

Implementation of Cleaner Production Methodology for Reduction of Energy Consumption and Waste Sand in Foundries

Mendon Dewa

Department of Industrial Engineering
Faculty of Engineering and the Built Environment
Durban University of Technology
Durban, South Africa
mendond@dut.ac.za

Abstract

Cleaner Production technologies have become increasingly more popular with the rise in governmental and regulatory actions to push the industrial sector toward sustainability. The case-in-point organisation has been facing challenges with waste foundry sand generation which was disposed of at landfills, and the high electricity bill was largely attributed to the induction furnaces used. Hence, the study was aimed to identify sources of waste and emissions, evaluate opportunities for sustainable improvements, minimise waste sand disposal and reduce energy consumption to achieve cost savings and promote environmental sustainability. A Cleaner Production assessment was conducted and the identified solutions that were implemented were good housekeeping programme and furnace energy optimisation. Reducing sand spillage was accomplished after identifying the key sand loss points which include sand transport between stations, manual handling spills, overflow during shake-out as well as loss due to defective moulds or cores. The structured good housekeeping programme resulted in an estimated 30% reduction in sand spillages, which is from 1092 tons per month to 322 tons, yielding disposal cost savings of approximately R1.7 million per year. Furnace energy optimisation was undertaken to address the identified key energy loss mechanisms which included overheating molten metal, unplanned idle time, surface heat losses, cold charge materials, flue gas losses, and poor refractory condition for the foundry furnaces. The implemented furnace energy optimisation measures resulted in an estimated 18% reduction in electricity consumption, annual saving of approximately 607 MWh, a reduction of 547 tons CO₂, and an annual financial saving of around R1.5 million.

Keywords

Cleaner Production, Energy Consumption, Material Balance, Waste Foundry Sand

1. Introduction

South African foundries are guided by National Environmental Management Act (NEMA), Carbon tax framework, Integrated Energy Efficiency Regulations and should operate according to National Cleaner Production Centre South Africa (NCPC-SA) guidelines (Ndifelani, 2022). While metal casting foundries have made significant strides in terms of sustainability over the years, they continue to be major consumers of raw materials and energy, often contributing heavily to environmental damage (Madan and Singh, 2022). In the foundry process, waste generation directly affects the economy as well as the environment, waste leads to higher material, energy, and disposal costs, reducing overall efficiency and profitability. Environmentally, waste often results in pollution of air, water, and soil, contributing to health risks and ecological damage. Cleaner production (CP) technologies offer a promising solution to reduce these negative impacts while maintaining profitability. A metal casting foundry has been facing significant challenges with high energy consumption, particularly electrical energy, leading to increased costs for the company. This higher energy usage also results in Eskom burning more coal, which negatively impacts the environment. Additionally, the

disposal of waste sand could be managed more efficiently, considering both the environmental and economic impacts. The current disposal practices increase the amount of sand sent to landfills, contributing to landfill capacity constraints and generating additional costs for the company, as it must cover the transport and unloading of the waste sand. Energy consumption primarily occurs during the melting phase, whereas waste foundry sand (WFS) is generated during the knockout phase. Energy is used for heating, operating equipment and fueling machinery(diesel). Therefore, minimising waste is crucial for improving economic performance and promoting environmental sustainability in foundry operations. The research objectives for the study are:

- To conduct a comprehensive CP Assessment at the Foundry Firm to identify sources of waste and emissions and evaluate opportunities for sustainable improvements.
- To minimise waste sand disposal to reduce landfill capacity demands while supporting environmental sustainability.
- To reduce energy consumption to achieve cost savings and promote environmental sustainability.
- To implement practical interventions aimed at improving material and energy efficiency.

2. Literature Review

2.2 Waste Foundry Sand Production

High-quality sand is essential for maintaining casting quality; however, using new sand for every casting does not have a good impact on the environment or production costs (Kim et al. 2025). Therefore, ‘sand reclamation’ is essential. It involves reusing sand from used casting moulds in a foundry by collecting, cooling, and cleaning sand exiting the casting process. This reclaimed sand is mixed with fresh materials (sand and binders) for reuse in new moulds, reducing waste and production costs.

However, there is a limit to how long reclaimed sand remains usable, as “repeated use of the sand leads to ageing effects, such as decreased permeability, reduced bonding strength, and increased fine particle content” (Kim et al. 2025). This can occur due to impurities from the casting process being mixed into the sand and forming a layer around the sand particles. The degradation in sand quality causes a loss in product quality and increases the burden on sand reclamation equipment (thus reducing equipment lifespan).

