set pressure at some machines;
- Pressure fluctuations during operation are still relatively large;
- Significant idle time (5–30%) exists in some machines;
- The load distribution among the machines is not optimal, with some machines operating at 20–30% lower capacity.

These problems mainly stem from the system's inability to flexibly regulate compressed air flow according to actual demand. Therefore, to improve energy efficiency for the compressed air system, it is necessary to add a solution that allows for continuous load adjustment and optimizes the operation of the entire station. Based on this, the proposed solution is to install 1–2 variable frequency air compressors per station, combined with a central controller to coordinate operation, stabilize pressure, and minimize idle time of the air compressors.

b. Solution description

The proposed solution is to add 1–2 variable frequency air compressors to each air compressor station, combined with a central controller to optimize the operation of the entire system.

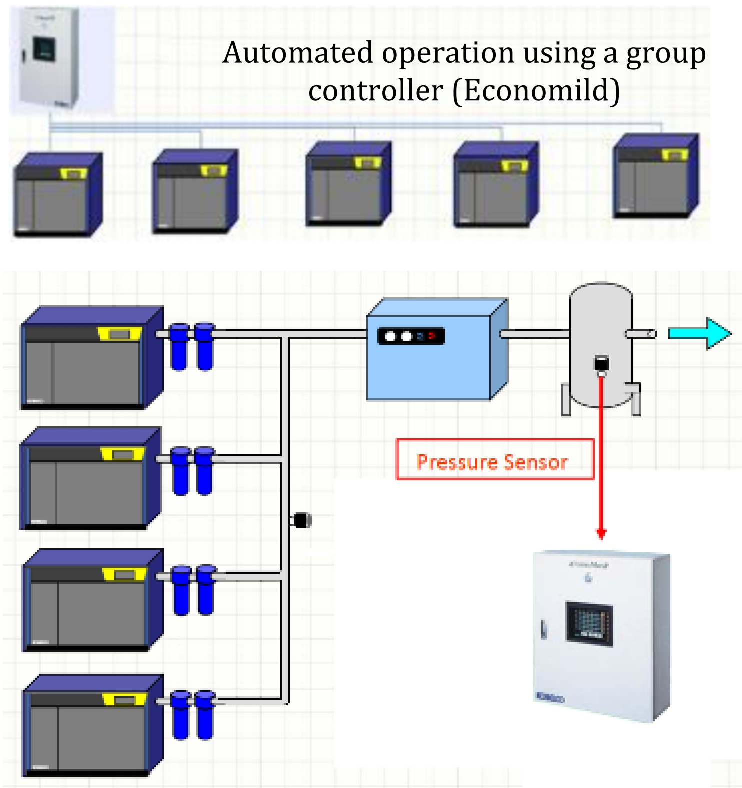


Figure 4.9. Description of the central controller's operation

Operating principle:

- Existing air compressors operate in baseline load mode, prioritizing operation near their optimal efficiency point;

- Variable speed drive (VSD) air compressors are responsible for adjusting the flow rate according to actual demand;
- The central controller performs the following actions:
    + System pressure monitoring;
    + Coordinate the number of machines in operation;
    + Optimize the operating sequence and rotation mode;
    + Minimize idle running.

With this configuration, the system switches from intermittent to continuous control, which helps to:

- Pressure stabilization;
- Reduce oscillations;
- Optimize overall station performance.

c. Expected energy savings

The addition of variable frequency air compressors combined with a central controller is expected to bring energy savings to the compressed air system by optimizing operating modes and reducing existing losses.

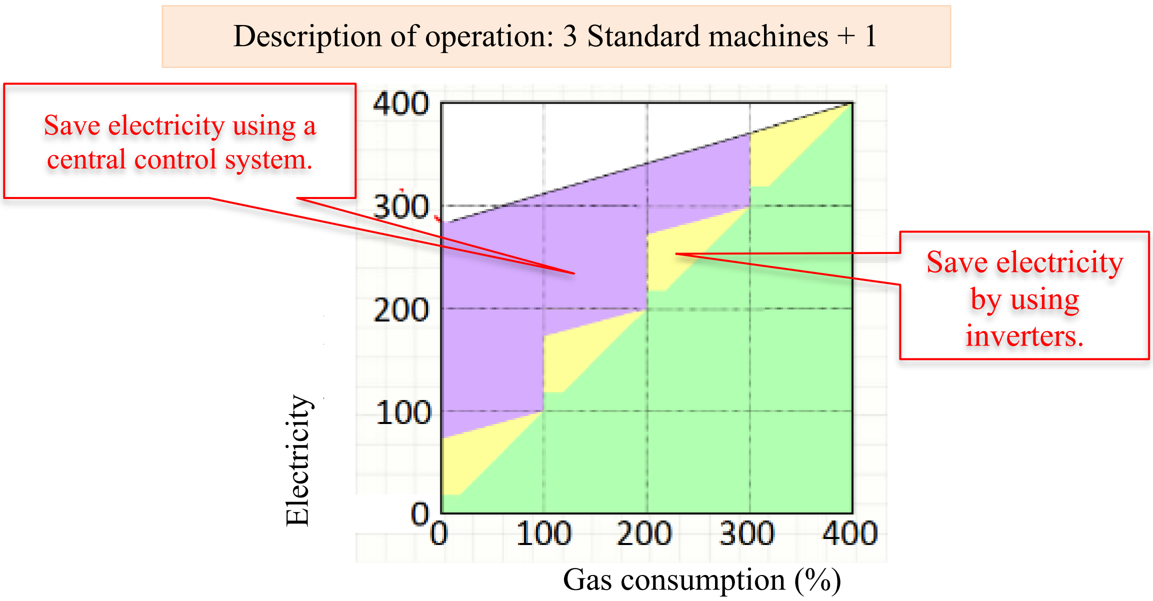


Figure 4.10. Describe the energy saving potential when combining an inverter and a central controller.

The solution delivers cost savings through the following key mechanisms:

- Reduce the set pressure:
    + A reduction of 0.02 – 0.05 MPa results in a saving of approximately 2 – 5% of electricity.

- Reduce idle time:
    + Reducing losses by 5–30% of the current situation → savings of approximately 3–8%;
- Optimizing station-wide operation:
    + Efficient machine scheduling → additional savings of 2-4%.

Therefore, the total potential savings are approximately 5-15% of compressed air system electricity (depending on the station).

The solution does not change the demand for compressed air but focuses on reducing the power consumption to produce the same amount of compressed air.

d. Conclusion and implementation plan

Installing a variable frequency drive (VFD) combined with a central controller for the compressed air system is a highly feasible solution, offering significant energy savings and improving operational stability.

In the next phase, the following is needed:

- Conduct a detailed survey of each station;
- Choose the appropriate device configuration;
- Prepare a pre-feasibility study (Pre-FS).
- Implement a pilot program at one station before scaling it up.

4.4 Pipeline renovation: "Installation of pressure distribution piping for the compressed air system"

a. Current Status

The plant's compressed air system is currently operating at relatively high pressure levels, typically in the following range:

- 0.68 – 0.75 MPa (no-load threshold)
- 0.60 – 0.65 MPa (load threshold)

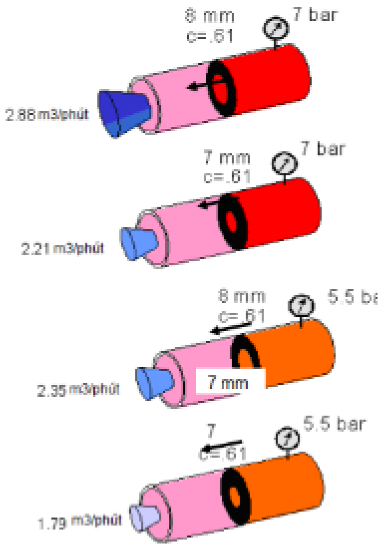
Meanwhile, actual operating data shows that system pressure continues to fluctuate over time, reflecting the unevenness in compressed air demand among different load groups.

Regarding specific usage characteristics:

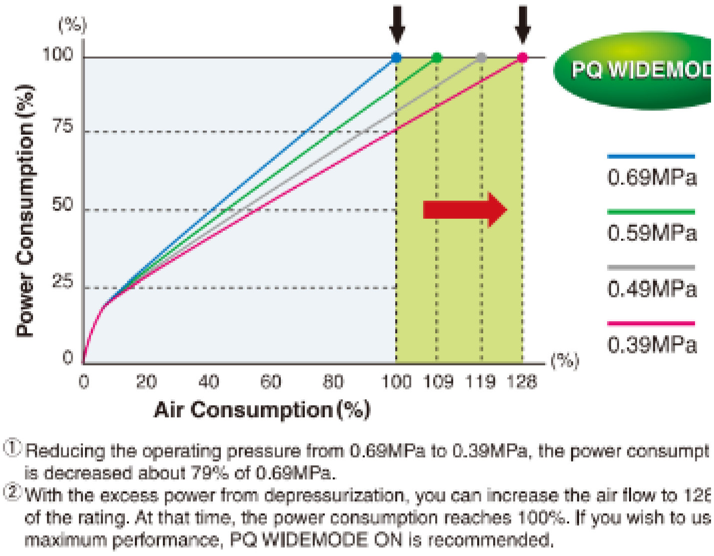
- The equipment in the plant does not require the same pressure level;
- Some loads only require low pressure (instrument air, air slide, control valves, etc.);
- Some specialized loads require high pressure (e.g., air pulse dust filters, air guns, air hammers...).

However, the entire system is currently operating at a generally high pressure level, leading to:

- Increased throttling losses at pressure reducing valves;
- Increase the amount of simulated compressed air at the leak points;
- This increases the power consumption of the air compressor.



The demand for compressed air increases with increasing working pressure.



The efficiency of the air compressor decreases with increasing air compressor working pressure.

Figure 4.11. A typical example illustrates the increase in artificial compressed air demand and the performance of AIR COMPRESSOR when the working pressure increases.

In fact, the plant has installed several pressure reducing valves at the points of use. However, this is only a localized pressure reduction solution on the consumption side, while the compressed air is still generated at high pressure from the start. This means the system is still "producing high-pressure compressed air before reducing the pressure," thus failing to eliminate the energy loss generated by operating at a pressure higher than the actual needs of most of the load.

Therefore, for a more in-depth assessment, pneumatic devices can be grouped into two main categories:

- Compressed air system for clinker production
- Compressed air system for cement production line

Below is a table based on experience in evaluating compressed air systems in cement plants, used for preliminary classification of load groups and required pressure levels. These values are for guidance only and should be adjusted based on actual surveys at each air application point.

Table 4.1. Compressed air system for clinker production.

No.	Device/group of devices	Description of usage	Required pressure (MPa)	Demand rate (%)
1	Pneumatic control valves on furnace systems, heat exchange towers, and clinker coolers.	Opening/closing, regulating actuator valves	0.45 – 0.55	15 – 20
2	Conventional air pulse dust filter (bag filter)	Air pulse for dust removal from filter bags.	0.55 – 0.65	10 – 15
3	Electrostatic dust filters, separators, and areas requiring high air pressure/pulse.	Cleaning, valve operation, mechanisms requiring higher pressure.	0.60 – 0.70	15 – 20
4	Air hammers and anti-fouling air guns for silos, chutes, and cyclones.	Breaks down material adhesion	0.55 – 0.65	10 – 15
5	Damper mechanism, flap valve, diverter gate	Adjust the airflow and material flow.	0.45 – 0.55	10 – 15
6	Instrument air for measuring devices and positioners.	Supply clean air to the measuring and control equipment.	0.40 – 0.50	10 – 15
7	Feeding system, coal feeding system, auxiliary actuator mechanism	Control of pneumatic valves and cylinders	0.45 – 0.55	5 – 10
8	Cleaning, localized air blowing	Clean the sensor head, device, and any dust accumulation points.	0.50 – 0.60	5 – 10

Table 4.2. Compressed air system for cement production line

No.	Device/group of devices	Description of usage	Required pressure (MPa)	Demand rate (%)
1	Control valves on cement mills, separators, and silos.	Opening/closing, regulating valves	0.45 – 0.55	15 – 20

No.	Device/group of devices	Description of usage	Required pressure (MPa)	Demand rate (%)
2	Conventional pulsed air dust filter	Shake the filter bag to remove dust.	0.55 – 0.65	15 – 20
3	Dust separation filter, points requiring high-pressure pulsed air.	Cleaning and maintenance at locations requiring higher pressure.	0.60 – 0.70	10 – 15
4	Air slide, aerodynamic chute, powder material flow assist	Support for transporting powdered materials	0.35 – 0.50	20 – 25
5	Cement bagging and dispensing system, pneumatic cylinders	Comply with the mechanical mechanism for opening and closing.	0.50 – 0.60	10 – 15
6	Instrument air	Supply clean air to the measuring and control equipment.	0.40 – 0.50	10 – 15
7	Cement silo anti-fouling system, air gun, air hammer	Disintegration and flushing	0.50 – 0.60	5 – 10
8	Cleaning, localized air blowing	Clean the equipment, probes, and pipes.	0.50 – 0.60	5 – 10

Table 4.3. Summary table of compressed air requirements by pressure level

No.	Pressure level	Required pressure	Demand Ratio – Clinker System (%)	Demand Ratio – Cement System (%)	Comment
1	Low pressure	< 0.55 MPa (Max)	40 – 55	50 – 65	It mainly consists of instrument air, conventional control valve, air slide, and auxiliary actuator.
2	High pressure	> 0.55 MPa (Min)	45 – 60	35 – 50	It mainly includes pulsed air dust collectors, electrostatic/separator dust collectors, air guns, air

					hammers, and specialized loads requiring high pressure.

