
Life Cycle Assessment approaches developed for glass sustainability

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Abstract

In recent years, the importance of environmental sustainability has become increasingly evident across various industries. This growing awareness has prompted businesses to reevaluate their operations and embrace more eco-friendly practices. As a result, Life Cycle Assessment (LCA) have gained significant traction being a systematic and comprehensive methodology used to assess the environmental loads, caused by use of resources, energy and environmental consequences of pollutants released into the environmental compartments associated with all stages of the life cycle of products, processes and services from raw material extraction through to disposal. The International Organization for Standardization (ISO), provides guidelines for conducting a Life Cycle Assessment within the series ISO 14040 and 14044.

ISO states that LCA methodology is able to i) identify opportunities to improve the environmental performance of products at various points in their life cycle, ii) inform decision-makers in industry, government or non-government organizations (e.g. for the purpose of strategic planning, priority setting, product or process design or redesign), iii) the selection of relevant indicators of environmental performance, including measurement techniques, and iv) marketing (e.g. implementing an ecolabelling scheme, making an environmental claim, or producing an environmental product declaration).

Therefore, this analytical tool provides industries with valuable insights into their environmental performance, enabling informed decision-making towards more sustainable practices. In the industrial sector, LCA holds immense potential as a strategic approach to assess and optimize the environmental footprint of products and processes. By quantifying environmental impacts across the entire life cycle, industries can identify opportunities for efficiency improvements, waste reduction, and the adoption of cleaner technologies. In addition, it is possible to facilitate the comparison of alternative production methods, materials, and design choices, enabling companies to make informed decisions that minimize environmental burdens while maximizing economic and social benefits.

Unlike the predominant environmental certifications currently proliferating within industrial contexts, such as those focused on Carbon Footprint or Environmental Product Declarations (EPD), the Life Cycle Assessment (LCA) methodology offers a more holistic approach encompassing a wide array of environmental indicators. This inclusivity enables a unique and holistic perspective on environmental sustainability.

Among the industrial sectors, the glass industry plays a significant role due to its widespread

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use in packaging, construction, and consumer goods. Understanding the environmental impacts associated with glass production and recycling is crucial for implementing sustainable practices.

After a preliminary description of the fundamentals of this methodological tool with reference to some aspects still under discussion in the international scientific community, some case studies relating to the functionalisation of self-cleaning float glass and the recycling of glass waste in the manufacturing of ceramic glazes will be examined.

The construction sector significantly influences energy consumption, material usage, and consequent environmental impacts. Addressing concerns such as reducing energy consumption and regulating the exploitation of non-renewable resources are crucial aspects to tackle within this sector. Implementing design systems that consider both energy and material usage throughout a building's lifespan, along with optimizing construction systems to maximize energy efficiency and minimize environmental impacts, becomes essential for eco-design. Consequently, the industrial sector advanced the development of engineered nanoparticles (ENPs) for use in an increasingly diverse array of consumer and industrial goods. Leveraging the distinctive physical and chemical attributes of nanoparticles enables the creation of innovative applications. These nanoparticles exhibit unique properties (chemical, mechanical, optical, magnetic, etc.) distinct from their bulk counterparts. Consequently, ENPs have found widespread application across various industrial domains, including the functionalization of different types of surfaces, such as metals, glass, composing architectural and decorative indoor and outdoor elements, to obtain specific surface properties. In particular, nanoparticles such as titanium dioxide, are often incorporated or coated onto building materials to confer additional and enhanced properties such as self-cleaning, antibacterial features, anti-fogging, lightweight characteristics, mechanical robustness, durability, and fire resistance. In the case study, the ecodesign of an industrial scale-up of nanoTiO₂ self-cleaning coated float glass production performed by LCA methodology will be discussed, focusing on the assessment of both human health effects and environmental loads of the entire life cycle of this nanomaterial. When exposed to radiation of adequate wavelength, nanotitanium dioxide (TiO₂) shows peculiar characteristics like photocatalysis of redox reactions, but also superhydrophilicity and antibacterial properties. The functionalized surface has an improved cleanability and antibacterial activity but it also becomes active, i.e., to reduce the concentrations of air pollutants such as nitrogen oxides (NO_x) and volatile organic compounds (VOCs) deposited on or in contact with the material surface. Among several coating methods to create a thin film on glass surface, such as vacuum arc deposition, alkaline hydrothermal method, hydrothermal method and others, in this work, a modified coating method consisting in first a decrease of the initial substrate roughness and then dip-coating of the softened glass into a TiO₂ nanosuspension has been used with the aim to produce films with enhanced adhesion to the substrate. The results of the environmental assessment has been discussed in terms of impact and damage categories and an LCA comparative analysis between nanotitania functionalized float glass and uncoated float glass has been analyzed in order to highlight the main critical hotspots.

To explore the recycling-related issues, the use of glass waste in the manufacturing of ceramic glazes will be illustrated. The ceramic industry stands as a pivotal manufacturing areas in the world. With the growth in the economy and the development of the ceramic industry, the need for ceramic products is increasing. These products find extensive application in different sectors, including ceramic tableware, floor and wall tiles, vitrified products, and sanitary ware. Ceramic tiles, in particular, holds a prominent place in the building sector.

With increasing demand for raw materials, production capacities are rapidly increasing, even if accompanied by difficult environmental challenges related to the finite nature of natural capital. It is therefore becoming imperative to curb raw material consumption. Considering the importance of the glassy part in the ceramic glaze, the usage rates of frit-based materials are quite high. Ceramic glaze protects products from external influences and gives the product an aesthetic feature. One of the most frequently used raw materials in the preparation of ceramic glazes is frits that are the main component of the batches used in the composition

of ceramic glazes. They can usually be sold in pure form to ceramic manufacturers who create their own glazes, or in some cases, frit manufacturers produce and supply the glazes themselves.

The environmental effect of the substitution of glass cullet instead of frit used in glaze compositions in the ceramic industry will be discussed and the comparative LCA analysis with traditional formulations will be considered.

Keywords: Life Cycle Assessment, environmental impacts, nanotitania, float glass, frits, ceramics