Environmental Product Declaration (EPD) Profiles of Ceramic Tiles, Sanitary Ware, Clay Roofing Tiles and Clay Bricks: Insights from One Click LCA and the International EPD System

Milica Vidak Vasić * , Tea Spasojević Šantić , Zagorka Radojević

Posted Date: 26 February 2026

doi: 10.20944/preprints202602.1219.v1

Keywords: environmental product declaration (EPD); energy use; ceramic industry; harmonization; One Click LCA; International EPD System; product category rules (PCR); climate policy doi:10.20944/preprints202602.1219.v1

Article

Environmental Product Declaration (EPD) Profiles of Ceramic Tiles, Sanitary Ware, Clay Roofing Tiles and Clay Bricks: Insights from One Click LCA and the International EPD System

Milica Vidak Vasić *, Tea Spasojević Šantić and Zagorka Radojević

Center for Materials, Institute for Testing of Materials, Bulevar vojvode Mišića 43, 11000 Belgrade, Serbia
* Correspondence: milica.vasic@institutims.rs

Abstract

This study presents a comparative evaluation of Environmental Product Declarations (EPDs) within the traditional ceramic industry, emphasizing the intersection of energy use, environmental performance, and policy-relevant data structures. Four product categories—ceramic tiles, sanitary ware, clay bricks, and clay roof tiles—were analyzed using datasets from One Click LCA and the International EPD System. Environmental indicators assessed include fossil-based and total Global Warming Potential (GWP), freshwater consumption, and energy demand, standardized per 1 kg of product. The analysis reveals significant discrepancies in data provenance and methodological consistency across platforms, with One Click LCA offering harmonized datasets for tiles and sanitary ware, while the International EPD System permits variable sources, particularly evident in brick EPDs. These inconsistencies hinder comparability and dilute the strategic value of EPDs in guiding low-carbon market transitions. The study highlights that energy-intensive production stages in tiles and sanitary ware contribute to elevated environmental burdens, underscoring the need for harmonized software tools, transparent reporting formats, and standardized background databases. Confidentiality regarding energy sources and firing temperatures remains a barrier to optimization, while the absence of fossil fuel-specific GWP guidance and high EPD development costs limit broader market uptake. By expanding comparative assessments across production sites and product types, the research supports the development of robust benchmarks and tailored Product Category Rules (PCRs), reinforcing the role of EPDs as actionable instruments in energy policy and sustainable market design.

Keywords: environmental product declaration (EPD); energy use; ceramic industry; harmonization; One Click LCA; international EPD system; product category rules (PCR); climate policy

---

1. Introduction

The ceramic industry plays a vital role in the global construction sector, with traditional clay-based products such as bricks, tiles, and sanitary ware representing a significant share of building materials used worldwide. Across Europe, the ceramic industry produces more than 59 million tons of material each year, generating approximately 19 million tons of CO_2 emissions. Energy use—primarily for high-temperature firing—can represent as much as 30% of total production costs, making it a major contributor to the sector's environmental footprint [1,2].

A critical factor influencing the environmental profile of ceramic products is the energy source used during firing. The modern systems include biofuels, biogas, or solar energy. The amount of energy needed for a given operation or process is constant, but the rate of consumption changes according to the fuel type, technology used, and system efficiency. Therefore, the effectiveness of

doi:10.20944/preprints202602.1219.v1

energy conversion into usable form, the energy used in the process, and particularly the performance of the kiln, are crucial determinants [3].

Coal is a relatively high-energy fuel, with a heat value of about 10-25 MJ/kg [4,5]. It can serve for a high-temperature ceramic production process, but coal-fired kilns often operate inefficiently, with considerable energy lost through exhaust gases. Additionally, coal use has significant environmental drawbacks, including gas emissions and particulate matter. Depending on its kind, origin, and pipeline infrastructure, natural gas has a heat value of 42–55 MJ/kg [5]. Natural gas stands out as an efficient choice for firing ceramics in contemporary kilns, delivering significant heat while maintaining comparatively low emission levels. Electric kilns are also widely used in ceramics, especially for smaller-scale operations. These kilns have very high efficiency in thermodynamic terms, as nearly all of the electrical energy is directly converted into heat with minimal loss [6]. However, their environmental impact depends greatly on the source of the electricity used. Electricity sourced from renewables like wind, solar, or hydro reduces the carbon footprint, while electricity obtained from fossil fuels such as coal or natural gas raises greenhouse gas emissions, greatly influencing the kiln’s environmental impact.