Therefore, maintaining the entire compressed air system at the same high pressure to meet all loads is not truly energy-efficient. This is the basis for considering a solution of dividing the compressed air system into low-pressure and high-pressure systems, which is more suitable to the actual consumption characteristics of each group of equipment.

b. Solution description

The renovation plan is described as follows:

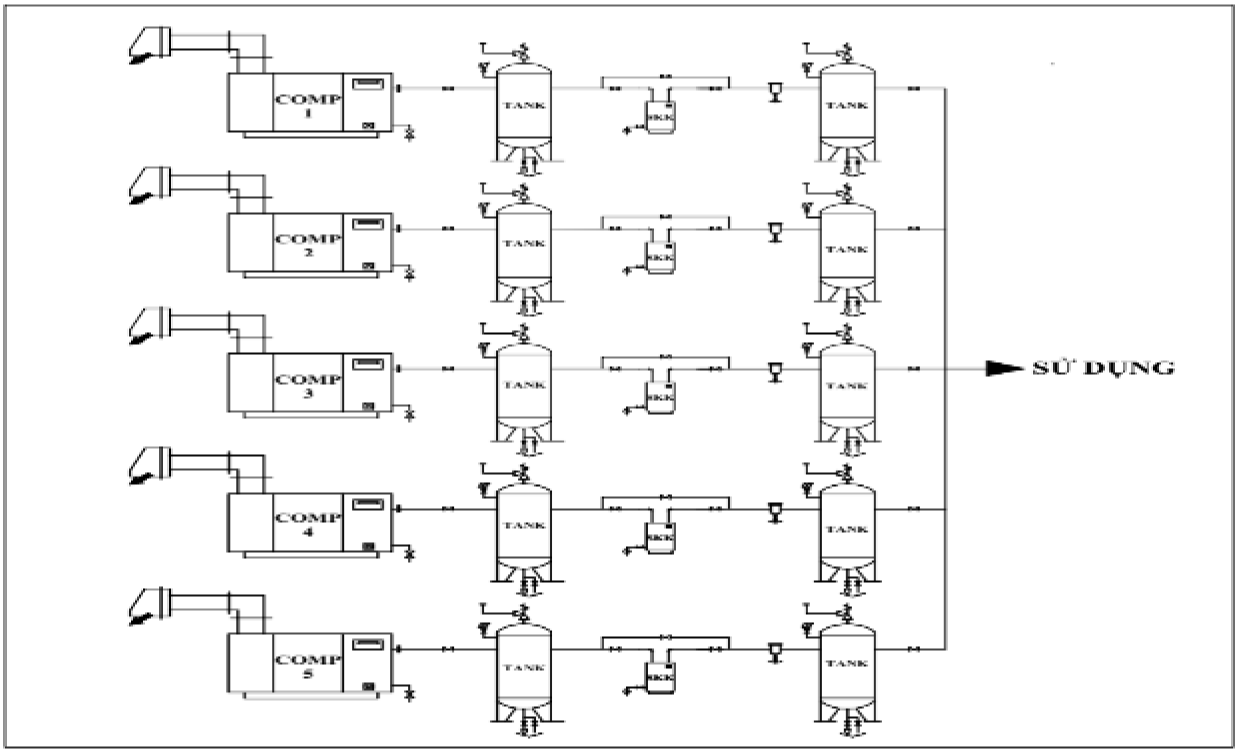


Figure 4.12. Current status of air compressor room

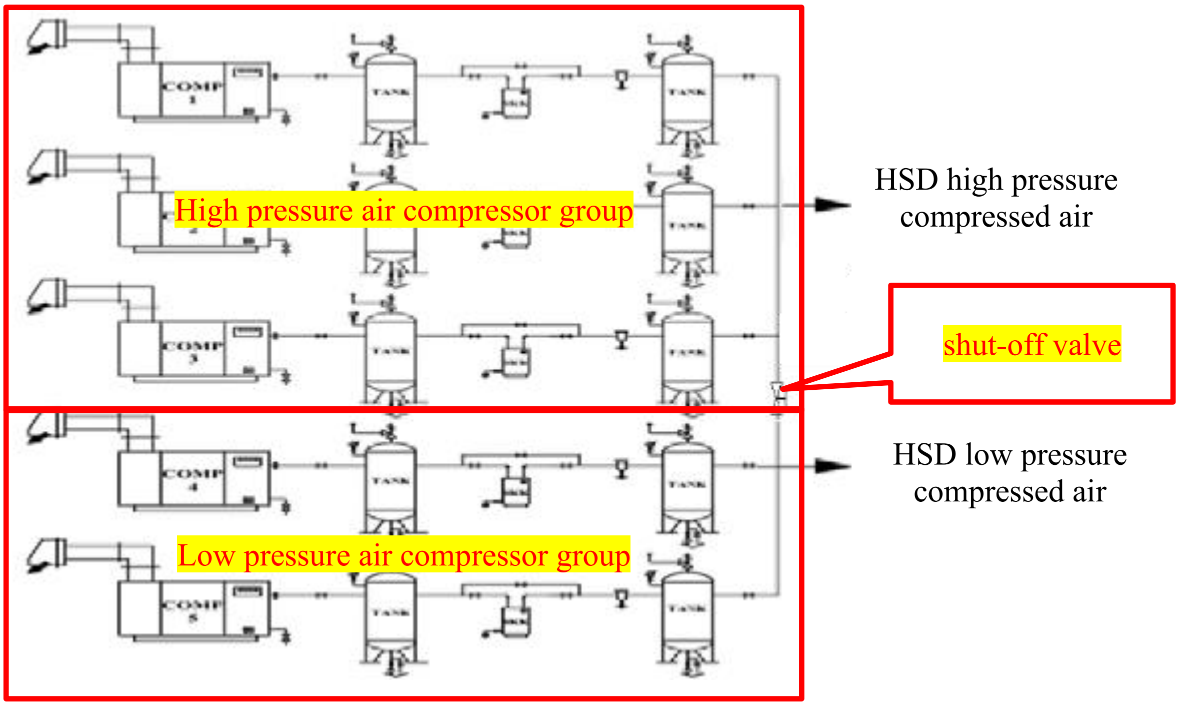


Figure 4.13. Rearrange the air compressor groups according to high pressure and low pressure groups.

The proposed solution is to maintain the overall configuration of the existing air compressor stations while reorganizing the compressed air supply method into two separate pressure levels, including:

- **High-pressure compressed air system**: supplying pressure to loads that actually require it;
- **Low-pressure compressed air system**: to supply the remaining loads that require lower pressure.

Accordingly, depending on the compressed air demand structure of each area, the air compressors in each machine room will be grouped into high-pressure and low-pressure groups. The number of air compressors in each group is not fixed but is determined based on the actual load ratio of each system, to ensure that demand is met while avoiding over-operation.

In terms of infrastructure, the existing compressed air distribution pipeline system will be retained for continued use at one of two pressure levels (high or low pressure, depending on the chosen option and the convenience of each area). Simultaneously, a new distribution pipeline system will be installed to supply the remaining load group. This approach allows for maximum utilization of the existing system, reduces the amount of renovation required, and minimizes the impact on production during implementation.

At intersection points or areas where the two systems may intersect, isolation shut-off valves and appropriate connection points will be installed to clearly separate the two compressed air networks. This prevents high-pressure air from entering the low-pressure system or vice versa, thus rendering the solution ineffective. Clearly separating the two pressure levels also facilitates management, operation, and monitoring of the energy efficiency of each individual system.

In terms of operation, the high-pressure air compressor group will only serve loads requiring high pressure, such as specialized dust filtration equipment, certain actuators, or points requiring high force. Meanwhile, the low-pressure air compressor group will supply air to most common loads such as instrument air, control valves, air slides, common actuators, and points of use that do not require high pressure. As a result, the plant no longer has to maintain the entire system at the same high pressure level as it currently does.

This solution allows for a reduction in compressed air pressure for most loads, thereby reducing the power consumption of air compressors, while also limiting losses due to throttling through pressure reducing valves, reducing spurious compressed air, and minimizing system leaks. This solution is suitable for the current state of the plant as it utilizes existing equipment and distribution networks, while gradually reorganizing the compressed air system to meet the actual pressure requirements of each load group.

c. Expected energy savings

The relationship between pressure and energy consumption:

- Reducing pressure by 1 bar (~0.1 MPa) → saves approximately 6-10% of electricity.
- Reducing from 0.60 MPa to 0.45 MPa results in savings of approximately 8-12%..

Reduce system losses:

- Reduce compressed air leaks;
- Reduce losses through the throttle valve;
- Reduce the amount of false compressed air.

Optimizing air compressor operation:

- The machine is operating near its optimal performance point;
- Reduce unnecessary workload;
- Increase the lifespan of the equipment.

Table 4.4. Table showing the projected energy saving potential of the high-pressure-low-pressure split system solution.

No	Air compressor system	Pressure group	Current pressure (MPa)	Pressure after renovation (MPa)	Utilization rate (%)	% of projected energy savings	% of overall energy efficiency
1	D31	High pressure	0.60	0.60	55	0	4.05

No	Air compressor system	Pressure group	Current pressure (MPa)	Pressure after renovation (MPa)	Utilization rate (%)	% of projected energy savings	% of overall energy efficiency
2		Low pressure	0.60	0.45	45	9	
3	D33	High pressure	0.60	0.60	55	0	4.05
4		Low pressure	0.60	0.45	45	9	
5	D35	High pressure	0.60	0.60	55	0	4.05
6		Low pressure	0.60	0.45	45	9	
7	D36	High pressure	0.60	0.60	55	0	4.05
8		Low pressure	0.60	0.45	45	9	
9	D32	High pressure	0.60	0.60	40	0	5.40
10		Low pressure	0.60	0.45	60	9	
11	D34	High pressure	0.60	0.60	40	0	5.40
12		Low pressure	0.60	0.45	60	9	

4.5 Install a HydroBall automatic cleaning system, electronic descaling device, and automatic controller for the circulating water pump and cooling tower fan based on condenser vacuum pressure.

❖ **Current situation and problems**

The plant's heat recovery system (WHR) is operating on a steam Rankine cycle, where the condenser plays a crucial role in determining the overall system efficiency. However, analysis of actual operation has revealed several limitations, as follows:

- Heat loss in the condenser is high (over 50%), reducing the power generation efficiency of the system;

- The vacuum pressure is not consistently maintained at an optimal level, depending heavily on:
    + Coolant temperature;
    + Scale buildup in heat exchanger tubes;
- Scale buildup in condensers reduces the heat transfer coefficient, leading to a decrease in heat exchange efficiency over time;
- Regular cleaning (every 6 months) is not enough to maintain optimal operational efficiency;
- The cooling tower pump and fan systems have variable frequency drives, but are currently mostly operated manually, lacking an automatic control mechanism to adapt to real-world conditions.

These problems lead to:

- Condensation pressure is higher than optimal;
- Reduced steam turbine efficiency;
- Increase heat dissipation per kWh of electricity generated.