Reclaimed sand that has degraded beyond usability is ultimately disposed of as waste foundry sand (WFS). According to Sithole et al. (2022), “the rapid increase in industrialisation, specifically, foundries has led to an accumulative capacity of waste foundry sand (WFS) envisaged as a global environmental concern”. They further state that WFS is on the uprise with around 0,5 million tons being produced in South Africa. This waste can be stockpiled, but that poses capacity constraints for the company, or it can be sent to the landfills. Strict dumping regulations are pushing industries, such as foundries, to improve how they recycle or reuse waste materials in support of zero-waste goals (Bogas, de Brito and Ramos 2016; Branca et al. 2020). Zero waste is the effort to reduce waste as much as possible to promote sustainability, protect the environment and human health and maximise material reuse. Landfilling is discouraged, as it conflicts with circular economy principles and environmental sustainability (Domingues, Santos Ferreira and Pires 2022). Additionally, foundries that used landfill dumping for WFS “pay high disposal penalty costs, which have become a financial burden that is unsustainable and affects their revenue” (Sithole et al. 2022). According to Gupta et al. (2017), WFS can be used as a replacement for natural sand in making ready-mixed concrete (RMC), which can be used in construction or paving. WFS decreases the strength of the concrete while simultaneously increasing the absorption properties of the concrete, and has been proven to be effective when combined to create RMC (Sithole et al. 2022; Aguiar, Cunha and Aguiar 2024). This is an effective way of reducing WFS dumping while also relieving the strain on natural sand consumption.

Another study by Magedi et al. (2025) shows that combining basic oxygen furnace slag (BOFS) and green WFS (does not contain chemical binders) with NaAlO_2 as an activator can produce concrete. This concrete is of a stronger type than that used by Gupta et al. (2017), however, it is more sustainable as it lowers CO_2 emissions and waste reuse.

2.3 Energy Consumption

Fayomi et al. (2016) state that “the foundry industry consumption of energy in the electrical form is increasing”. This has also contributed to a rise in the total cost of product manufacturing. As a result, effective energy consumption management has become a critical focus for foundries. This has raised production costs, making energy management a key concern for foundries. Additional areas of concern include waste sand produced during the moulding and core-making processes. There have been many advancements in sand reclamation; however, once the usage threshold has

been exceeded, the sand is sent to landfills. The melting phase in the casting process has been identified as the largest energy consumer due to the use of furnaces (Fayomi et al. 2021). This can be caused by various motives such as material impurities, high temperature requirements, continuous operation and heat loss through furnace walls. According to Domingues, Santos Ferreira and Pires (2022), “the disposal of 1 ton of WFS in landfills presents direct and indirect costs to the sector”. A study conducted by Noro and Lazzarin (2016) aimed to identify the primary causes of high energy consumption, it noted that “the electricity demand is very high, particularly for the induction melting furnaces”. Their findings indicated that although induction furnaces are well-suited for heat recovery, they can be costly to maintain and require additional time to heat rusty and dirty scrap metal, leading to increased energy consumption. Suggested improvement strategies included minimising heat loss by keeping the furnace lid closed during melting operations, operating furnaces at full capacity, and using clean scrap metal. Furthermore, the researchers explored energy-saving opportunities in lighting, recommending the adoption of LED lights and the installation of sensors to automatically turn off lights when no activity is detected, particularly in office areas. While lighting may appear to be a minor concern, it can contribute significantly to long-term energy savings. Similarly, Fayomi et al. (2021) referenced a study that identified lighting, melting, and compressed-air operations as the primary contributors to high energy consumption. Compressed air is the second largest source of energy consumption, after the melting process, it is used in the moulding and core making process to stabilise the sand (with the addition of binders and such). It is further stated that “compressed air loss is a major worry in many foundries as it is pricier than water, electricity, and even steam”. Suggested methods of reducing compressed air consumption include reducing leakages, using separate compressed air grids as they should not all be at the same pressure and setting the smaller compressors to varying loads and the large compressors to full loads (to avoid overworking the large compressors).

2.4 Emissions

Industrial entities are major contributors to air pollution, which increases environmental degradation and this means that while foundries aim to produce castings efficiently and make a profit, they also have a responsibility to think about how their processes affect the environment (Madan and Singh, 2022). During casting, there are different types of emissions and pollution generated, including dust, particulate matter (PM), noise, heat, volatile organic compounds (VOCS), sulphur oxides (SOx), nitrogen oxides (NOx) and smoke. Particulate matter is defined as “a mixture of solids and aerosols composed of small droplets of liquid, dry solid fragments, and solid cores with liquid coatings” (Naylor, 2001). Although dust and PM are related, dust is just one type of PM, while PM can consist of finer particles that are more hazardous than dust. Foundry PM contains metal, which can be harmful to the growth of plants in contact with it. Gupta et al. (2017) state that there has been a decrease in VOCS produced at foundries over the years due to the switch to water-based coatings. It is further suggested to implement baghouses/fabric filters, which remove airborne dust and metal particles generated during melting and casting. They can “collect over 99.9% of the entering particulates, even fine PM” (Gupta et al. 2017). Not only do baghouses collect PM they can also be used for heat recovery in induction furnaces, by absorbing the heat emitted during melting. That heat can then be used for other applications, such as heating materials or drying, which is very cost-effective.

