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Implementing Lean and Green Strategies for Sustainable Efficiency in the Indian Steel Sector

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Abstract: This research presents a comprehensive case study on the integration of Lean and Green manufacturing strategies at a small scale ABC Alloys Ltd non-ferrous metal processing enterprise. The company faced multiple operational and environmental challenges, such as high levels of production waste, excessive energy consumption, extended lead times, and inadequate compliance with environmental regulations. To address these issues, a structured transformation initiative was undertaken that combined Lean tools namely 5S, Kaizen, Single-Minute Exchange of Dies (SMED), and Value Stream Mapping (VSM) with Green practices like wastewater recycling, LED lighting retrofitting, and the implementation of noise reduction systems. This integrated Lean-Green approach led to notable improvements, including reduced scrap generation, optimized energy and water usage, shorter production lead times, and increased employee engagement through participatory methods. The case demonstrates that even resource constrained Small and Medium Enterprises (SMEs) can successfully adopt Lean-Green strategies to achieve operational efficiency, environmental sustainability, and long term cost savings. The findings underline the viability of a systematic and phased implementation model, offering a scalable roadmap for similar manufacturing units across India.

Keywords: Lean-Green Integration, SMEs (Small and Medium Enterprises), Sustainable Manufacturing, Operational Efficiency, Environmental Performance

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INTRODUCTION

In today's competitive and environmentally conscious industrial landscape, manufacturing enterprises are under increasing pressure to enhance productivity while minimizing their ecological footprint. This dual requirement has led to a growing interest in the integration of Lean and Green manufacturing strategies a holistic approach that aims to simultaneously improve operational efficiency and environmental sustainability (Gupta & George, 2016). While Lean manufacturing focuses on eliminating waste, reducing process inefficiencies, and enhancing value for the customer, Green manufacturing seeks to minimize the negative environmental impacts of production by optimizing the use of energy, water, and raw materials, and reducing emissions and waste generation (Jayal et al., 2010).

Despite the recognized benefits of both strategies, their integration often referred to as Lean-Green manufacturing remains underutilized in Small and Medium Enterprises (SMEs), particularly in developing economies such as India (Vinodh et al., 2011). SMEs often struggle with limited financial and technical resources, lack of specialized knowledge, and resistance to change, which pose significant barriers to the adoption of sustainable practices (Choudhary et al., 2020). However, these enterprises also stand to gain the most from Lean-Green integration due to their high cost-sensitivity and growing need to comply with evolving environmental regulations (Cherrafi et al., 2017).

This research presents a detailed case study of ABC Alloys Ltd., a small-scale non-ferrous metal processing unit based in Pune, India, which successfully implemented a Lean-Green transformation to address critical operational and environmental issues. The company was facing significant challenges including high levels of production waste, inefficient energy and water use, prolonged production lead times, and weak compliance with environmental norms. To overcome these hurdles, ABC Alloys adopted a structured improvement framework combining key Lean tools such as 5S, Kaizen, Single-Minute Exchange of Dies (SMED), and Value Stream Mapping (VSM) with targeted Green initiatives including wastewater recycling, LED retrofitting, and noise control systems.

The transformation yielded measurable improvements in multiple performance dimensions, including reductions in scrap rate and resource consumption, as well as improved employee engagement and process efficiency. This case demonstrates that, with a well-planned and participatory approach, Lean-Green integration is not only feasible for SMEs but also strategically beneficial in achieving long-term competitiveness and sustainability (Zhu & Sarkis, 2004}.

The aim of this study is to contribute practical insights into how resource-constrained SMEs in India can adopt and benefit from Lean-Green practices. The case further provides a replicable framework for other organizations seeking to align operational excellence with environmental stewardship.