Figure 4.14. Mornitoring screen for heat recovery system, line 1

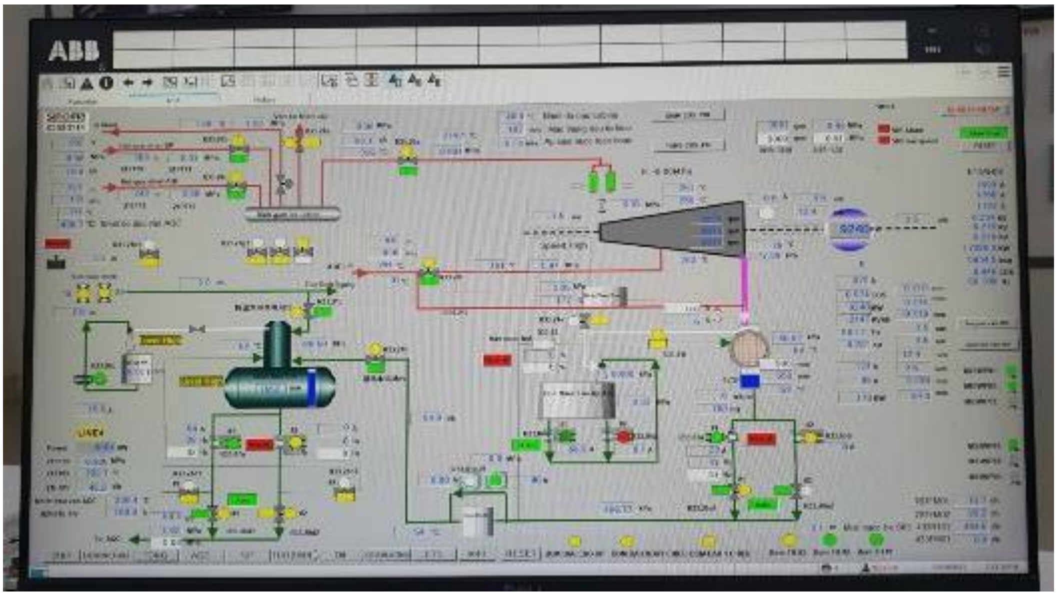


Figure 4.15. Monitoring screen heat recovery system line 4

Figure 4.16. Heat recovery system condenser

❖ **Solution description**

The proposed solution aims to maintain optimal vacuum pressure and improve the heat exchange efficiency of the condenser, comprising three main groups of solutions:

(1) Install an automatic pipe cleaning system (Hydroball ATCS)

The system uses porous rubber balls that move in a circulating manner within the heat exchanger tubes to continuously clean scale deposits during operation.

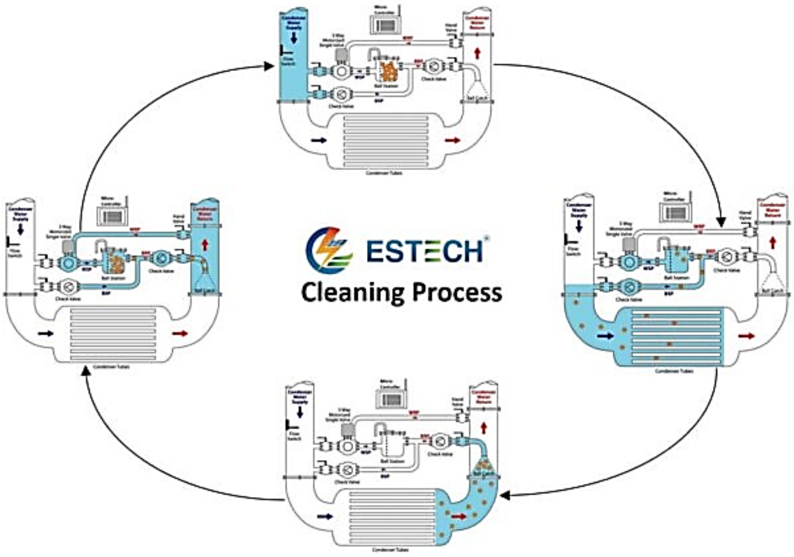


Figure 4.17. Illustrating the operating principle of the Hydroball ATCS automatic pipe cleaning system.

Principle:

- Rubber balloons are inflated into the coolant stream;
- It moves through the heat exchanger tubes;
- Friction against the pipe walls to remove scale buildup;
- It is recovered and recycled back into the system.

(2) Install electronic scale removal device

The device uses electromagnetic waves/shocks to:

- Changes in the crystallization structure of mineral salts ($CaCO_3$, $MgCO_3$…);
- Prevent the formation of scale deposits on heat exchange surfaces.

👉 This solution helps:

- Maintain a clean heat exchange surface over a long period of time;
- Reduce the frequency of mechanical cleaning.

(3) Automation of cooling tower pump and fan control

- Use a PLC/EMS to control the inverter of:
  + Water circulation pump;
  + Cooling tower fans;
- Optimize operations based on signals:
  + Condenser vacuum pressure;
  + Coolant temperature;
  + Environmental conditions (temperature, humidity).

👉 The system will automatically:

- Adjust the water and air flow rates;
- Maintain the vacuum pressure at an optimal level;
- Reduce auxiliary power consumption.

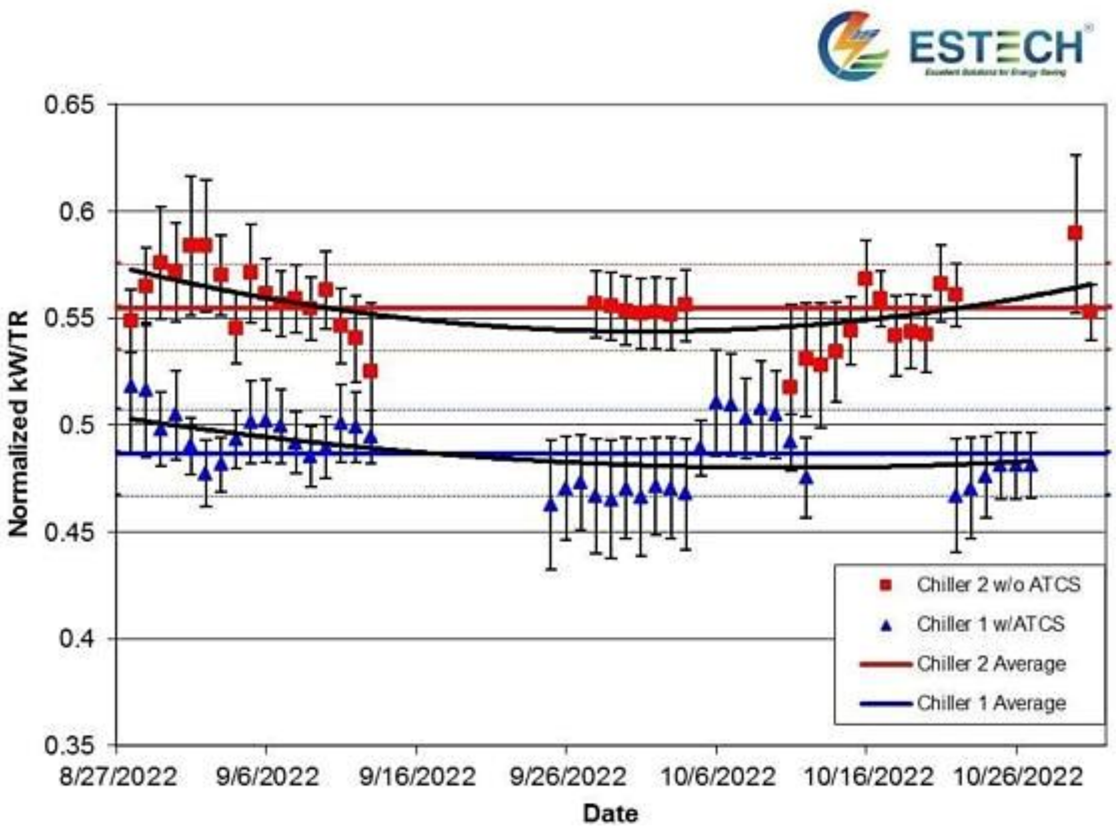


Figure 4.18. Comparison of chiller models with and without automatic condenser cleaning systems in the same system.

❖ **Expected energy savings**

The solution delivers results through the following mechanisms:

(1) Improve heat exchange efficiency

- Reduced scale buildup → increased heat transfer coefficient;
- Lowering the condensation temperature → lowering the condensation pressure.

(2) Increase steam turbine efficiency

- When the vacuum pressure decreases (the vacuum improves) → the enthalpy difference increases;

→ Increase the amount of electricity generated from the same amount of heat input.

(3) Reduce auxiliary power consumption

- Optimize the operation of pumps and fans;
- Avoid operating under overload.

- Summary of potential savings:
    + Increase electricity generation output: ~2 – 5%
    + Reduce auxiliary power for cooling system: ~5 – 10%
    + Reduce overall system heat loss (WHR).

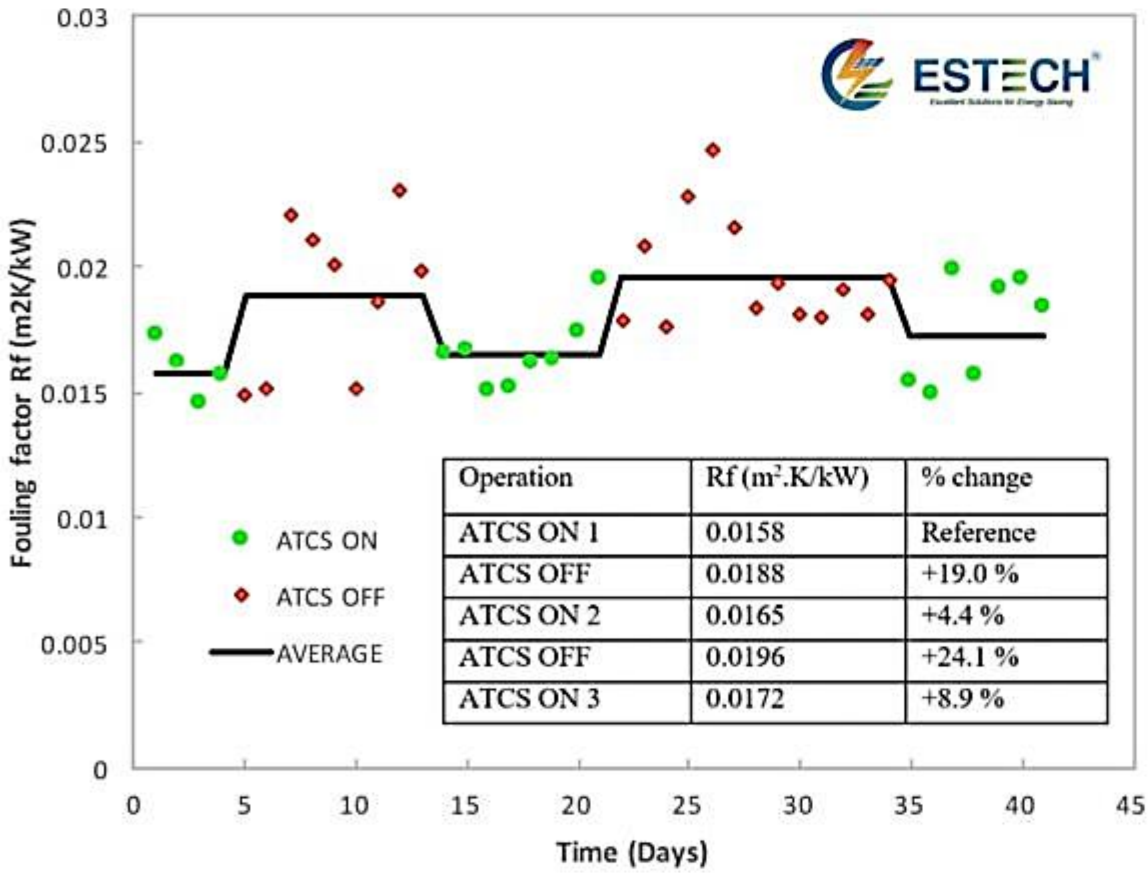


Figure 4.19. *Sample chiller performance with ATCS on and off.*

4.6 Waste heat recovery solution (>100°C) using absorption chiller technology to serve the air-conditioning system for loads in the control room and electrical substation areas (L1–L4).

a. Current status of air conditioning in cement plants

Most cement plants today use compressor-type air conditioning systems to cool power stations, offices, and other factory spaces.