3. Methods

This methodology employed a quantitative approach, utilising quantitative data from reports on waste disposal and energy consumption rates. The methodology was characterized by reviewing existing reports, production processes, and historical records. Data was collected on energy use, waste sand production, and environmental impacts in current operations. Step-by-step leak detection and control was undertaken to eliminating compressed air leaks, commencing with baseline measurement of kw of air compressors, line pressure (bar) and leak frequency and location. A compressed air audit was conducted using ultrasonic leak detectors, all air lines, valves, couplings, hoses, and fittings were mapped and it was also imperative to log current supply pressure and flow at peak, off-peak, and during idle periods.

Operational Control was characterised by switching off dust extractors, conveyor belts, cooling fans, induction furnaces (holding mode) and auxiliary motors when they are idling and instituting some furnace discipline. Standardised charging plans through use of lean mix charts were developed according to alloy type, charge mix of scrap and pig iron, target yield and desired casting output. Lean mix charts for the foundry were developed through the following steps:

- Step 1: Analyse Demand (Takt Time) - Calculate the Takt Time (the rate at which you need to produce a casting to meet customer demand).

- Step 2: Understand Constraints - Pattern changeover times are critical since the mix must account for time to switch patterns on the moulding machine. Product sequence must align with core availability and type while similar alloy grades must be together to minimise furnace changeovers.
- Step 3: Design the Sequence & Mix – The scheduling rule was to sequence from high-volume/ easy-to-run parts to more difficult ones with the goal to minimise changeover time through, grouping parts using similar pattern plates or core boxes where possible). It was also critical to ensure that the foundry load was balance, total moulds per slot should be feasible and the workload be level for the core room and melting.
- Step 4: Create the visual board - A physical board at the moulding line supervisor's station was developed and Kanban card system was deployed to facilitate lean movement of the products.
- Step 5: Train and empower the shift team on the new system, if the sequence cannot be followed (breakdown, quality issue), by using an andon cord, the team stops and problem-solves immediately.
- Step 6: Monitor & Adapt - Track actual versus planned output for each shift slot. Stand-up meeting at the board would be held to address deviations and adjust the next day's mix if needed.

Regarding sand handling optimisation, material flow mapping was undertaken to observe sand flow through the mixer, moulder, curing and casting stages, and identify frequent spill spots. Good housekeeping practices such as ensuring bins are not overfilled were encouraged, containment strategies such as installation of low-profile chutes and skirts as well as laying rubber conveyor skirts to reduce fugitive sand. Employees were trained to clean spills immediately and conduct 15-min end-shift clean-ups. Instituting visual management system was characterised by demarcating with red lines to show where sand should not accumulate, hourly visual checks, capturing return sand and evaluating its quality and tracking return rates per shift.

Furnace energy performance was evaluated using five key performance indicators: specific energy consumption (kWh/t) for determining overall furnace efficiency, and melt time per batch to provide insight into heat loss and furnace scheduling. Superheat deviation, which should be less than 10 °C, was used to provide insight into overheating losses while slag generation rate fed into charge quality and oxidation, and furnace availability provided insight into idle losses and reheat cycles. These indicators were derived from direct measurements of energy consumption, melt output, operational timing, temperature monitoring, and downtime records.

4. Data Collection

Data was collected for overall company description and overview of production process, the process of producing a casting is complex and relies on inter-departmental communication, suitable scheduling practices and resource management. The production process is characterised by the following steps:

- Order Processing & Planning: Once an order is placed, the planning department assumes responsibility for identifying and allocating the necessary resources required for casting production.
- Mould Preparation: The pattern shop creates a blueprint for the sand to be moulded into, and additional components are added, such as cores, runners, and sleeves. A paint is applied to the mould surface before sealing to help the casting cool quicker.
- Melting & Pouring: Molten metal is poured into the mould, smoke is released during solidification, the smoke levels are within range and are being controlled and monitored efficiently.
- Cooling & Knockout: After cooling, the casting is manually removed from the mould, where the sand is loosened using a vibrator and sent back to the silo as reclaimed sand.
- Post-Casting Treatments: The casting undergoes shot blasting (compressed air and pellets to remove residual sand) and, if required, heat treatment for enhanced mechanical properties such as hardness or softness. Thereafter, the casting is sent for fettling, a process that includes grinding to remove excess material (producing metal shavings) and gouging, where metal rods are melted to fill surface gaps.
- Quality Control: This step ensures quality control by identifying defects and determining whether the casting can be salvaged or must be scrapped for remelting.
- If approved, the casting proceeds to machining for final finishing (which produces metal shavings to be added to scrap) before being dispatched to the customer.

