

Managing Environmental Trade-offs in Electric Arc Furnace Stainless Steel Production: A Grade-Specific Life Cycle Perspective

Luca Testini¹, Alessandro Misul², Vincenzo Morreale², Philippe Brocard², Livia Persico², Davide Mombelli³, Giovanni Dotelli¹

¹Dipartimento di Chimica, Materiali e Ingegneria Chimica "Giulio Natta", Politecnico di Milano, Piazza Leonardo Da Vinci 32, 20133 Milano, Italy

²Cogne Acciai Speciali S.p.A, Via Paravera 16, 11100 Aosta, Italy

³Dipartimento di Meccanica, Politecnico di Milano, Via La Masa 1, 20156 Milano, Italy

Stainless steel production via Electric Arc Furnace (EAF) is characterized by a high share of indirect environmental impacts due to the intensive use of alloying elements. Despite this, the contribution of raw materials procurement to the overall impact of different stainless-steel grades remains insufficiently quantified, limiting the accuracy of corporate sustainability reporting and the identification of effective mitigation strategies.

This study develops a cradle-to-gate (A1-A3) Life Cycle Assessment (LCA) model that integrates direct process emissions with upstream impacts associated with raw materials, energy supply, transport and auxiliary operations. The model covers a broad portfolio of stainless-steel grades and enables a grade-specific environmental characterization. Primary data on raw material inputs, electricity consumption, process emissions, waste and water flows were collected at facility level, while upstream processes were modelled using ecoinvent 3.11 datasets. LCA calculations were performed with Brightway 2.5 and Life Cycle Impact Assessment was carried out using the Environmental Footprint 3.1 method, including normalization and weighting to derive single-score indicators.

Results demonstrate that raw materials systematically account for more than 90% of total impacts across all stainless-steel categories. Duplex and austenitic grades show the highest single scores, followed by precipitation-hardening, ferritic and martensitic steels. The dominant contributions originate from Molybdenum (Mo), Nickel (Ni), Chromium (Cr) related raw materials, mainly ferroalloys, whereas the influence of direct emissions and energy use is comparatively limited. The analysis also confirms that climate change total results for stainless steels are significantly higher than those typically reported for generic EAF steel production, reflecting their higher alloy content.

However, a critical divergence emerges between indicators: while climate change total is dominated by the carbon intensity of Ni and Cr raw materials, the comprehensive single score is heavily driven by Mo-related resource depletion potential. This finding highlights that decarbonization strategies focusing solely on Cr and Ni risk burden-shifting towards Mo.

By providing grade-level granularity and fully integrating upstream processes, this work highlights the central role of strategic sourcing and supply chain management in stainless steel sustainability. The model improves the accuracy of environmental reporting and supports targeted mitigation actions by linking impacts directly to steel composition and raw material requirements, instead of relying on generic industry-average values. Moreover, identifying high-impact grades enables anticipation of financial risks associated with the EU Carbon Border Adjustment Mechanism (CBAM) via extra-EU ferroalloy procurement.

1

2

- (1) Worldstainless. *CO2 Emissions Report*; 2024. <https://worldstainless.org/sustainability/environment/stainless-steels-and-co2-industry-emissions-and-related-data/> (accessed 2025-06-18).
- (2) Worldsteel Association. *Sustainability Indicators Report 2025*; 2025. <https://worldsteel.org/wider-sustainability/sustainability-indicators/> (accessed 2026-01-09).