Figure 4.20. Local air conditioning systems are installed in areas around the factory.

Currently, the air conditioning system at the cement plant is arranged in a localized, dispersed manner across various areas such as:

- Central Control Room (CCR);
- Electrical room, inverter room;
- Engine control room;
- The MCC cabinet area and power substations.

These systems primarily utilize independent electric compressor air conditioners, lacking overall optimization.

During operation, several major problems arose, as follows:

- High energy consumption: Due to the use of traditional compressor-based air conditioners, all cooling energy is generated from electricity, while the plant has a large amount of unutilized waste heat. This results in relatively high electricity costs for cooling.
- Decentralized operation, difficult to control: Air conditioning units operate independently, without a central control system, leading to difficulties in monitoring performance, optimizing operation, and detecting abnormalities.
- Working in a harsh environment: Cement plants are characterized by dusty environments and high temperatures, causing heat exchangers to easily become dirty, reducing heat exchange efficiency and increasing energy consumption.
- Equipment operating underloaded or locally overloaded: Due to the design for individual zones, many devices do not operate at their optimal efficiency point (low COP), or have to run continuously to maintain temperature conditions, resulting in energy waste.

- Difficulty in utilizing available waste heat: Although the factory has many sources of waste heat from production processes (rotary furnace, calciner, exhaust gases, etc.), the current air conditioning systems are unable to utilize this energy source.
- Maintenance costs and equipment lifespan: Continuous operation in dusty and high-temperature environments increases the frequency of maintenance, reduces equipment lifespan, and increases operating costs.

Based on the results of constructing the energy mapping for the plant's energy operation using waste heat data, we have preliminarily obtained the following:

Waste heat potential							
Section	Process	Medium	Stream no		Temp. In °C	Temp. Out °C	Total kWh
Production line 1 - Dây chuyền chính - Main product line	L1 - Silo Clinker	Product	L1.3.6		140	50	46.526.296
	L1 - Nghiền liệu	Air	L1.2.1.3		85	25	107.285.617
	L1 - Nghiền than	Air	L1.2.3.2		65	25	14.925.183
	L1 - Nghiền xi măng	Air	L1.4.2.2		100	25	27.362.900
	L1 - Lọc bụi	Air	X2.5		150	25	109.795.325
Production line 1 - Dây chuyền phụ Điện năng tự sản xuất - Auxiliary line for self-generated electricity	L1 - Hóa hơi LP (AQC Boiler)	Water	X3.3		200	25	43.931
	L1 - AQC Boiler (HP)	Water	X9.2		330	25	1.056.616
	L1 - SP boiler	Water	X10.2		290	25	571.088
	L1 - IP turbine	Steam	X11.2		300	25	738.993
	L1 - LP turbinne	Steam	X5.2		136	25	23.813
	L1 - IP turbine	Steam	X11.1		49	48	198.332.826
	L1 - LP turbinne	Steam	X5.1		49	48	22.261.848
Production line 2 - Dây chuyền chính - Main product line	L2 - Silo Clinker	Product	L2.3.6		140	50	56.162.840
	L2 - Nghiền liệu	Air	L2.2.1.3		85	25	52.970.013
	L2 - Nghiền than	Air	L2.2.3.2		65	25	4.110.333
	L2 - Nghiền xi măng	Air	L2.4.2.2		100	25	76.775.790
	L2 - Lọc bụi	Air	E2.5		150	25	103.908.184
Production line 2 - Dây chuyền phụ Điện năng tự sản xuất - Auxiliary line for self-generated electricity	L2 - Hóa hơi LP (AQC Boiler)	Water	E3.3		136	25	24.259
	L2 - AQC Boiler (HP)	Water	E9.2		160	25	337.582
	L2 - SP boiler	Water	E10.2		335	25	728.115
	L2 - IP turbine	Steam	E11.2		300	25	745.310
	L2 - LP turbinne	Steam	E5.2		90	25	12.462
	L2 - IP turbine	Steam	E11.1		49	48	200.027.978
	L2 - LP turbinne	Steam	E5.1		49	48	39.278
	TOTAL						1.024.766.581

Figure 4.21. Data on heat sources from the energy mapping model.

Energy mapping results show that the plant currently has many sources of waste heat in the form of hot air streams generated from the main production processes, especially in areas such as dust filtration, cement grinding, material grinding, coal grinding, and clinker silos. These air streams carry a significant amount of heat due to their operation at high temperatures and high flow rates.

The temperature of these exhaust gas streams typically ranges from 65–150°C, with some streams, such as post-filter gas or gas from the grinding system, reaching higher and relatively stable levels over operating time. This is a crucial characteristic, as the exhaust gas streams not only have suitable temperatures but also large and continuous flow rates, facilitating heat recovery through air-water heat exchangers.

Characteristics of absorption air conditioning systems:

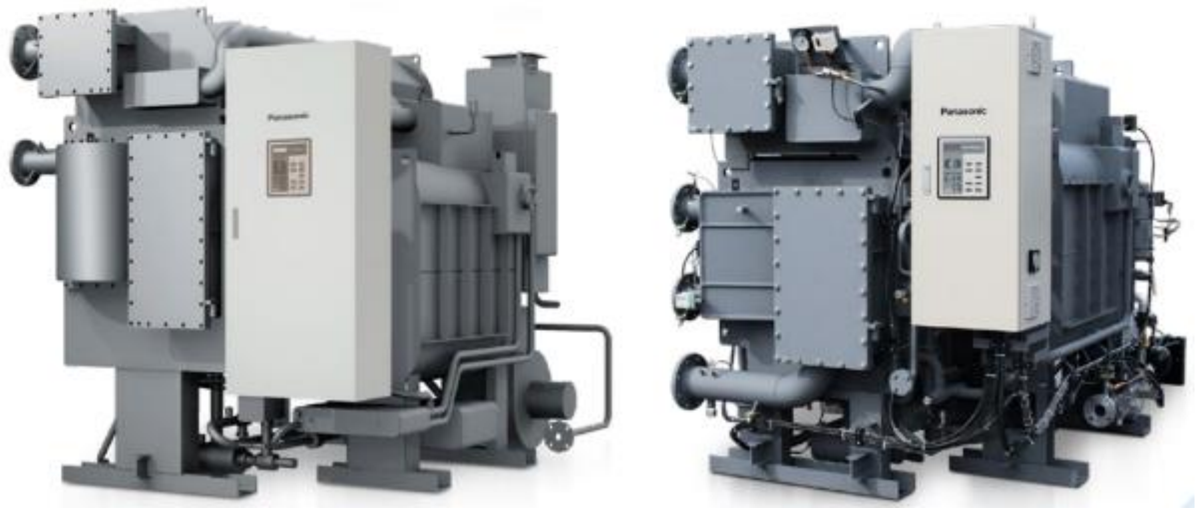


Figure 4.22. Image of an absorption air conditioner

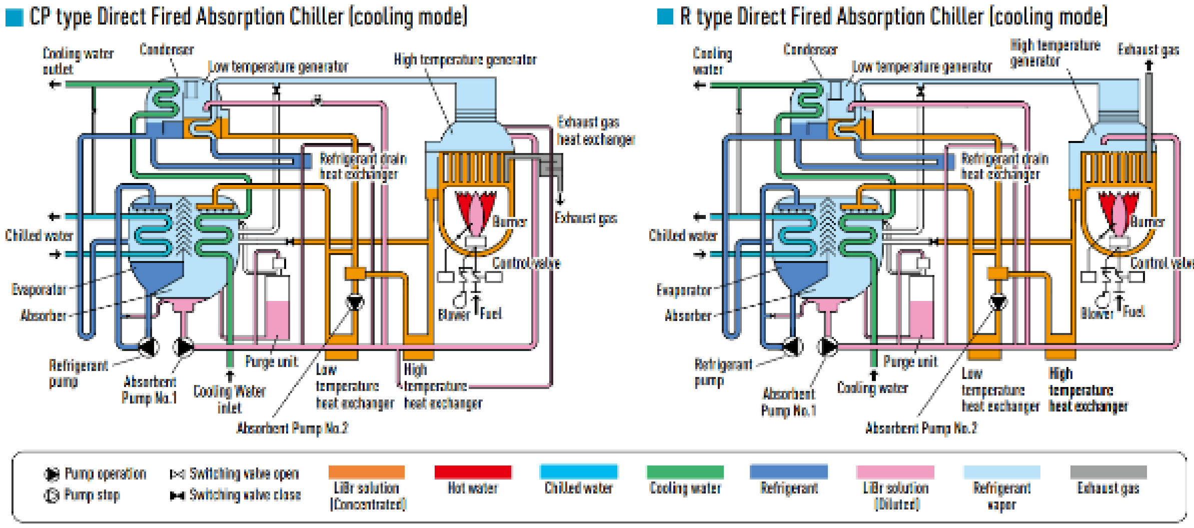


Figure 4.23. Describe the operating cycle of an absorption air conditioning system.

Model Name				QAW-CP***FC	QBW-CP***FC			
				180	210	240	280	320
Cooling capacity			kW	633	738	844	985	1,125
			USRT	180	210	240	280	320
Heating capacity			kW	421	491	561	655	748
			kcal/h	361,980	422,310	482,640	563,080	643,520
Chilled water	Temperature (Inlet→Outlet)		°C	12→7				
	Flow rate		m^3/h	109	127	145	169	194
	Pressure drop		kPa	35.9	36.5	37.7	75.0	76.1
	Connection diameter (JIS)		A	125			150	
Hot water	Temperature (Inlet→Outlet)		°C	56.7→60				
	Flow rate		m^3/h	109	127	145	169	194
	Pressure drop		kPa	35.9	36.5	37.7	75.0	76.1
	Connection diameter (JIS)		A	125			150	
Cooling water	Temperature (Inlet→Outlet)		°C	32→37				
	Flow rate		m^3/h	180	210	240	280	320
	Pressure drop		kPa	70.6	76.4	84.2	78.2	82.7
	Connection diameter (JIS)		A	150			200	
Power supply	Power			3 phases, 380 V, 50 Hz				
	Total current (50/60Hz)		A	18.1	19.9	21.7	21.7	25.4
	Power capacirty (50/60Hz)		kVA	11.8	13.3	14.7	14.7	17.8
Fuel System	Fuel connection diameter	Gas	A	50	100			
		Diesel oil	A	15 x2				
	Gas Consumption	Cooling: LHV gas calorific value	kW	444	519	593	692	791
		Heating: LHV gas calorific value	kW	444	519	593	692	791
	Diesel oil consumption	Cooling	L/h	43.9	51.1	58.5	68.2	77.9
		Heating	L/h	44.4	51.8	59.2	69.1	79.0
Dimension	Length	(L)	mm	3,780	3,800		4,970	5,000
	Width	(W)	mm	2,240	2,460			
	Height	(H)	mm	2,280	2,340		2,360	
	Tube extracting space		mm	3,430	3,440		4,510	
Weight	Operating weight		ton	8.0	10.2	10.5	12.5	13.3
	Total shipping weight		ton	7.2	9.2	9.4	11.2	11.9
Shipping method				1 piece				
Holding water amount	Chilled/Hot water		L	280	380	415	490	535
	Cooling water		L	500	610	670	770	840

Figure 4.24. Specifications of the absorption air conditioning system

A comparison between the two sets of information reveals the suitability of the solution in terms of heat source temperature. Specifically, waste heat sources with temperatures of 85°C or higher are relatively suitable for consideration of direct or indirect heat recovery via hot water circuits. For streams with lower temperatures, the applicability will depend on flow rate, thermal stability, and the efficiency of the heat exchange system. Among these, exhaust gases from dust filtration areas, cement grinding, and some clinker processing stages are more promising sources due to their relatively suitable temperature and high waste heat capacity.