Figure 1 shows the input/output diagram for data collected, the foundry firm does generate PM, which is managed by utilising baghouses that are placed at every foundry section to collect dust particles and metal fragments in the air. They do not generate hazardous waste or metal waste (as metal waste is remelted within a closed-loop system). The

dust, which is non-hazardous due to the non-hazardous nature of the resins, is then safely disposed of in landfills. Currently, the electricity consumption rate is a concern as the amount used affects the company and the environment. The foundry firm cannot operate using generators, solar power, or diesel, they are either expensive or incapable of meeting the required energy levels; thus, their electricity consumption is high. Electric heating is impractical because it is difficult to precisely control the temperature. Gas heating is a possible alternative, but it carries more safety risks. Diesel is the preferred option, using only 4 litres per ton of sand dried, making it highly efficient and cost-effective.

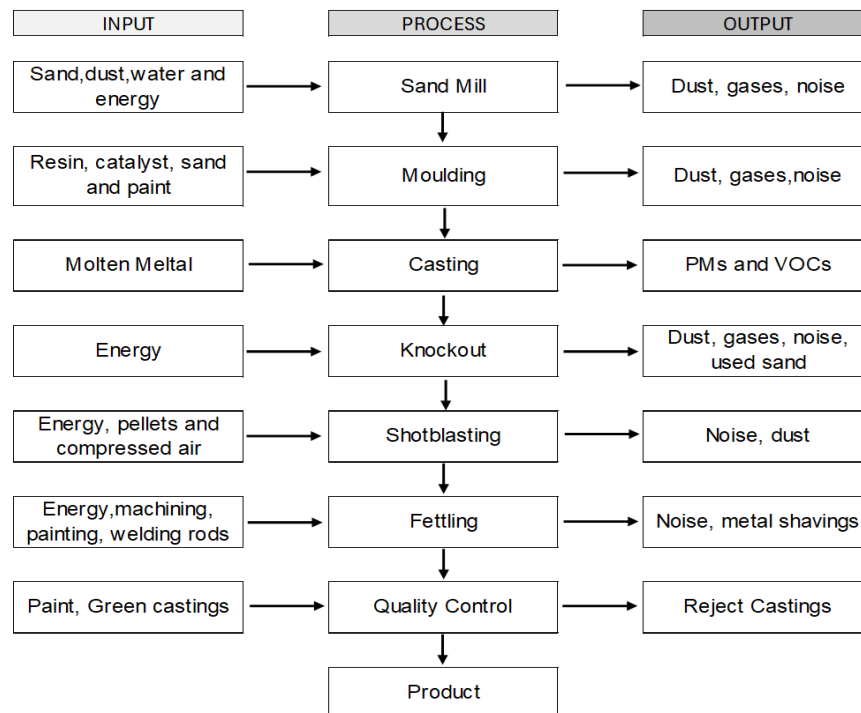


Figure 1. Input/Output diagram for data collected

Table 1. Baseline Performance

Parameter	Value
Energy intensity	650 kWh / tonne
Electricity tariff	R2.50 / kWh
Average annual electricity use	300 000 kWh
Average annual electricity cost	R900 000
Annual sand use	14,000 tonnes
Sand disposal cost	R450 / tonne
Annual sand disposal cost	R6.3 million

Table 1 shows the baseline performance information; the plant uses an average of 25 000 kWh of electricity costing about R75 000 per month when including other service charge and network charge based on the notified maximum demand. Table 2 shows the breakdown of electricity consumption, key energy drivers for induction furnaces include charge composition and cleanliness, melt cycle scheduling, melt temperature discipline and furnace lining condition. Key energy drivers for heat treatment ovens are low load factor (half-empty ovens), overheating beyond specification, poor insulation and door sealing and extended soak times, while shotblast machines are influenced by poor compressor control, air leaks and excessive pressure settings. Sand feeder and sand handling systems may be affected by oversized motors, continuous running during downtime and mechanical resistance due to poor lubrication. Key energy drivers

for finishing operations include excessive fettling due to poor mould quality, inefficient tooling and excessive idle running.

Table 2. Breakdown of electricity consumption

Operational Area	Energy Consumption (%)
Induction Furnaces	45%
Heat Treatment Processes (Ovens)	20%
Compressed Air Systems (Shotblast machine)	10%
Sand Feeder	8%
Lighting	5%
Finishing (Grinding, Fettling)	6%
Administration Block	3%
Metallurgical Laboratory	3%

5. Results and Discussion

5.1 Material Balance Analysis

A material balance analysis as shown in Table 3 was conducted with the view to track all material inputs, outputs, losses, as well as to identify inefficiencies, waste streams, and yield losses that would foster CP and cost-reduction initiatives and become a basis for quantitative basis for decision-making and environmental reporting.