METHODOLOGY

Baseline Diagnosis, Tool Selection, and Customization

The methodology began with a comprehensive baseline diagnosis to identify operational inefficiencies and environmental challenges at ABC Alloys Ltd. This involved conducting Gemba walks and Value Stream Mapping (VSM) to visualize workflows, detect process delays, and locate non-value-added activities. Interviews with shop floor workers and supervisors revealed key issues such as high scrap generation, energy overuse, inconsistent changeover procedures, and a lack of resource conservation practices. Utility audits were performed using municipal bills, sub-metering, and flow meters to accurately assess electricity and water usage, while noise levels were recorded with calibrated decibel meters in high-risk zones like the press shop. These activities offered a complete understanding of the plant's critical inefficiencies and environmental shortfalls (Luthra et al., 2016).

Based on the diagnostic findings, relevant Lean and Green tools were carefully selected and customized to suit the company's resource-constrained SME context. Lean tools such as 5S, Kaizen, SMED (Single Minute Exchange of Die), and Future-State VSM were chosen for their potential to improve productivity, reduce setup time, and streamline material flow. Simultaneously, Green practices including a water recycling system, LED lighting upgrades, furnace insulation, and acoustic noise control systems were identified to reduce energy and water consumption and improve workplace safety. Each intervention was mapped to specific performance indicators such as scrap reduction, energy efficiency, water usage, lead time, and noise control to ensure targeted and measurable outcomes during implementation (Cherrafi et al., 2017).

Structured Implementation and Standardization of Lean and Green Tools in Manufacturing

Following tool selection, the Lean and Green interventions were systematically implemented in a phased manner, beginning with pilot initiatives in the melting and extrusion sections. A cross-functional team comprising production engineers, environmental officers, and floor supervisors oversaw the rollout to ensure alignment with operational realities. Training workshops and visual Standard Operating Procedures (SOPs) were conducted to familiarize shop-floor workers with Lean practices such as 5S and SMED. Simultaneously, Green initiatives including the installation of a 20,000-liter water recycling unit, retrofitting of LED lighting, and the placement of acoustic paneling in the press zone were executed. Each implementation followed iterative PDCA (Plan-Do-Check-Act) cycles to support structured change management and continuous improvement.

To evaluate the impact of these interventions, a four-month monitoring phase was conducted wherein key performance indicators (KPIs)—including scrap rate, energy consumption per kg, water usage, changeover time, lead time, and workplace noise levels—were tracked and compared against baseline data. ISO 14001 compliance benchmarks were used to assess environmental progress, while operator feedback, audit scores, and production logs were reviewed monthly to ensure transparency and prompt corrective actions. This real-time monitoring framework enabled data-driven decision-making and adaptive implementation across the organization.

In the final phase, a comprehensive review of results was undertaken to identify lessons learned and opportunities for standardization. Structured interviews and feedback surveys were conducted with both employees and management to evaluate satisfaction, ease of implementation, and perceived impact. Based on these insights, best practices were formalized into updated SOPs and disseminated company-wide. This phase also helped embed a culture of continuous improvement through regular Kaizen activities, setting the foundation for ABC Alloys Ltd. to extend Lean-Green practices across other departments. Together, these final three phases ensured that the transformation process remained practical, inclusive, and sustainable enabling measurable gains in productivity, environmental performance, and organizational capability.

Operational Tools and Strategic Interventions

The implementation of Lean, Green, and Smart manufacturing practices requires the deployment of a combination of analytical, managerial, and technological tools. These tools can be categorized into three dimensions—Lean Tools, Green Tools, and Smart (Industry 4.0) Tools —each contributing to operational efficiency, environmental sustainability, and digital transformation, as shown in Figure 1 (Bag et al., 2021).