Furthermore, absorption air conditioners are characterized by very low power consumption, mainly for pumps and controls, while the main energy is supplied from waste heat. Therefore, for cement plants – where there are already sources of excess heat but electricity is still needed for cooling or air conditioning – this solution has significant implications in terms of energy savings.

b. Solution description

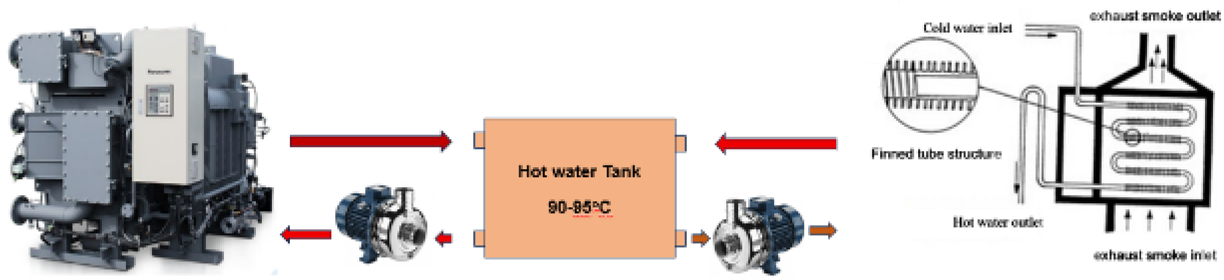


Figure 4.25. Description of heat recovery operation for system

Hot flue gas from the production processes is routed through a gas-water heat exchanger. Here, heat from the flue gas stream is transferred to the circulating water, raising the water temperature to approximately 90–95°C. After heat transfer, the flue gas cools down and is then directed to the exhaust fan/chimney system as is currently the case.

The recovered hot water is then directed to the generator of the absorption chiller. Here, the hot water acts as the heat source to operate the absorption cycle, replacing the electrical energy used in traditional mechanical chillers. The absorption chiller then produces chilled water at 7/12°C, which is supplied to the AHU/FCU units or other process cooling loads in the plant.

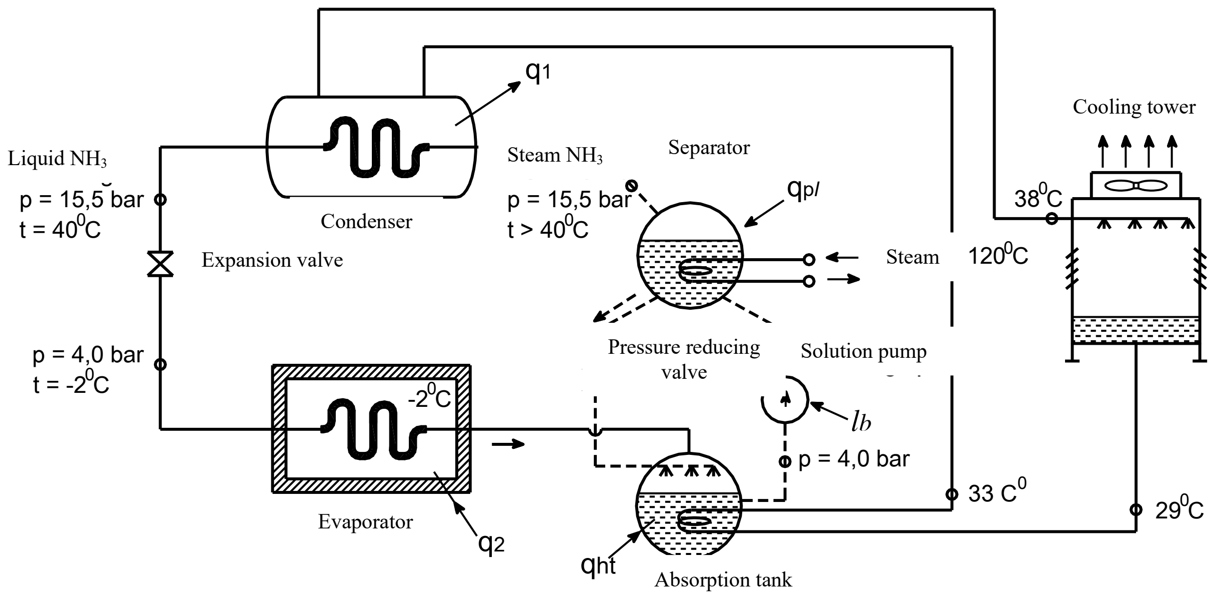


Figure 4.26. Description of the operating cycle of an absorption refrigeration system. (Absorption Chiller).

Simultaneously, the absorption chiller requires a cooling water circuit to dissipate excess heat into the environment via a cooling tower. Thus, the entire system forms three main circulation loops:

- Exhaust gas heat recovery loop → hot water
- Cold water loop → supplies the load
- Cooling water loop → cooling tower

Essentially, this solution doesn't create new energy sources, but rather utilizes existing surplus heat to partially replace the electricity currently used for air conditioning/cooling. This is a rational energy use approach, particularly suitable for cement plants with large amounts of hot emissions and a need for stable cooling.

c. Calculating energy saving potential with absorption air conditioning systems:

Table 4.5. Current status of the conventional air conditioning power capacity of power substations.

Location of equipment installation	Cooling capacity indicated on the outdoor unit in BTU (kW)	Outdoor unit power factor COP = 1.9 - (kW)	Power rating on the indoor unit (kW)	Working hours per year (hours/year)
LS04 Air Conditioning Station	240,000 Btu (120 Kx2)	37	(1.1 x 2)	24/7
LS05 Air Conditioning Station	760,000Btu (200Kx3) + (160Kx1)	118	(2.2 x 4)	24/7
LS06 Air Conditioning Station	500,000Btu (200 Kx2) + (120x1)	78	(2.2 x 2) + (1.1 x 1)	24/7
LS07 air conditioning station	160,000 Btu	24	(2.2 x 1)	24/7
LS08 air conditioning station	320,000 Btu (160K x 2)	48	(2.2 x 2)	24/7
Add	1,980,000 Btu (580 kW cooling)	305 kWe	23 kWE	
Total		**328 kWe**		

Table 4.6. Table for calculating the power consumption of an absorption air conditioning system.

Describe	Qty	Cooling capacity	Electrical power
Absorption air conditioners use hot water.	01	633 kW (180 RT)	11.8 kW

Describe	Qty	Cooling capacity	Electrical power
AHU, 160 Pa, 10000 m3/h	12	200,000 BTU (16.67 RT)	8.8 kW
Hot water circulation pump 90-95°C	02	120 m3/h; H=48 m	11 kW
7°C circulating chilled water pump	01	120 m3/h; H=48 m	11 kW
Cooling water pump	01	215 m3/h; H=27 m	11 kW
160°C centrifugal fan	01	8618 kg/h	22 kW
300 RT Cooling Tower	01	120 m3/h	7.5 kW
Total			**180 kW**

4.7 Machine Learning solutions for optimizing manufacturing operations

a. Current situation and problems

Currently, the operation of the cement production lines at the plant is mainly based on a traditional control system (LINES/SCADA) combined with the experience of the operating staff. Although the system is fully equipped with high-frequency measurement and data acquisition devices, the exploitation and use of the data still have many limitations.

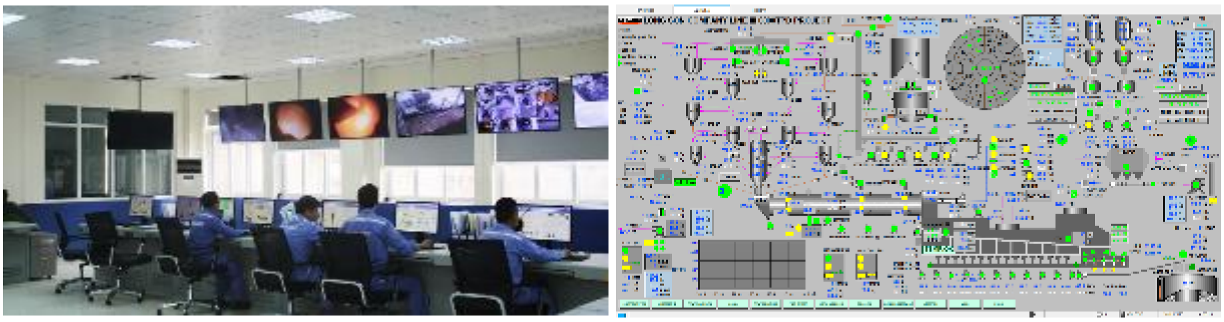


Figure 4.27. Monitoring and control operations at the Cement Plant Control Room & LINES system interface with high operational data density.

In reality, the plant is in a state of "data-rich but analytical information-poor"—meaning a large amount of operational data has been recorded, but it hasn't been effectively transformed into useful information for decision-making. Thousands of operational signals such as temperature, pressure, flow rate, gas composition, equipment load, energy consumption, etc., are constantly fluctuating over time, but haven't been systematically analyzed to identify patterns and trends.

In this context, the role of operational experience becomes particularly important. Adjustment decisions such as:

- Increase/decrease the amount of coal supplied to the calciner and rotary kiln;

- Adjust the airflow (id fan, fd fan, three-way air);
- Control the temperature in the fire zone;
- Balancing fuel consumption and clinker quality;
- It largely relies on the accumulated experience and intuition of the operator.

This approach leads to several key drawbacks:

- Heavy reliance on human resources: Operational efficiency is uneven across shifts, depending on the skill and experience of each individual.
- The system is primarily reactive: it only processes issues after they have occurred, lacking the ability to predict and prevent them.
- Safe (conservative) operating trend: To ensure stability, parameters are often maintained at "safe" levels, leading to higher-than-optimal energy consumption.
- Simultaneously optimizing multiple objectives is difficult: Balancing heat loss, electricity consumption, output, and product quality is a complex problem that cannot be solved manually.
- Historical data is not being effectively utilized: Long-term accumulated operational data has not been exploited to build predictive models or optimize processes.

In particular, for kiln systems – the most energy-intensive stage – factors such as fluctuations in raw material input, environmental conditions, and equipment status have a significant impact on operational efficiency. However, the relationship between these factors is non-linear and complex, making it difficult to identify them solely through observation or experience.

The result is:

- Energy consumption (coal, electricity) has not reached optimal levels;
- Operational fluctuations still exist, affecting system stability;
- Product quality is not yet absolutely consistent;
- The potential for energy savings is still large but largely untapped.

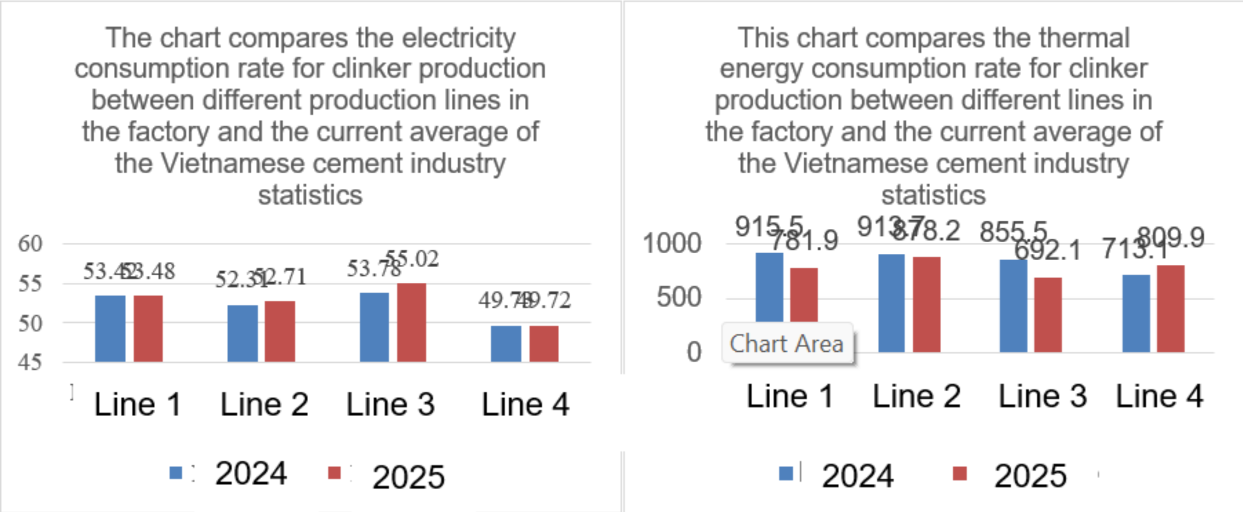


Figure 4.28. *Electricity and heat consumption rates vary from year to year and are not uniform.*

From the limitations mentioned above, it is clear that the current system lacks a tool capable of:

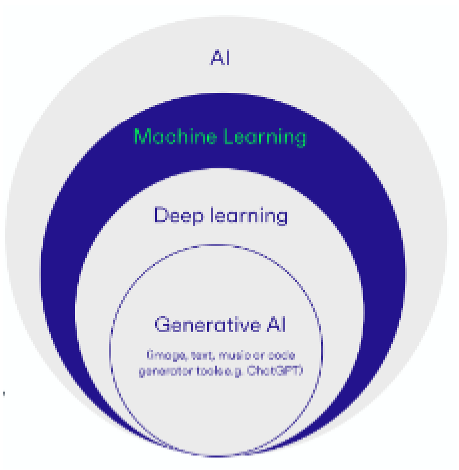
- Processing and analyzing large-scale data;
- Identify the hidden patterns in the operational process;
- Predicting trends and fluctuations in advance;
- And it supports optimal decision-making in real time.