Table 3. Monthly Foundry Material Balance

Material	Input (tons)	Output Destination
Sand	10919,51	218 tons used in process (adhered sand, slag entrainment) (i.e. 2%)
		91 tons WFS is dumped, 12 times per week = 1092 tons (i.e. 10%)
		9391 tons reclaimed/recycled sand (i.e. 86%)
		218 tons Dust and fines as airborne losses (i.e. 2%)
Molten Metal	158,311	final castings from each foundry section: $74,51 + 11,55 + 49,42 = 135,47$ tons
		6-ton scrap
		Pigged from each foundry section: $7,16 + 2,06 + 7,62 = 16,84$
		Sleeves and runners = $31,93 + 4,95 + 21,18 = 58,06$
Resin and Catalyst	2,71	Resin and Catalyst = 1,65 and 1,06 tons respectively, combined = 2,71
Paint	0,75	3 drums of 250kg paint drums = 750 kg
Welding rods (for fettling)	7,37	0.2 tons as metal waste (shavings)
Emissions	36,28	PM lost = 15 tons
		CO2 emissions = 21,28 tons during the melting process
Pellets (for shotblasting)	1	Entirely consumed → dust waste
Total Material in	11125,93	
Category	Tons/Month	Details
Material out (product)	1336,06	Energy, Sand, metal, resin, paint, welding rods, pellets
Material out (waste)	619,4	WFS, non-conforming, shavings, pellet dust
Material out (emissions)	36,28	PM lost and CO2

Material Accumulated	9134,19	Recycled sand + scrap + pigged + recovered metal
Total Material Out	11125,93	

The results from the Table 3 were derived from averaging monthly reports such as sand consumption reports, daily casting reports, paint viscosity readings, and resin and catalyst calibrations. A material balance of the green sand system indicated that out of 9391 tons of sand input, approximately 86% was recovered and reused, while 14% was lost through spillage, shake-out losses, dust extraction, and disposal with slag and defective moulds. The molten metal and scrap tonnages were taken from the Metallurgical Laboratory measurements. Some of the information was estimated due to the lack of recording data. Below are the estimates and their corresponding justifications:

- On average, 13 welding rods are used, and the average quantity of castings produced per month is 1103. The size of welding rods used is medium (12 mm × 50 cm): $\sim 0,5$ kg, so $(13 \times 1103 \times 0,5)/1000 = 7.17$ tons.
- The foundry uses roughly 1,5 flow bins of resin per month and 63% of the catalyst flow bin. The amount of liquid in the flow bins is 1100 kg and 1675 kg, respectively. Therefore, the total resin and catalyst material usage = $(1.1 \text{ tons} \times 1,5) + (1,675 \text{ tons} \times 0,63) = 2,71$ tons.

5.2 Cleaner Production Opportunities

It was thereafter imperative to establish CP opportunities for the reduction of energy consumption and waste sand in the foundry plant. Table 4 shows a summary of proposed CP options for waste management.

Table 4. Summary of proposed CP options for reduction of energy consumption and waste sand

CP option	Description
Good Housekeeping Programme	Switching-off idle equipment, improving furnace charging discipline, reducing sand spillage and eliminating compressed air leaks.
Waste foundry sand reduction	Rework and defect reduction, reducing WFS at the source by re-designing patterns, mechanical and thermal sand reclamation as well as reuse of moulding and core sand and creating building material
Waste heat recovery	Using flue gas to preheat scrap and returns so as to improve melting efficiency.
Furnace Energy Optimisation	Optimising melting schedules, refurbishing refractory lining, and reducing the holding time.

Instituting standardised start-up and shut-down procedures with clear rules on idle time limits and logbook sign-off by operators would prevent unnecessary reheating and avoid heat losses during extended idling. Implementation of better furnace practices can be accomplished by closing the furnace lid when operational and using clean/rust-free scrap to reduce the amount of time the furnace needs to stay on to remove the impurities. Good housekeeping around sand conveyors and hoppers, as well as installation of simple trays and guards would prevent clean sand being discarded as waste. Weekly leak inspections to detect compressed air leaks using an ultrasonic detector would reduce compressor run time and electricity use.

Rework and defect reduction at moulding stage through first-time-right mould inspection, immediate repair instead of discard, defect tagging and root-cause analysis would aid to reduce waste sand through fewer rejected moulds and cores and less shake-out waste. Reducing WFS at the source can be accomplished by re-designing patterns to decrease the amount of sand needed for moulding. A kilogram reduction per casting could make a huge impact on the total sand consumed. However, the foundry produces a wide range of castings which would need an excessive number of hours to redesign both technically and manually. Alternatively, combining WFS with furnace slag and a chemical activator to create building material that is strong and durable can aid in reducing WFS.