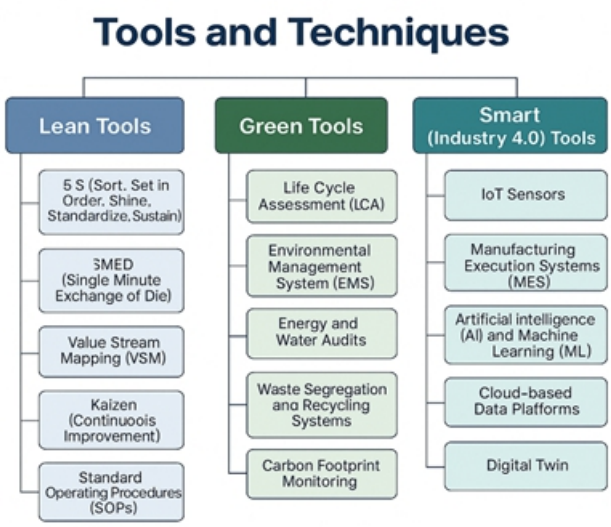

Figure 1: Key Tools for Lean-Green-Smart Manufacturing

The image illustrates a categorized overview of tools and techniques used across Lean, Green, and Smart (Industry 4.0) manufacturing paradigms. Lean Tools focus on efficiency and waste elimination, including practices like 5S, SMED, Value Stream Mapping (VSM), Kaizen, and Standard Operating Procedures (SOPs). Green Tools emphasize environmental sustainability through Life Cycle Assessment (LCA), Environmental Management Systems (EMS), energy and water audits, waste segregation and recycling, and carbon footprint monitoring. Smart Tools integrate digital technologies such as IoT sensors, Manufacturing Execution Systems (MES), Artificial Intelligence (AI) and Machine Learning (ML), cloud-based data platforms, and digital twin systems to enhance decision-making and process automation.

FRAMEWORK IMPLEMENTATION LEAN AND GREEN TRANSFORMATION

The implementation of the Lean and Green transformation was conducted in a phased and collaborative manner, beginning with targeted interventions in high-impact areas. The key focus was to reduce operational waste, improve energy efficiency, streamline production, and ensure environmental compliance. The implementation strategy encompassed both technical upgrades and organizational change initiatives, as described below (Jabbour et al., 2022)

Phase I & II: Problem Diagnosis, Baseline Assessment, and Tool Selection

The transformation initiative began with Problem Diagnosis and Baseline Data Collection, where Gemba walks and Value Stream Mapping (VSM) were conducted to uncover operational inefficiencies and environmental bottlenecks across key production processes. A range of quantitative baseline metrics was recorded, including:

- Scrap Rate: 12.2%
- Energy Consumption: 0.72 kWh/kg

- Water Usage: 95,000 L/month
- Noise Levels: 91 dB(A)
- Lead Time: 14.5 hours/job

Based on these insights, Selection of Lean and Green Tools was initiated. A targeted suite of Lean and Green interventions was selected through a structured cost-benefit and feasibility analysis, ensuring alignment with identified Key Performance Indicators (KPIs). The selected tools included:

- Lean Tools: 5S, Kaizen, SMED, and Post-VSM interventions
- Green Practices: Installation of a water recycling unit, adoption of IE3 energy-efficient motors, retrofitting of LED lighting, and deployment of noise and dust suppression systems

Implementation of Tools and Monitoring

The implementation phase marked the practical deployment of the selected Lean and Green tools, with continuous monitoring to evaluate their effectiveness and impact.

A. Lean Implementation

The Lean initiatives began with the systematic application of the 5S methodology, which significantly improved workplace organization and visual management. This directly translated into a 9% increase in productivity, as operators experienced fewer delays and easier access to tools and materials. Kaizen events were conducted to address specific inefficiencies. These focused on reducing internal material movement and minimizing compressed air leakage, resulting in smoother operations and reduced energy loss.

The implementation of SMED (Single-Minute Exchange of Dies) brought about a notable enhancement in operational agility. Changeover times were reduced from 65 minutes to 38 minutes, marking a 41.5% decrease, which allowed for faster response to varying production demands. Post-VSM interventions helped streamline process flows and eliminate non-value-added activities, leading to a substantial 29.6% reduction in lead time per job, enhancing overall throughput and responsiveness.

B. Green Implementation

On the environmental front, a series of Green practices were operationalized. A water recycling unit was commissioned, enabling the reuse of 26% of process water, which saved approximately 24,700 liters per month and reduced fresh water dependency. The installation of IE3 energy-efficient motors led to a significant annual energy saving of 18,400 kWh, while concurrently cutting down carbon emissions by 15.3 tons of CO_2 per year, supporting the company's sustainability objectives.