This provides the basis for considering the application of Machine Learning solutions to improve the operational efficiency and energy usage of the plant.

b. Solution description

From the aforementioned shortcomings, it is clear that the core problem of the plant lies not in a lack of data or equipment, but in the ability to leverage data to support optimal operational decision-making. This is precisely the gap that traditional analytical methods and human experience cannot fully address.

In this context, Machine Learning is seen as a suitable tool for improving analytical capabilities and optimizing operations.



Machine Learning is a subset of artificial intelligence (AI), situated within a hierarchical structure: AI → Machine Learning → Deep Learning → Generative AI. In this structure, AI is the overarching concept, Machine Learning focuses on learning from data, Deep Learning is a specialized branch utilizing multi-layered neural networks, and Generative AI is an advanced application layer capable of content generation.

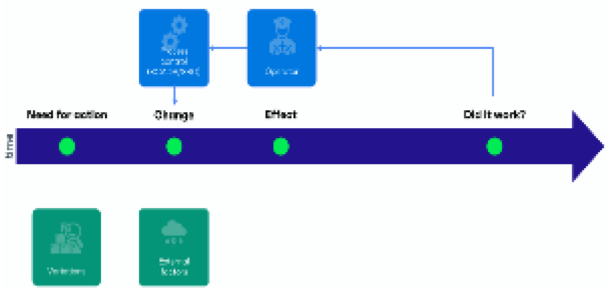
Within the scope of this report, the solution focuses on applying Machine Learning/Deep Learning to optimize operations, without using generated models.

Machine learning is a subset of artificial intelligence (AI) that allows systems to learn from historical and real-time data to identify complex patterns, trends, and relationships in their operations. Based on this, the system can:

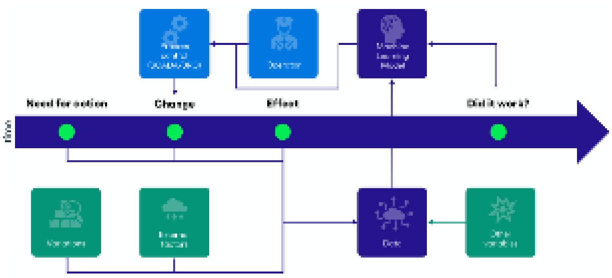
- Predicting operating conditions in advance;
- Detecting abnormal signs;
- And it suggests or automatically adjusts operating parameters towards optimal performance.

Unlike traditional reactive operating methods (only addressing issues when they occur), Machine Learning allows for a shift to a more reactive operating approach:

- From reaction → to prediction;
- From personal experience to data-driven decision-making;
- From conservative operation to continuous optimization.



Traditional operating procedures



Operating procedures based on Machine Learning methods.

Figure 4.29. Comparing the differences between traditional operating procedures and Machine Learning

In particular, for complex systems such as cement kilns – where many non-linear relationships exist between raw materials, heat, gas, and equipment states – Machine Learning has the capability to:

- Discovering connections that are difficult for people to recognize;
- Evaluate multiple variables simultaneously;
- And provide optimal operational solutions in real time.

Accordingly, the application of Machine Learning in the factory is not intended to replace the existing control system, but rather to act as an additional layer of intelligence, helping to:

- Improve the quality of operational decisions;
- Reduce reliance on personal experience;
- And effectively utilize the available data sources.

By implementing this solution, the factory can directly address existing "situations" such as:

- Optimize energy consumption (coal, electricity);
- Reduce vibration and improve operational stability;
- Improve product quality;
- And improve the efficiency of data utilization throughout the entire production system.

c. Scope of application

The proposed Machine Learning solution will be implemented across all four production lines of the factory, focusing on processes with high energy consumption and direct impact on operational efficiency, including:

- Kiln system (calciner and rotary kiln);
- Material grinding system;
- Coal crushing system;
- Cement grinding system;
- The fan systems and auxiliary equipment consume a lot of electricity.

The solution leverages existing data from the LINES/SCADA system, thus not requiring investment in replacing core technology equipment, but focusing on optimizing the operation of existing assets.

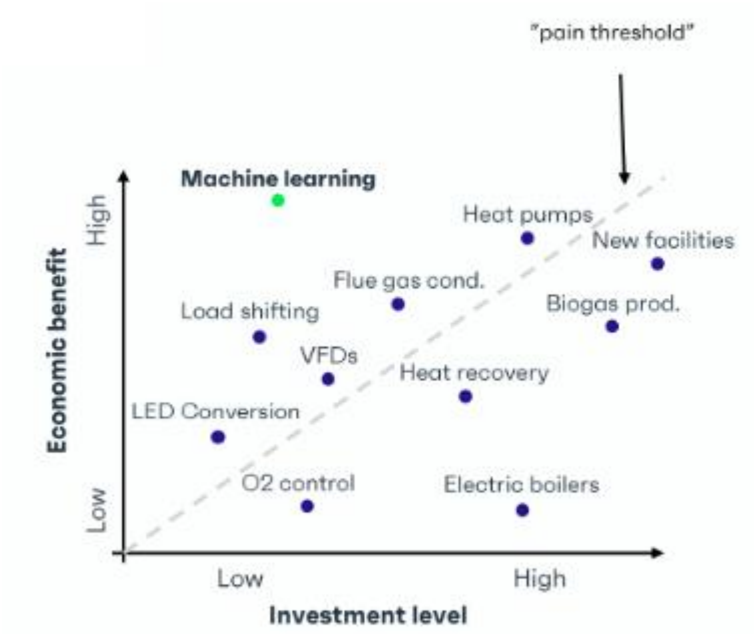


Figure 4.30. The position of Machine Learning in relation to economic efficiency and investment level.

As illustrated in the image, Machine Learning falls into the category of solutions that include:

- Average investment level but high economic efficiency.Compared to traditional solutions such as heat recovery, inverters, or equipment upgrades, ML (Material-Based Optimization) represents the next step in the optimization process, maximizing the efficiency of existing systems before considering large investments.

Therefore, the application scope of the solution is not limited to a single stage, but can be extended across the entire production line, acting as an overall optimization layer for the system.

The solution leverages existing infrastructure, requiring no large investment in new equipment and primarily utilizing readily available data.

d. Improvement activities after implementation

Implementing Machine Learning solutions in manufacturing operations not only brings energy efficiency but also creates comprehensive value in terms of engineering, economics, and operational management.

❖ **Energy and economic benefits**

- Reduced fuel (coal) consumption: By optimizing the combustion process and heat distribution in the calciner and rotary kiln, heat consumption is reduced by approximately 2-5%.
- Reduce electricity consumption: Optimizing the operation of high-power electrical appliances such as fans and grinders can save approximately 3-7% of electricity.

- Efficient heat recovery: Optimizing coordination between processes to improve heat utilization efficiency throughout the system.

❖ **Operational benefits**

- Stabilize the production process: Reduce fluctuations in temperature, pressure, and other critical operating parameters, especially in the kiln system.
- Shifting from reactive to predictive operation: The system is capable of forecasting trends and providing early warnings, enabling action before incidents occur.
- Reduce reliance on individual experience: Standardize operational decisions based on data, reducing discrepancies between shifts.
- Multi-objective optimization: Simultaneously balancing energy consumption, output, and product quality.

❖ **Benefits in terms of quality and yield**

- Improving clinker quality: Maintaining stable operating conditions, reducing variability in product composition and properties.
- Increased production line productivity: Through operational optimization, output can increase by approximately 3-10% without investing in new equipment.
- Reduce the rate of defective products: Minimize deviations due to process variations.

❖ **Benefits in terms of equipment maintenance and reliability.**

- Early detection of abnormalities: Identify signs of abnormal operation in equipment (fans, grinders, furnaces, etc.).
- Switch to condition-based maintenance: Reduce reliance on scheduled maintenance and optimize maintenance costs.
- Extend equipment lifespan: Reduce vibration and shock loads during operation.

❖ **Benefits of digital transformation and management**

- Enhancing operational digitalization: Leveraging data to support decision-making.
- Laying the foundation for smart factories: A crucial step in the digital transformation roadmap.
- Operational transparency: Decisions are supported by data and models, making them easy to track and evaluate.

e. Estimated investment level for the solution

Machine learning solutions are data-driven operational optimization solutions that do not require investment in replacing core technology equipment, but primarily focus on digital infrastructure, software, and model deployment. Overall, the investment is moderate, but the return is high, making them suitable for large-scale factories.

❖ **Main investment items**

The project's investment components include:

- Data and storage infrastructure:
  + Server or cloud computing platform;
  + Historical data archiving system (historian);
  + Upgrade data connectivity from LINES/SCADA (if necessary).
- Machine Learning software and platforms:
  + Software for data analysis and model building;
  + Visualization tools and operational dashboards;
  + The solution integrates with the existing control system.
- Costs of model development and implementation:
  + Collect, clean, and normalize data;
  + Develop machine learning models (prediction, optimization);
  + Adjust the model to the actual conditions of the factory;
  + Run a test and evaluate its effectiveness.
- Training and technology transfer:
  + Providing system operation training for engineers and operators;
  + A guide to using dashboards and decision support tools.

5 Appendix

5.1 Financial efficiency analysis of solar power system installation

Table 5.1. Financial efficiency analysis of solar power system installation

No.	Interpretation	Unit	Result		
			PA1: No storage	PA2: Has 10MWh storage	PA2: Has 20MWh storage
I	**Savings potential**				
1.1	Typical solar power system capacity	MWp	10	10	10
1.2	Storage system capacity	MWh	-	10	20
1.3	Annual electricity output of the system	kWh/year	14,134,437	14,134,437	14,134,437
1.4	Total estimated investment cost	Million VND	172,250	212,000	265,000
1.5	Number of working days in a year	Day/Year	360	360	360
1.6	Normal hour electricity prices	VND/kWh	1,811	1,811	1,811
1.7	Peak hour electricity prices	VND/kWh	3,266	3,266	3,266
1.8	Off-peak electricity prices	VND/kWh	1,146	1,146	1,146
1.9	Electricity produced from solar power is distri-ed during normal hours.	%	74.00%	52.35%	9.05%

No.	Interpretation	Unit	Result		
			PA1: No storage	**PA2: Has 10MWh storage**	**PA2: Has 20MWh storage**
1.10	Electricity produced from solar power is distri-ed during peak hours.	%	26.00%	47.65%	90.95%
1.11	Electricity produced from solar power is distri-ed during off-peak hours.	%	0.00%	0.00%	0.00%
1.12	The electricity output from the solar power system corresponds to normal hours.	kWh/year	10,459,483	7,399,483	1,279,483
1.13	The amount of electricity distri-ed from the solar power system corresponds to peak hours.	kWh/year	3,674,954	6,734,954	12,854,954
1.14	The amount of electricity allocated from the solar power system corresponds to off-peak hours.	kWh/year	-	-	-
1.15	Cost savings from a solar power system.	Million VND	30,945	35,397	44,301
II	**Analyze the economic efficiency of implementing the solution.**				
2.1	Electricity generated by the system in one year	kWh/year	14,134,437	14,134,437	14,134,437
2.2	The amount of money saved from energy saving.	Million VND	30,945	35,397	44,301
2.3	Project investment costs	Million VND	172,250	212,000	265,000