Optimising melting schedules can be accomplished through scheduled melts back-to-back and avoiding furnace cool-down periods thereby maintaining thermal inertia and reducing reheating losses. Replacing conventional refractory with low thermal conductivity lining or adding insulating backup layer would yield reduced heat losses through

furnace walls. Another useful practice would be pre-heating the scrap using furnace exhaust gases before adding it to the furnace, this will reduce the strain on the furnace to heat the metal from cold.

5.3 Evaluation of CP Options

Table 5 shows the rationale for scores on evaluation of good housekeeping CP option in terms of environmental impact, economic performance, technical feasibility, implementation complexity and organisational fit. It was found that good housekeeping can yield immediate reductions in energy and sand losses and can utilise the existing systems.

Table 5. Rationale for scores on evaluation of good housekeeping CP option

Criterion	Reason for Score
Environmental	Can yield immediate reductions in energy and sand losses
Economic	Characterised by minimal capital cost and very short payback
Technical	Can utilise the existing systems
Complexity	Characterised by simple operational changes
Organisational	Better acceptance by stakeholders

Table 6 shows the rationale for scores on evaluation of sand reclamation system CP option in terms of environmental impact, economic performance, technical feasibility, implementation complexity and organisational fit. It was found that sand reclamation system can yield high long-term savings but high capital cost, and complexity of installation is a challenge.

Table 6. Rationale for scores on evaluation of sand reclamation system CP option

Criterion	Explanation
Environmental	Major reduction in virgin sand use and landfill disposal
Economic	Can yield high long-term savings but high capital cost
Technical	Proven technology, moderate integration effort
Complexity	Complexity of installation is a challenge
Organisational	Moderate training required for employees

Table 7 shows the rationale for scores on evaluation of furnace energy optimisation CP option in terms of environmental impact, economic performance, technical feasibility, implementation complexity and organisational fit. It was found that furnace energy optimisation can yield significant electricity and CO₂ reduction with short payback.

Table 7. Rationale for scores on evaluation of furnace energy optimisation CP option

Criterion	Reason for Score
Environmental	Significant electricity and CO ₂ reduction
Economic	Can yield high cost savings, short payback
Technical	Highly feasible within existing furnaces
Complexity	Moderate optimisation effort
Organisational	Requires discipline and monitoring of system

Table 8 shows that the waste heat recovery CP option is characterised by long payback, faces complex integration into the organization's existing systems and processes, and is difficult to implement.

Table 8. Rationale for scores on evaluation of waste heat recovery CP option

Criterion	Reason for Score
Environmental	Lowers greenhouse gas emissions and positions organisation to align with sustainability goals
Economic	Characterised by long payback and high capital cost
Technical	Complex integration into the organization's existing systems and processes
Complexity	Difficult to implement
Organisational	Low familiarity, employees do not have experience and lack sufficient knowledge

Table 9 shows a weighted evaluation of Cleaner Production (CP) options for the foundry plant, with the objective of prioritizing the CP options by concurrently taking environmental impact, economic performance, technical feasibility, implementation complexity and organisational fit into consideration. This method ensures a balanced, defensible decision as opposed to selecting options based only on cost or intuition.

To ensure that high-impact criteria dominate the ranking and that low scores in critical areas penalise options appropriately, the weighted score is calculated using:

$$\text{Weighted Score} = 0.25 (\text{Env}) + 0.25(\text{Economic}) + 0.25(\text{Technical}) + 0.10(\text{Complexity}) + 0.15(\text{Org Fit})$$

Table 9. Technical Evaluation of CP Options

CP Option	Env Benefit (25%)	Economic (25%)	Technical (25%)	Complexity (10%)	Org Fit (15%)	Weighted Score
Good Housekeeping	5	5	5	5	5	5
Sand Reclamation System	5	4	4	3	4	4.15
Waste Heat Recovery	4	3	3	2	3	3.15
Furnace Energy Optimisation	4	4	5	4	4	4.25

5.4 Implementation of CP options

Table 10 shows the ranking of CP options for implementation with Good Housekeeping scoring highest followed by Furnace Energy Optimisation, while Waste Heat Recovery ranked last. Hence, the implementation measures focused on the first 2 CP options. The cost analysis revealed that Good Housekeeping CP option, if implemented would provide the “low-hanging fruits”, cost-effective actions that have greater environmental and energy benefits as well as simple methodology and technologies for implementation, within 6 months.

Table 10. Strategies for implementation of CP options

Rank	CP Option	Strategy
1	Good Housekeeping	Immediate (0–6 months)
2	Furnace Energy Optimisation	Short term (6–12 months)
3	Sand Reclamation System	Medium term (1–3 years)
4	Waste Heat Recovery	Long term / strategic

Table 11 shows the implementation plan for good housekeeping programme, highlighting the key activities, timelines and responsibilities.

