
A Comprehensive Literature Review on Lean Six Sigma Practices for Sustainable Operational Excellence in the UAE Cement Industry

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Abstract.

The cement industry is energy and carbon-intensive. Research increasingly integrates sustainability with Lean Six Sigma (LSS), circular economy practices, energy efficiency, and alternative fuels. This review examines success and failure factors, Multicriteria Decision Making (MCDM), DMAIC-based sustainability frameworks, and their validation, providing a basis for a sustainability-driven DMAIC model for the UAE cement industry.

Keywords. Lean Six Sigma (LSS); Sustainable Operational Excellence; Cement Industry; DMAIC; Sustainability.

1. INTRODUCTION

Cement is essential for infrastructure but generates substantial CO₂ emissions and industrial waste. Rising energy costs, stricter regulations, and investor expectations have encouraged Lean Manufacturing, Six Sigma, and Green Lean Six Sigma. This review covers sustainability success factors and barriers, MCDM, DMAIC, alternative fuels, and framework validation.

2. EARLY SUSTAINABILITY AND ENERGY EFFICIENCY RESEARCH

Early studies aimed to reduce energy costs and emissions. Following the 1970s fuel crisis, cement manufacturers explored alternative fuels, clinker substitution, waste-heat recovery, and energy-efficient technologies (Coito et al., 2000; Madloul et al., 2011; Hasanbeigi et al., 2011). Later work confirmed alternative fuels, combustion optimization, and clinker substitution as important CO₂-reduction routes (Mikulčić et al., 2012; Balsara et al., 2019), establishing a basis for sustainable cement operations.

3. LEAN MANUFACTURING AND INTEGRATION WITH LEAN SIX SIGMA

Lean Manufacturing improves productivity by reducing waste and improving process flow (Ruben et al., 2018; Chowdhury et al., 2020). Value Stream Mapping identifies non-value-added activities and constraints (Singh et al., 2017). LSS combines lean waste reduction with Six Sigma's statistical control. Success depends on management commitment, training, communication, and culture (Albliwi et al., 2014; 2015). Green LSS integrates operational, environmental, and economic goals, using energy, greenhouse-gas emissions, and waste as DMAIC indicators (Cherrafi et al., 2016; Hariharan et al., 2021).

4. ENVIRONMENTAL, SOCIAL, AND FINANCIAL SUSTAINABILITY ELEMENTS

Environmental barriers include fossil-fuel dependence, emissions, poor waste management, and regulatory gaps, addressed through emissions control, carbon auditing, clinker substitution, and alternative fuels (Malek and Desai, 2019; Abdullah et al., 2023). Social sustainability relies on leadership, training, communication, and culture, while economic adoption depends on costs, returns, investment feasibility, incentives, and long-term performance (Mangla et al., 2017; McLean et al., 2015; Dube, 2016; Wang, 2016).

5. RENEWABLES, CIRCULAR ECONOMY, AND DECARBONIZATION

Recent literature emphasizes alternative fuels and circular economy integration, including their effects on kiln performance and clinker quality (Larsen, 2007; Saha and Karstensen, 2017; Khokhar et al., 2020). Co-processing, waste recovery, raw-material replacement, supplementary cementitious materials, and pollution prevention are increasingly essential to sustainable cement production (Habert et al., 2020; Hosen and Bărbulescu, 2026).

6. MCDM TECHNIQUES AND SUSTAINABILITY ASSESSMENT

MCDM methods assess sustainability factors and operational barriers. AHP, TOPSIS, VIKOR, and PROMETHEE support manufacturing decisions (Li et al., 2015; Dweiri et al., 2016), while DEMATEL and Fuzzy AHP address causal relationships and uncertainty in circular-economy and green-lean applications (Kashyapa et al., 2022; Garza-Reyes et al., 2025). Integrated MCDM methods provide more robust assessments than standalone techniques.

7. VALIDATION OF SUSTAINABILITY FRAMEWORKS BASED ON DMAIC

DMAIC-based sustainability frameworks are increasingly applied in industry (Mathiyazhagan et al., 2019; Jena et al., 2024). In cement manufacturing, DMAIC has reduced emissions, waste, and energy use, while Statistical Process Control supports stability (Raikar, 2018; Bonetti et al., 2023). LSS frameworks show that DMAIC can integrate operational and environmental improvements (Garza-Reyes et al., 2015; Cherrafi et al., 2016), but empirical validation remains limited, especially in the UAE.

8. RESEARCH GAPS

Most studies treat sustainability and operational excellence separately. The UAE cement sector remains underexplored despite its economic and environmental importance. Few empirical studies combine DMAIC, sustainability KPIs, and alternative fuels to maximize thermal substitution rate (TSR); practical industrial validation is therefore lacking.

9. CONCLUSION

Sustainable cement manufacturing integrates operational, environmental, and economic improvement through LSS, DMAIC, alternative fuels, energy efficiency, circular economy practices, and MCDM. However, the UAE lacks an empirically validated sustainability-DMAIC framework, highlighting the need for future industry-specific research.

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Biographies



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