No.	Interpretation	Unit	Result		
			PA1: No storage	PA2: Has 10MWh storage	PA2: Has 20MWh storage
2.4	Loan capital for the project is expected to be provided.	Million VND	-	-	-
2.5	Operating costs increase annually due to renovation investments.	Million VND	200	300	400
2.6	Operating costs decreased due to annual investment in renovations.	Million VND	-	-	-
2.7	The proceeds from selling off old equipment.	Million VND	-	-	-
2.8	Increased costs to remove old equipment.	Million VND	-	-	-
2.9	The residual value of the project after depreciation.	Million VND	-	-	-
2.10	Project lifespan	Year	20	20	20
2.11	Tax rate	%	20.00%	20.00%	20.00%
2.12	Discount factor	%	12.00%	12.00%	12.00%
2.13	interest rate	%	12.00%	12.00%	12.00%
2.14	Repayment period	Year	-	-	-
2.15	Simple payback period	Year	5.60	6.04	6.04
2.16	IRR	%	14.21%	13.01%	13.02%

No.	Interpretation	Unit	Result		
			PA1: No storage	**PA2: Has 10MWh storage**	**PA2: Has 20MWh storage**
2.17	NPV	Million VND	24,331.7	13,558.2	17,129.4
2.18	Electricity produced from a solar panel system (TOE)	TOE/year	2,180.9	2,180.9	2,180.9
2.19	Corresponding CO2 emissions	Tons of CO2e/year	9,317.4	9,317.4	9,317.4

5.2 Financial efficiency analysis of replacing halogen bulbs with LED headlights

Table 5.2. Investment efficiency calculation table for replacing halogen bulbs with LED headlights

No.	Parameter	Unit	Solution: Replace the 70W halogen bulb with a 30W LED floodlight.		Solution: Replace the 150W halogen bulb with a 70W LED floodlight.	
			Halogen 70W	30W LED floodlight	Halogen 150W	70W LED floodlight
1	**Database**					
1.1	Power rating of the light fixture (Bulb + Ballast)	W	85	30	170	70
1.2	Number of light bulbs	Ball	4362	4362	149	149
1.3	Simultaneous utilization factor		80%	80%	80%	80%
1.4	Installation and material costs (for 1 light bulb)	million VND/ball	0	0.1	0	0
1.5	Cost of light bulb (Per 1 bulb)	million VND/ball		1		1,500,000
1.6	Average operating time: 1 day	Hour	10	10	10	10
1.7	Number of operating days in a year	Day	365	365	365	365
1.8	Number of operating hours in one year	Hour	3,650	3,650	3,650	3,650
1.9	Electricity consumption	kWh	1,082,648	382,111	73,964	30,456
2	**Energy saving potential**					

No.	Parameter	Unit	Solution: Replace the 70W halogen bulb with a 30W LED floodlight.		Solution: Replace the 150W halogen bulb with a 70W LED floodlight.	
			Halogen 70W	30W LED floodlight	Halogen 150W	70W LED floodlight
2.1	Annual energy savings	kWh		700,537		43,508
2.2	Average electricity price	VND/kWh	1,948.0	1,948.0	1,948	1,948
2.3	Annual electricity cost of the lights	million	2,109.0	744.4	144,081,093	59,327,509
2.4	Save on your annual electricity bill.	million		1,364.6		84,753,584
2.5	Total investment cost	million		2,617.2		223,500,000
2.6	Payback period	Year		1.92		2.6
2.7	Project lifespan	Year		5.00		5.00
2.8	Tax rate	&		12.0%		12.0%
2.9	Internal Rate of Return (IRR)	%		43.6%		26.0%
2.10	Net present value (NPV) (over 5 years, discounted 12% per year)	4		2,055.40		4,145
3	**Environment**					
3.1	TOE conversion	TOE/year		167.1		11.4
3.2	Reduce CO2 emissions	tons of CO2/year		713.7		48.8

5.3 Financial efficiency analysis of the solution "Installing frequency converters for air compressor combined with a central controller for the compressed air system"

Table 5.3. Investment efficiency calculation table for the solution "Installing frequency converters for air compressor combined with a central controller for the compressed air system"

No	Interpretation	Unit	Compressed air system					
			D31	D32	D33	D34	D35	D36
I	Savings potential							
1.1	Number of air compressor	Machine	5	4	5	4	6	6
1.2	Total rated capacity of the air compressor system	MCU	600	480	600	480	720	660
1.3	Power consumption of air compressor system based on the year 2024	Machine	2,308,445	2,649,025	2,097,953	3,335,406	3,309,729	4,572,671
1.4	Average pressure of the system	MPa	0.68	0.65	0.65	0.65	0.65	0.65
1.5	Average load operating time of the system	%	97.74%	95.00%	97.24%	95.00%	85.39%	99.78%
1.6	Average pressure of the system after renovation	MPa	0.62	0.62	0.62	0.62	0.62	0.62
1.7	Average load operating time of the system after renovation	%	99.00%	99.00%	99.00%	99.00%	99.00%	99.78%
1.8	% load of air compressor operating in idle (Unload) mode	%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%
1.9	Energy efficiency percentage decreased after renovation.	%	3.68%	3.00%	2.33%	3.00%	5.88%	1.80%

No	Interpretation	Unit	Compressed air system					
			D31	D32	D33	D34	D35	D36
1.10	Total electricity consumption reduced by one year.	kWh/year	84,935	79,471	48,869	100,062	194,713	82,308
1.11	Average electricity price	VND/kWh	1,948	1,948	1,948	1,948	1,948	1,948
1.12	Savings	Million VND/year	165.45	154.81	95.20	194.92	379.30	160.34
II	Analyze the economic efficiency of implementing the solution.							
2.1	Electricity generated by the system in one year	kWh/year	84,935	79,471	48,869	100,062	194,713	82,308
2.2	The amount of money saved from energy saving.	Million VND	165.45	154.81	95.20	194.92	379.30	160.34
2.3	Project investment costs	Million VND	600.00	600.00	600.00	600.00	600.00	600.00
2.4	Loan capital for the project is expected to be provided.	Million VND	-	-	-	-	-	-
2.5	Operating costs increase annually due to renovation investments.	Million VND	10	10	10	10	10	10
2.6	Operating costs decreased due to annual investment in renovations.	Million VND	-	-	-	-	-	-
2.7	The proceeds from selling off old equipment.	Million VND	-	-	-	-	-	-

No	Interpretation	Unit	Compressed air system					
			D31	D32	D33	D34	D35	D36
2.8	Increased costs to remove old equipment.	Million VND	-	-	-	-	-	-
2.9	The residual value of the project after depreciation.	Million VND	-	-	-	-	-	-
2.10	Project lifespan	Year	10	10	10	10	10	10
2.11	Tax rate	%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%
2.12	Discount factor	%	12.00%	12.00%	12.00%	12.00%	12.00%	12.00%
2.13	interest rate	%	12.00%	12.00%	12.00%	12.00%	12.00%	12.00%
2.14	Repayment period	Year	-	-	-	-	-	-
2.15	Simple payback period	Year	3.86	4.14	7.04	3.24	1.62	3.99
2.16	IRR	%	18.60%	16.80%	5.65%	23.40%	50.37%	17.74%
2.17	NPV	Million VND	170.5	122.4	- 147.1	303.7	1,137.1	147.3
2.18	Electricity produced from a solar panel system (TOE)	TOE/year	13.1	12.3	7.5	15.4	30.0	12.7
2.19	Corresponding CO2 emissions	Tons of CO2e/year	56.0	52.4	32.2	66.0	128.4	54.3

5.4 Energy saving potential analysis of the solution "Regularly inspect and rectify compressed air leaks”

Table 5.4. Energy saving potential calculation table when implementing the solution "Regularly inspect and fix compressed air leaks"

No	Interpretation	Unit	Compressed air system					
			D31	D32	D33	D34	D35	D36
1	Number of air compressor	Machine	5	4	5	4	6	6
2	Total rated capacity of the air compressor system.	MCU	600	480	600	480	720	660
3	Power consumption of air compressor system based on the year 2024.	Machine	2,308,445	2,649,025	2,097,953	3,335,406	3,309,729	4,572,671
4	Energy efficiency decreased after fixing the leaks.	%	1%	1%	1%	1%	1%	1%
5	Total electricity consumption reduced by one year.	kWh/year	23,084	26,490	20,980	33,354	33,097	45,727
6	Average electricity price	VND/kWh	1,948	1,948	1,948	1,948	1,948	1,948
7	Savings	Million VND/year	44.97	51,60	40.87	64.97	64.47	89.07
8	Estimated investment cost	Million VND	20.0	20.0	20.0	20.0	20.0	20.0
9	Simple payback period	Year	0.44	0.39	0.49	0.31	0.31	0.22
10	Energy savings as converted to TOE	TOE/year	3.56	4.09	3.24	5.15	5.11	7.06
11	CO_2 emissions decreased after implementing the solution.	Tons of CO2e/year	15.22	17.46	13.83	21.99	21.82	30.14

5.5 Financial efficiency analysis of the solution "Piping upgrade and installation of pressure-separated piping for the compressed air system"

Table 5.5. Investment efficiency calculation table for the solution "Piping renovation and installation of pressure-classified piping for compressed air systems"

No.	Interpretation	Unit	Compressed air system					
			D31	D32	D33	D34	D35	D36
I	Savings potential							
1.1	Number of air compressor	Machine	5	4	5	4	6	6
1.2	Total rated capacity of the air compressor system.	MCU	600	480	600	480	720	660
1.3	Power consumption of air compressor system based on the year 2024.	Machine	2,308,445	2,649,025	2,097,953	3,335,406	3,309,729	4,572,671
1.4	Average pressure of the system	MPa	0.68	0.65	0.65	0.65	0.65	0.65
1.5	% of compressed air consumption for low-pressure equipment	%	45.00%	60.00%	45.00%	60.00%	45.00%	45.00%
1.6	Average pressure of the low-pressure system after renovation	MPa	0.50	0.50	0.50	0.50	0.50	0.50
1.7	Energy efficiency percentage decreased after renovation.	%	4.73%	5.40%	4.05%	5.40%	4.05%	4.05%
1.8	Total electricity consumption reduced by one year.	kWh/year	109,074	143,047	84,967	180.112	134,044	185,193

No.	Interpretation	Unit	Compressed air system					
			D31	**D32**	**D33**	**D34**	**D35**	**D36**
1.9	Average electricity price	VND/kWh	1,948	1,948	1,948	1,948	1,948	1,948
1.10	Savings	Million VND/year	212.48	278.66	165.52	350.86	261.12	360.76
II	Analyze the economic efficiency of implementing the solution.							
2.1	Electricity generated by the system in one year	kWh/year	109,074	143,047	84,967	180.112	134,044	185,193
2.2	The amount of money saved from energy saving.	Million VND	212.48	278.66	165.52	350.86	261.12	360.76
2.3	Project investment costs	Million VND	750.00	750.00	750.00	750.00	750.00	750.00
2.4	Loan capital for the project is expected to be provided.	Million VND	-	-	-	-	-	-
2.5	Operating costs increase annually due to renovation investments.	Million VND	10	10	10	10	10	10
2.6	Operating costs decreased due to annual investment in renovations.	Million VND	-	-	-	-	-	-
2.7	The proceeds from selling off old equipment.	Million VND	-	-	-	-	-	-

No.	Interpretation	Unit	Compressed air system					
			D31	D32	D33	D34	D35	D36
2.8	Increased costs to remove old equipment.	Million VND	-	-	-	-	-	-
2.9	The residual value of the project after depreciation.	Million VND	-	-	-	-	-	-
2.10	Project lifespan	Year	10	10	10	10	10	10
2.11	Tax rate	%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%
2.12	Discount factor	%	12.00%	12.00%	12.00%	12.00%	12.00%	12.00%
2.13	interest rate	%	12.00%	12.00%	12.00%	12.00%	12.00%	12.00%
2.14	Repayment period	Year	-	-	-	-	-	-
2.15	Simple payback period	Year	3.70	2.79	4.82	2.20	2.99	2.14
2.16	IRR	%	19.68%	28.08%	13.22%	36.67%	25.91%	37.82%
2.17	NPV	Million VND	250.0	549.1	37.7	875.5	469.9	920.2
2.18	Electricity produced from a solar panel system (TOE)	TOE/year	16.8	22.1	13.1	27.8	20.7	28.6
2.19	Corresponding CO2 emissions	Tons of CO2e/year	71.9	94.3	56.0	118.7	88.4	122.1