The existing lighting infrastructure was retrofitted with LED systems, achieving a 52% reduction in lighting-related energy consumption, thereby lowering operating costs and improving illumination levels. Lastly, to improve workplace safety and environmental comfort, noise and dust suppression systems were implemented. These efforts successfully brought down ambient noise levels from 91 dB(A) to 83 dB(A), aligning with occupational health standards and creating a more worker-friendly environment.

This integrated implementation approach not only enhanced productivity and process efficiency but also delivered measurable environmental and sustainability benefits, demonstrating the effectiveness of Lean-Green synergy.

RESULTS AND DISCUSSION

The results from the Lean and Green implementation were substantial and validated through both quantitative metrics and qualitative feedback:

Quantitative Results

The quantitative results from the Lean and Green integration reflect significant improvements across key performance indicators shown in table 1. Scrap generation was reduced from 12.2% to 7.4%, indicating better material utilization and fewer defects. Energy consumption dropped by 18.1%, from 0.72 to 0.59 kWh per kg of steel, following the installation of IE3 motors and LED lighting. Water usage decreased by 26%, owing to the implementation of a 25,000-liter/day recycling unit. Lead time per job was cut by 29.6%, from 14.5 to 10.2 hours, due to process reengineering and SMED. Changeover times improved by 41.5%, enhancing flexibility and responsiveness. Noise levels in grinding areas fell from 91 to 83 dB, improving workplace safety. CO_2 emissions were reduced by 15.3 tons annually due to energy efficiency measures. Monthly energy costs decreased by approximately ₹12,250. Additionally, water cost savings amounted to ₹6,800 per month, making the overall implementation both economically and environmentally beneficial.

Table 1. Quantitative results from the Lean and Green integration

Performance Indicator	Before	After	% Change	Key Tools/Practices
Scrap Generation Rate (%)	12.2	7.4	↓ 39.3%	Kaizen, 5S
Energy Consumption (kWh/kg)	0.72	0.59	↓ 18.1%	IE3 Motors, LEDs
Water Usage (Liters/month)	95,000	70,300	↓ 26%	Water Recycling Unit
Lead Time (Hours/job)	14.5	10.2	↓ 29.6%	SMED, Post-VSM
Changeover Time (Minutes)	65	38	↓ 41.5%	SMED
Noise Level in Grinding (dB)	91	83	↓ 8.8%	Acoustic Enclosure

Estimated CO_2 Reduction (tons)	—	15.3	—	IE3 Motors + LEDs

Qualitative Outcomes

The implementation of Lean and Green practices at XYZ Steel Pvt. Ltd. yielded notable qualitative outcomes alongside measurable performance gains. The introduction of the 5S system transformed workplace organization, leading to safer, cleaner, and more efficient shop-floor conditions. A significant 84% of employees reported that their daily tasks became easier due to improved tool access and reduced clutter. Kaizen sessions empowered frontline workers to contribute ideas, fostering a sense of ownership and continuous improvement, with 92% of managers supporting its long-term adoption. Awareness programs and hands-on involvement in sustainability initiatives heightened employee consciousness regarding energy and water conservation, with 70% of the workforce expressing increased environmental awareness. Improved collaboration across departments, better noise conditions, and structured workflows boosted morale and reduced operational frustration. Overall, these qualitative shifts cultivated a proactive, engaged workforce more aligned with the company's goals for quality, compliance, and sustainability.

DISCUSSION

The implementation of Lean and Green practices at XYZ Steel Pvt. Ltd. brought substantial improvements in both operational efficiency and environmental performance. Key Lean tools like 5S, Kaizen, SMED, and Post-VSM helped streamline processes, reduce scrap by 39.3%, and cut lead times by nearly 30%. SMED alone led to a 41.5% reduction in changeover time, enhancing production flexibility. Workplace organization improved significantly with 5S, while Kaizen initiatives addressed recurring defects and waste. These interventions not only improved productivity but also boosted employee involvement and ownership of the improvement process.