Table 11. Implementation plan for good housekeeping programme

Phase	Key Activities	Timeline	Responsibility
Planning & Awareness	Baseline studies, training	Weeks 1–3	EHS/Operations
Leak Detection & Control	Compressed air, fans, pumps	Weeks 4–6	Maintenance
Operational Control	Idle equipment, furnace discipline	Weeks 7–10	Production
Sand Handling Optimisation	Spillage reduction	Weeks 11–14	Moulding Dept
Monitoring & Review	Data tracking, audits	Ongoing	Continuous Improvement Team

All leaks were tagged, worn hoses, seals, and couplings were replaced while loose fittings were tightened and noisy valves were re-insulated. Auto-shutoff valves on distribution branches were installed, pressure zone control was achieved through implementation of receiver tank balancing. Compressor pressure was set to minimum required for tools and the operators were trained to report leaks during shift hand-overs.

Concerning operational control, it was imperative to switch off the foundry's idle equipment such as dust extractors, conveyor belts, cooling fans, induction furnaces (holding mode) and auxiliary motors. Dust extractors were switched off during breaks and cleaning blocks, conveyor motors were turned off when there is no moulding load. The control of holding furnace cycles was crucial for production flow, designed to optimize energy efficiency, as well as adjusting the furnace's heat-up, soak, and discharge times, based on the specific material being processed is not just about turning on and off to maintain a temperature. visual control boards were placed on the shopfloor as signage and operator Signals, with tags labelled "Idle? Switch Off" being used and the shift leaders were tasked to verify compliance. Weekly energy diaries and monthly kilowatt-hour trend analysis and reviews were conducted as a means of verification. To enhance staff morale, best performing crews were recognised and rewarded accordingly.

By implementing a lean mix chart per shift, a foundry moved from a "push and hope" batch mentality to a disciplined, predictable, and customer-focused "pull" system, a key component of Lean manufacturing in a complex process environment. As a means of improving furnace charging discipline, Table 12 shows a sample lean mix chart for the foundry moulding line with a shift target of 400 good castings produced in an 8-hour shift at a takt time of 1 min.

Table 12. Lean Mix Chart: Foundry Moulding Line

Time Slot (Hour)	Part Number (SKU)	Mould Cavities	Sequence #	Target Quantity (Moulds)	Explanation (Pattern and Core Type)
6:00 - 8:00	FH-123 (Bracket)	4	1	120 moulds (≈480 pcs)	Use Pattern A, Cores from Rack 5
8:00 - 9:00	<i>Changeover & Break</i>	-	-	-	Clean pattern, set up for GC-456
9:00 - 11:00	GC-456 (Housing)	2	2	120 moulds (≈240 pcs)	Use Pattern B, Requires Cores 7 & 8
11:00-12:00	<i>Changeover & Lunch</i>	-	-	-	Clean, prepare for VL-789
12:00 - 14:00	VL-789 (Valve Body)	1	3	120 moulds (≈120 pcs)	Use Pattern C, No cores. Critical customer.

14:00 - 15:00	Changeover & Cleanup	-	-	-	Return to FH-123 for next shift start
---------------	-------------------------	---	---	---	--

Reducing sand spillage was accomplished after identifying the key sand loss points which include sand transport between stations, manual handling spills, overflow during shake-out as well as loss due to defective moulds or cores. Table 13 shows a summary of savings that were derived from reducing sand spillage, the structured good housekeeping programme resulted in an estimated 30% reduction in sand spillages, which is from 1092 tons per month to 322 tons. This yielded direct disposal cost savings of approximately R1 739 556 per year with additional indirect benefits that were derived from implementing lean mix charts.

Table 13. Summary of savings derived from reducing sand spillage

Source of Spillage	Baseline Spillage Share (%)	Baseline Sand Loss (tons)	Reduction Achieved (%)	Sand Saved (tons)	Disposal Cost (R/ton)	Cost Saving (R)
Manual handling spills	30	328	30	98	450	44226
Transport between stations	25	273	20	55	450	24570
Overflow during shake-out	25	273	30	82	450	36855
Defective moulds / cores	20	218	40	87	450	39312
Total Monthly	100	1092		322		144963
Annual Total		13104		3866		1 739 556

The second CP option implemented was Furnace Energy Optimisation and it was noted that the key energy loss mechanisms for the foundry furnaces were overheating molten metal, unplanned idle time, radiation and surface heat losses, cold charge materials, flue gas losses, and poor refractory condition.

Table 14. Implemented measures for furnace energy optimization

Measure	Energy Reduction (%)	Energy Saved per Period (kWh)	Annual Energy Saved (kWh)	Electricity Cost Saving (R/year)	CO ₂ Reduction (t/year)	Carbon Tax Avoided (R/year)
Charge optimisation	6%	675	202500	506250	182.25	34627.5
Temperature discipline	5%	562.5	168750	421875	151.875	28856.25
Scheduling and batching	3%	337.5	101250	253125	91.125	17313.75
Refractory improvements	4%	450	135000	337500	121.5	23085
TOTAL	18%	2025	607500	1518750	546.75	103882.5

The implemented furnace energy optimisation measures shown in Table 14 resulted in an estimated 18% reduction in electricity consumption. When scaled to annual production, this corresponds to a saving of approximately 607 MWh, a reduction of 547 t CO₂, and an annual financial saving of around R1.5 million.