5.6 Solution Analysis: "Optimizing the vacuum pressure of the condenser in the heat recovery system for line 1"

Table 5.6. Solution calculation results: "Optimizing the vacuum pressure of the condenser in the heat recovery system for line 1"

No	Parameter	Symbol	Calculation formula	Unit	Value
1	Total electricity production	E_total	-	kWh	52,667,600
2	Current electricity consumption	E_self	-	kWh	2,841,397
3	Current rate of self-consumption of electricity	R_HAM	E_self / E_total	%	5.39
4	Expected reduction in self-consumption of electricity	ΔE_self	E_self × 12%	kWh	340,968
5	Electricity prices	P_elec	-	VND/kWh	1,948
6	Save on electricity costs for self-consumption.	S_cost	ΔE_self × P_elec	Million VND	664.21
7	CO_2 emission factor of Vietnam's power grid	EF_CO2	-	tCO_2/MWh	0.6592
8	CO_2 emissions reduction	ΔCO2	ΔE_self × (EF_CO2 / 1.000)	tCO_2	224.77
9	Expected system performance increase	n_inc	-	%	4
10	Electricity production is expected to increase.	ΔE_prod	E_total × η_inc	kWh	2,106,704
11	Total annual cost savings	S_total	S_cost + (ΔE_prod × P_elec)	Million VND	4,768.07
12	Investment costs	C_invest	-	Million VND	3,000
13	Payback period	Thv	C_invest/S_total*12	Month	7.55
14	Discount factor	i		%	10
15	Project lifespan	n		year	10
16	Net profit of the project	NPV		Million VND	26,300.00
17	Internal rate of return	IRR	-	%	150

5.7 Analyze the effectiveness of replacing low-efficiency IE1 motors with high-efficiency motors (IE3-IE4) when the opportunity arises

Table 5.7. Replace low-efficiency IE1 motors with high-efficiency motors (IE3-IE4) whenever possible.

No.	Parameter	Unit	Replace the IE1 motor with an IE4 motor (LINE 1)		Replace the IE2 motor with an IE4 motor (LINE 2)	
			Crusher code 221CR01 - IE1	**New IE4 motor**	**Conveyor belts code 322BC02 and 522BC08MT01 - IE2**	**New IE4 motor**
I	**Database**					
1.1	Rated power	MCU	160	160	90	90
1.2	Number of engines that need replacing	the	**1**	**1**	**2**	**2**
1.3	Total capacity required	MCU	160	160	180	180
1.5	Rated power factor		0.85	0.93	0.88	0.93
1.6	Rated performance	%	93.80%	96.60%	93.00%	96.10%
1.7	Average operating time: 1 day	Hour	24	24	24	24
1.8	Number of operating days in a year	Day	360	360	360	360
1.9	Concurrent operation rate	%	70%	70%	70%	70%
1.10	Number of operating hours in one year	Hour	8,640	8,640	8,640	8,640
1.11	Apparent power of the load	kVA	131.76	120.43	143.18	135.48
1.12	Iron loss in the engine	MCU	5.33	1.69	3.00	2.19
1.13	Copper loss in the engine	MCU	5.18	2.76	6.64	3.58
1.14	Total losses	MCU	10.52	4.45	9.64	5.77
II	**Energy saving potential**					

No.	Parameter	Unit	Replace the IE1 motor with an IE4 motor (LINE 1)		Replace the IE2 motor with an IE4 motor (LINE 2)	
			Crusher code 221CR01 - IE1	New IE4 motor	Conveyor belts code 322BC02 and 522BC08MT01 - IE2	New IE4 motor
2.1	Energy saving	MCU		6.07		3.87
2.2	Energy saving	kWh		52,415		33,418
2.3	Average electricity price	VND/kWh	1,948	1,948	1,948	1,948
2.4	Amount of savings	VND/year		102		65
2.5	Total investment cost	4		450		640
2.6	Payback period	Year		4.41		9.83
III	**Environment**					
3.1	TOE conversion	TOE/year		8.09		5.16
3.2	Reduce CO2 emissions	tons of CO2/year		34.55		22.03

5.8 Financial effectiveness analysis of the solution "Waste heat recovery solution (>100°C) using absorption chiller technology to serve the air-conditioning system for loads in the control room and electrical substation areas (L1–L4)".

Table 5.8. Financial analysis of the solution "Waste heat recovery solution (>100°C) using absorption chiller technology to serve the air-conditioning system for loads in the control room and electrical substation areas (L1–L4)"

No.	Interpretation	Unit	Invest in an absorption air conditioning system for LINE 1.	
			Before	After
I	Savings potential			
1.1	Cooling capacity of the air conditioning system	RT	580	630
1.2	Total system power consumption	MCU	328	180
1.3	Number of hours the system operates in one day.	Hour/Day	24	24
1.4	Number of days the system is operational in a year.	Day/Year	365.00	365.00
1.5	Average power consumption of the system over one year.	kWh/year	2,873,280	1,576,800
1.6	Average electricity price	VND/kWh	1,948	1,948
1.7	Electricity costs for one year	Million VND/year	5,597.15	3,071.61
II	Analyze the economic efficiency of implementing the solution.			
2.1	Electricity generated by the system in one year	kWh/year	1,296,480	
2.2	The amount of money saved from energy saving.	Million VND	2,525.54	
2.3	Project investment costs	Million VND	9,000.00	
2.4	Loan capital for the project is expected to be provided.	Million VND	-	
2.5	Operating costs increase annually due to renovation investments.	Million VND	50	

No.	Interpretation	Unit	Invest in an absorption air conditioning system for LINE 1.	
			Before	After
2.6	Operating costs decreased due to annual investment in renovations.	Million VND	200	
2.7	The proceeds from selling off old equipment.	Million VND	500	
2.8	Increased costs to remove old equipment.	Million VND	50	
2.9	The residual value of the project after depreciation.	Million VND	2,000	
2.10	Project lifespan	Year	10	
2.11	Tax rate	%	20.00%	
2.12	Discount factor	%	12.00%	
2.13	interest rate	%	12.00%	
2.14	Repayment period	Year	-	
2.15	Simple payback period	Year	3.20	
2.16	IRR	%	24.65%	
2.17	NPV	Million VND	5,076.1	
2.18	Electricity produced from a solar panel system (TOE)	TOE/year	200.0	
2.19	Corresponding CO2 emissions	Tons of CO2e/year	854.6	

5.9 The effectiveness analysis of Machine Learning applications in optimizing production operations

Table 5.9. Machine Learning solutions for optimizing manufacturing operations.

No.	Interpretation	Unit	Result			
			Line 1	Line 2	Line 3	Line 4
I	Savings potential					
1.1	Total electricity consumption in the base year (2024)	kWh/year	221,504,477	188,688,568	117,778,111	120,356,000
1.2	Total coal consumption in the base year (2024)	Tons/year	321601	304357	301772	296708
1.3	Average electricity price	VND/kWh	1948	1948	1948	1948
1.4	Average coal price	Million VND/Ton	2.5	2.5	2.5	2.5
1.5	Potential for electricity savings after implementing the solution.	%	2.00%	2.00%	2.00%	2.00%
1.6	Potential coal savings after implementing the solution.	%	1.50%	1.50%	1.50%	1.50%
1.7	Expected electricity savings	kWh/year	4,430,090	3,773,771	2,355,562	2,407,120
1.8	Expected amount of coal to be saved	Tons/year	4,824	4,565	4,527	4,451
1.9	Potential savings after implementing the solution	Million VND/year	20,690	18,765	15,905	15,816

No.	Interpretation	Unit	Result			
			Line 1	Line 2	Line 3	Line 4
II	Analyze the economic efficiency of implementing the solution.					
2.1	Amount of electricity saved in one year	kWh/year	4,430,090	3,773,771	2,355,562	2,407,120
2.2	Amount of coal saved in one year	Tons/year	4,824	4,565	4,527	4,451
2.3	The amount of money saved from energy saving.	Million VND/year	20,690	18,765	15,905	15,816
2.4	Project investment costs	Million VND	31,800	31,800	26,500	26500
2.5	Loan capital for the project is expected to be provided.	Million VND	-	-	-	-
2.6	Operating costs increase annually due to renovation investments.	Million VND	200	200	200	200
2.7	Operating costs decreased due to annual investment in renovations.	Million VND	-	-	-	-
2.8	The proceeds from selling off old equipment.	Million VND	-	-	-	-
2.9	Increased costs to remove old equipment.	Million VND	-	-	-	-
2.10	The residual value of the project after depreciation.	Million VND	-	-	-	-
2.11	Project lifespan	Year	20	20	20	20

No.	Interpretation	Unit	Result			
			Line 1	**Line 2**	**Line 3**	**Line 4**
2.12	Tax rate	%	20.00%	20.00%	20.00%	20.00%
2.13	Discount factor	%	12.00%	12.00%	12.00%	12.00%
2.14	interest rate	%	12.00%	12.00%	12.00%	12.00%
2.15	Repayment period	Year	-	-	-	-
2.16	Simple payback period	Year	1.55	1.71	1.69	1.70
2.17	IRR	%	52.54%	47.68%	48.39%	48.12%
2.18	NPV	Million VND	93,013.5	81,509.6	69,326.0	68,791.4
2.19	Energy savings are converted into TOE.	TOE/year	2,895.1	2,739.8	2,716.3	2,670.7
2.20	Corresponding CO2 emissions	Tons of CO2e/year	14,835.6	13,764.1	12,733.4	12,579.8

5.10 Analysis of the effectiveness of implementing the ISO 50001:2018 energy management system

Table 5.10. Economic calculation for implementing the ISO 50001:201 energy management system

No.	Interpretation	Unit	Result
I	Savings potential		
1.1	Total electricity consumption for the entire plant in the base year (2024)	kWh/year	648,327,157
1.2	Total coal consumption in the base year for the entire plant (2024)	Tons/year	1,224,438
1.3	Average electricity price	VND/kWh	1,948
1.4	Average coal price	Million VND/Ton	2.5
1.5	Potential for electricity savings after implementing the solution.	%	0.20%
1.6	Potential coal savings after implementing the solution.	%	0.20%
1.7	Expected electricity savings	kWh/year	1,296,654
1.8	Expected amount of coal to be saved	Tons/year	2,449
1.9	Money saved after implementing the solution	Million VND/year	8,648.07
II	Analyze the economic efficiency of implementing the solution.		
2.1	Amount of electricity saved in one year	kWh/year	1,296,654
2.2	Amount of coal saved in one year	Tons/year	2,448.9
2.3	The amount of money saved from energy saving.	Million VND/year	8,648.07
2.4	Project investment costs	Million VND	3000
2.5	Loan capital for the project is expected to be provided.	Million VND	-
2.6	Operating costs increase annually due to renovation investments.	Million VND	500
2.7	Operating costs decreased due to annual investment in renovations.	Million VND	-
2.8	The proceeds from selling off old equipment.	Million VND	-

No.	Interpretation	Unit	Result
2.9	Increased costs to remove old equipment.	Million VND	-
2.10	The residual value of the project after depreciation.	Million VND	-
2.11	Project lifespan	Year	3
2.12	Tax rate	%	20.00%
2.13	Discount factor	%	12.00%
2.14	interest rate	%	12.00%
2.15	Repayment period	Year	-
2.16	Simple payback period	Year	0.37
2.17	IRR	%	216.91%
2.18	NPV	Million VND	13,136.60
2.19	Energy savings are converted into TOE.	TOE/year	1,469.53
2.20	Corresponding CO2 emissions	Tons of CO2e/year	6,903.48

5.11 Analyzing the effectiveness of load shifting solutions, peak load control, and WHR integration

Table 5.11. Economic calculations for load shifting solutions, peak load control, and WHR integration

No.	Data	Unit	Parameter
1	Total electricity consumption during peak hours	kWh.year	51,621,152
2	Normal hour electricity prices	VND/kWh	1,811
3	Peak hour electricity prices	VND/kWh	3,266
4	Off-peak electricity prices	VND/kWh	1,146
5	The amount of electricity distributed from the solar power system corresponds to peak hours.	kWh/year	3,674,954
6	The rate of load shifting from peak to normal hours.	%	4
7	Amount of electrical energy transferred	kWh/year	2,064,846
8	Amount of savings	VND/year	3,004,351,046