On the environmental side, Green practices such as the installation of a water recycling unit, energy-efficient IE3 motors, and LED lighting produced measurable benefits. Water usage decreased by 26%, energy consumption dropped by 18.1%, and CO_2 emissions were cut by over 15 tons annually. Noise levels in the grinding zone were also brought within safe limits using acoustic enclosures, ensuring compliance with occupational health standards. Together, these efforts strengthened the company's readiness for ISO 14001 certification and improved its reputation in sustainable manufacturing. The success of this initiative demonstrates that even small-scale enterprises can adopt a holistic approach to sustainable growth.

CONCLUSION

This study successfully demonstrates that the integration of Lean and Green manufacturing practices can drive significant improvements in productivity, environmental sustainability, and regulatory compliance, even within the constraints of a small-scale enterprise. The structured application of tools such as 5S, Kaizen, SMED, and VSM alongside Green initiatives like water recycling, energy efficient motors, LED lighting, and pollution control resulted in measurable gains across key performance indicators, including reduced scrap, energy and water consumption, shorter lead times, and improved workplace safety.

The study highlights that a phased, employee inclusive, and data driven implementation framework can overcome traditional barriers faced by SMEs in adopting sustainable practices. Beyond operational and environmental benefits, the transformation positioned the company for future growth through improved compliance, cost savings, and enhanced stakeholder perception. This paper thus offers a replicable model for other SMEs aiming to pursue sustainable manufacturing and triple-bottom-line performance people, planet, and profit.

References

1. Cherrafi, A., Elfezazi, S., Govindan, K., Garza-Reyes, J. A., Benhida, K., & Mokhlis, A. (2017). A framework for the integration of Green and Lean Six Sigma for superior sustainability performance. International Journal of Production Research, 55(15), 4481–4515.
2. Choudhary, A. K., Nayak, R., Dora, M., Mishra, N., & Ghadge, A. (2020). Integration of lean and green practices for sustainable business: A case study in an Indian manufacturing firm. Production Planning & Control, 31(2-3), 107-124.
3. Gupta, S., & George, J. F. (2016). Toward the development of a big data analytics capability. Information & Management, 53(8), 1049–1064.
4. Jayal, A. D., Badurdeen, F., Dillon, O. W., & Jawahir, I. S. (2010). Sustainable manufacturing: Modeling and optimization challenges at the product, process and system levels. CIRP Journal of Manufacturing Science and Technology, 2(3), 144–152.
5. Vinodh, S., Arvind, K. R., & Somanaathan, M. (2011). Tools and techniques for enabling sustainability through lean initiatives. Clean Technologies and Environmental Policy, 13(3), 469–479.
6. Zhu, Q., & Sarkis, J. (2004). Relationships between operational practices and performance among early adopters of green supply chain management practices in Chinese manufacturing enterprises. Journal of Operations Management, 22(3), 265–289.
7. Luthra, S., Garg, D., & Haleem, A. (2016). The impacts of critical success factors for implementing green supply chain management towards sustainability: An empirical investigation of Indian automobile industry. Journal of Cleaner Production, 121, 142-158.
8. Cherrafi, A., Elfezazi, S., Chiarini, A., Mokhlis, A., & Benhida, K. (2017). The integration of Lean manufacturing, Six Sigma and sustainability: A literature review and future research directions for developing a specific model. Journal of Cleaner Production, 139, 828–846.
9. Bag, S., Pretorius, J.H.C., Gupta, S., Dwivedi, Y.K., & Kumar, S. (2021). Role of smart technologies in enabling Lean and Green manufacturing: A systematic review. Journal of Cleaner Production, 296, 126660.
10. Jabbour, C. J. C., de Sousa Jabbour, A. B. L., Sarkis, J., & Filho, M. G. (2022). Unlocking the synergy between Lean and Green: A pathway to sustainable operations in emerging economies. Journal of

Cleaner Production, 331, 129956.