

<https://doi.org/10.7250/CONNECT.2026.074>

# IMPLEMENTING SAFE AND SUSTAINABLE BY DESIGN: A LIFE CYCLE COSTING APPROACH FOR FIRE RETARDANT CHEMICALS IN WOOD PRODUCTS

Nidhiben PATEL<sup>1\*</sup>, Chiara LEGGERINI<sup>2</sup>, Francesco ROMAGNOLI<sup>3</sup>

<sup>1,3</sup> *Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia*

<sup>2</sup> *University of Brescia, Department of Mechanical and Industrial Engineering, Via Branze 38 – 25123 Brescia, Italy*

\* **Corresponding author.** Email address: [nidhiben-arvindbhai.patel@rtu.lv](mailto:nidhiben-arvindbhai.patel@rtu.lv)

**Abstract** – The development of new fire-retardant chemicals for wood products is increasingly driven by the need to overcome the limitations of existing solutions, which often raise concerns regarding sustainability while failing to provide extended fire resistance performance. In this context, assessment approaches are required that support the integration of safety, sustainability, and economic considerations during early stages of chemical and product development. The Safe and Sustainable by Design (SSbD) framework provides overarching guidance for such integration by addressing environmental, social, functional, and economic dimensions across the life cycle. However, practical methodologies for implementing its economic dimension remain limited. This study focuses on operationalizing the economic pillar of the SSbD framework through the development of a Life Cycle Costing (LCC) methodology tailored to fire retardant chemicals for wood products. Within the SSbD concept, economic sustainability is interpreted beyond short-term production costs and includes long-term performance, resource efficiency, and the avoidance of future costs related to safety, regulatory compliance, and redesign. Based on this interpretation, LCC is selected as an appropriate tool to translate SSbD principles into a structured and transparent economic assessment. The LCC methodology is developed by defining system boundaries directly from an SSbD perspective, focusing on product system stages where design and production decisions have a direct influence on safety, sustainability, and economic performance. Five key stages are considered: raw material procurement, fire retardant production, mixing and product preparation, product packaging, and quality and safety control. These stages represent the core processes involved in the development of fire-retardant products and allow the economic implications of SSbD oriented choices to be systematically captured. For each stage the cost categories are identified and structured in alignment with SSbD principles. Particular emphasis is placed on linking economic assessment to functional performance, including improved and longer-lasting fire resistance, as well as to the substitution of less sustainable fire-retardant solutions. The proposed methodology demonstrates how the economic dimension of the SSbD framework can be transformed into a practical and application-oriented LCC approach. It supports transparent comparisons of alternative fire-retardant formulations and production strategies and provides a structured basis for SSbD-based decision-making in the development of fire-safe, economically viable, and more sustainable wood products.

**Keywords** – *Decision-support framework; Economic assessment; Fire safety engineering; Material sustainability; Performance-based evaluation; Product system analysis.*



SSbD based LCC fraemwork for developing new fire retardant

**ACKNOWLEDGEMENT**

This work is supported by the ERDF, Interreg Estonia – Latvia program, project " Development of wood flame retardants with low environmental impact (FireStop) project No. EE-LV00014.