6. Conclusion

A comprehensive CP Assessment was conducted for a foundry firm to identify sources of waste and emissions and evaluate opportunities for sustainable improvements. A material balance analysis was undertaken with the view to track all material inputs, outputs, losses, as well as to identify inefficiencies, waste streams, and yield losses that would foster CP and cost-reduction initiatives and become a basis for quantitative basis for decision-making and environmental reporting. A good housekeeping programme which included switching-off idle equipment, improving furnace charging discipline, reducing sand spillage and eliminating compressed air leaks, was implemented, resulting in minimization of waste sand disposal to reduce landfill capacity demands while supporting environmental sustainability. Practical interventions aimed at reducing energy consumption, were implemented to achieve cost savings and promote environmental sustainability. The implemented measures for furnace energy optimisation which include charge optimisation, temperature discipline, scheduling and batching, and refractory improvements led to reduction in electricity consumption and avoided CO₂ emissions.

References

- Aguiar, I., Cunha, S. and Aguiar, J., Application of foundry wastes in eco-efficient construction materials: a review. *Applied Sciences*, 15(1), p.10, 2024.
- Bogas, J.A., De Brito, J. and Ramos, D., Freeze–thaw resistance of concrete produced with fine recycled concrete aggregates. *Journal of Cleaner Production*, 115, pp.294-306, 2016.
- Branca, T.A., Colla, V., Algermissen, D., Granbom, H., Martini, U., Morillon, A., Pietruck, R. and Rosendahl, S., Reuse and recycling of by-products in the steel sector: Recent achievements paving the way to circular economy and industrial symbiosis in Europe. *Metals*, 10(3), p.345, 2020.
- Domingues, L.G.F., Santos Ferreira, G.C.D. and Pires, M.S.G., Waste foundry sand used to cover organic waste in landfills. *Journal of Material Cycles and Waste Management*, 24(1), pp.378-385, 2022.
- Fayomi, O.S.I., Agboola, O., Oyedepo, S.O., Ngene, B. and Udoeye, N.E., A review of energy consumption in foundry industry. In *IOP Conference Series: Earth and Environmental Science* (Vol. 665, No. 1, p. 012024). 2021.
- Kim, B., Jung, W., Choi, Y. and Lee, J., Bayesian neural networks for predicting quality in reclaimed waste sand for foundry applications. *Journal of Manufacturing Systems*, 79, pp.584-597, 2025.
- Magedi, F., Nseke, J., Siwal, S., Schmidt, W., Ghamari, A., Falayi, T. and Sithole, T., From waste to worth: Assessing the feasibility of sodium aluminate as an activator for transforming steel slag modified waste foundry sand into a valuable resource. *Results in Engineering*, 26, p.104554, 2025.
- Madan, J. and Singh, P.P., Sustainability in foundry and metal casting industry. In *Sustainable Manufacturing Processes* (pp. 29-52), Academic Press, 2023.
- Naylor, T.J., *Development of a pollution prevention methodology for the metal-casting industry*. Cranfield University (United Kingdom), 2001.
- Ndifelani, M.M.P., *Implementing Resource Efficient and Cleaner Production as a Tool to Reduce Carbon Tax in the Manufacturing Industries* (Master's thesis, University of the Witwatersrand, South Africa, 2022).
- Noro, M. and Lazzarin, R.M., Energy audit experiences in foundries. *International Journal of Energy and Environmental Engineering*, 7(4), pp.409-423, 2016.
- Sithole, N. T., N. T. Tsotetsi, T. Mashifana, and M. Sillanpää., "Alternative cleaner production of sustainable concrete from waste foundry sand and slag." *Journal of Cleaner Production* 336. 130399, 2022.

Biography

Mendon Dewa is an Associate Professor at the Durban University of Technology in the Department of Industrial Engineering in South Africa. He has presented at local and international conferences and has written several journal articles. He is an experienced engineer and lecturer specializing in sustainable production practices, waste reduction, and cleaner technology implementation in industrial settings. With a strong background in process optimization, he has worked extensively on identifying root causes of inefficiency in production, warehousing, and dispatch to create more sustainable, resource-efficient operations. His research and teaching focus on practical, cost-effective strategies for reducing environmental impact through cleaner production technologies, aiming to equip the next generation of engineers with the tools to make data-driven decisions for environmental and economic improvement. He has also

supervised masters and doctoral students and has a strong passion for optimisation of manufacturing systems and operations management.