

Mind the gap: An in-depth analysis of methodological frameworks for integrating environmental criteria in MEAT-based public tenders for metro rolling stock platforms

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EXTENDED ABSTRACT

Public procurement has increasingly emerged as a key strategic lever for achieving environmental policy goals [1], particularly in sectors like public transportation where long asset lifetimes and significant upstream and operational emissions make early intervention impactful. Within this landscape, the ecological decision making in procurement of metro rolling stock plays a pivotal role, as choices made today regarding vehicle design, energy use, and materials have lasting consequences for carbon emissions, local air quality, and resource efficiency over several decades [2]. European procurement law, notably through the Most Economically Advantageous Tender (MEAT) principle enshrined in EU Directives, allows contracting authorities to integrate environmental criteria alongside cost and technical performance [3,4]. However, in practice, many public transport authorities (PTAs) struggle to embed environmental performance in a methodologically sound, practically feasible, and legally defensible manner [1] – often supported by the eco-design paradox [5]. The complexity of rigorous Life Cycle Assessments (LCA), combined with limited in-house expertise and data access at early tender stages, often leads to either a minimal consideration of environmental impacts or the application of generic, non-comparable criteria.

This paper addresses this gap by proposing a streamlined yet structured method for integrating environmental performance into the MEAT evaluation of metro rolling stock tenders, with a focus on greenhouse gas emissions over the entire vehicle lifecycle. Drawing on the principles of the *TU Delft's* “Fast Track method” [6] and adapting them to the context of public tenders in the metro sector, a simplified LCA framework is operationalised that balances methodological rigor related to *ISO 14040* [7] and the *Product category rules for rolling stock and parts thereof (PCR)* [8] with feasibility subject to real-world constraints such as limited data at lower technology readiness level (TRL).

The Fast Track LCA methodology applied follows the *ISO 14040* framework, comprising objective and scope definition, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), and interpretation. Based on the developed model, the CO₂ footprint and other key environmental indicators of metro rolling stock are assessed at an early stage of product development, aligned with procurement specifications and the applicable PCR. The system boundaries encompass the entire life cycle, which divided into upstream (raw material extraction and processing), core (assembly and transport), downstream use (operation and maintenance), and end-of-life (recycling, incineration, disposal) phases. Due to the limited primary data available during the tendering stages, the LCI uses secondary data sources based on *UNIFE's* 16 material categories [9] and the metro's high-level Bill of Materials. Operational energy use and maintenance spare parts are crucial contributors to the impact of environmental emissions, given the frequent acceleration of the metro and the use of auxiliary systems. The end-of-life assessment incorporates the *UNIFE* factors for material recycling, energy recovery, and waste [9] to realistically model the impact of disposal.

The LCIA focuses primarily on Global Warming Potential (GWP), using the open-source *IDEMAT* database [10]. The results are then visualised and interpreted to identify environmental hotspots and provide a transparent comparison between tender submissions, facilitating informed design improvements and procurement decisions.

To validate the developed streamlined LCA model, data from a reference metro trainset in Vienna was used to analyse the GWP across the life cycle phases. The results indicate that the core phase contributes minimally to the total GWP ($\sim 4.4E-05$ kg CO₂eq), while the downstream use phase accounts for the majority of emissions ($\sim 1.45E-02$ kg CO₂eq). Upstream material production accounts for roughly 8% of the total GWP. The analysis of the material hotspots revealed that ferrous and non-ferrous metals (especially

aluminium) make the largest contribution (35% each), followed by industrial batteries (20%), with control units and elastomers represent a smaller share.

To assess the sensitivity of the model, three additional scenarios were added: an eco-optimised metro variant and two geographic contexts (Vienna and Seoul). The eco-friendly variants showed modest upstream GWP reductions due to the choice of sustainable materials. In the scenarios for Seoul, core phase emissions were slightly higher due to longer transport distances. The downstream phase exhibited the largest differences, with the higher carbon intensity of the local electricity mix in Seoul leading to much higher operational emissions. Nevertheless, energy-efficient design significantly reduced the negative impact on the environment in both regions.

The study demonstrates that a high-level BOM approach in combination with open-source LCI data (e.g. *IDEMAT*) provides a resource-efficient yet robust environmental assessment suitable for early-stage procurement decisions. In line with *UNIFE*, PCR and EPD guidelines, this method enhances transparency and supports the environmental awareness among contracting authorities. The flexibility of the model allows it to be adapted to different rolling stock types and encourages innovation in the areas of energy efficiency and circular economy. As public transport increasingly integrates sustainable technologies and renewable energy, such environmental evaluation frameworks will be essential. Future advancements, including AI-driven tools and *Digital Product Passports*, promise to improve assessment accuracy and stakeholder collaboration. Overall, the integration of environmental criteria into procurement fosters sustainable public transport systems that are in line with international climate goals.

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