Biomass is increasingly used due to its near-zero carbon and pollutant emissions, unlimited reserves, and high reactivity [7]. The carbon dioxide released during the combustion is offset by the carbon absorbed by plants during their growth. Due to its relatively low energy density comparable to that of coal, it is feasible to use it as a fuel in a co-gasification process [4]. Furthermore, its efficiency is influenced by the quality and moisture of the biomass and the kiln’s ability to maintain uniform heat distribution, which then determines the overall environmental impact.

The energy efficiency of ceramic industry kilns depends on their design, the fuel used, and the combustion technology, all of which also impact particulate matter and other air emissions. One of the often-used solutions to reduce energy consumption is heat recovery from the kiln and its usage in the drying process [8].

During the firing of traditional ceramics, various flue gases are emitted, mainly including CO_2, CO, SO_2, NO_x, and particulate matter. These gases result from the combustion of fuels and the chemical reactions occurring within the kiln [9]. The total quantity of gases is usually recalculated to a CO_2 equivalent [10].

Despite its industrial importance, the environmental performance of ceramic products remains under-documented, particularly in standardized formats accessible to stakeholders [11]. This gap underscores the need for robust and transparent tools such as Environmental Product Declarations (EPDs). EPDs provide transparent, standardized data on the environmental impacts of products throughout their life cycle, making them valuable to a wide range of stakeholders [12]. Manufacturers can use EPD results to identify hotspots and improve production efficiency, while architects, builders, and consumers benefit from informed decision-making based on verified sustainability metrics. Crucially, EPDs also support eco-design during product development—allowing producers to assess environmental performance before production begins, guiding innovation toward lower-impact solutions [13,14].

EPDs are grounded in Life Cycle Assessment (LCA), a comprehensive analytical tool that evaluates the environmental burdens from raw material extraction through production, transport, installation, use, and end-of-life treatment. While LCA provides detailed datasets for international decision-making, EPDs translate this information into externally verified, standardized formats governed by Product Category Rules (PCRs) and international standards such as EN 15804 [15] and ISO 14025 [16]. These declarations support sustainable procurement, regulatory compliance, and market differentiation by presenting key indicators—such as Global Warming Potential (GWP), acidification, and resource use—transparently and comparably [17,18].

In the EPDs, the GWP total includes those of fossil, biogenic, and land use and land use change (LULUC). GWP fossil accounts for the greenhouse gas emissions resulting from the combustion of fossil fuels and fossil carbon-containing substances (coal, oil, or gas). On the other hand, a biogenic GWP is obtained from biomass burning. It also considers the carbon absorbed during the growth of

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 26 February 2026 doi:10.20944/preprints202602.1219.v1

biomass, which can result in negative values when carbon is stored in products. Furthermore, GWP LULUC considers the emissions from deforestation or agricultural land conversion [15].

This study aimed to evaluate the environmental profiles of various clay-based product sectors—clay bricks, clay roof tiles, ceramic tiles (wall and floor), and sanitary ware—through a comparative analysis of EPDs generated using two platforms: One Click LCA and the International EPD System. The analysis focuses on key impact categories, including GWP fossil, GWP total, freshwater consumption, and energy use, based on a functional unit of 1 kg of final product. While the study does not compare identical products across platforms, it highlights discrepancies in data handling and reporting that affect cross-sector comparability.

Limitations of the study include restricted access to proprietary data such as firing temperatures and energy sources, which are often confidential in published EPDs. Additionally, the evolving nature of standards and databases introduces challenges in maintaining consistency across declarations. Despite these constraints, the findings underscore the need for harmonized methodologies and sector-specific EPD frameworks to improve transparency and reduce confusion in environmental communication [11,12]. The comparison of the findings from the literature review and the relevant platforms reveals a gap in knowledge transfer from science to the market. Based on this, the most sensible approach is to establish sector-specific EPDs. This will enable construction product manufacturers to manage development costs effectively and prevent confusion caused by non-comparable environmental impact data.

The findings of this study demonstrate that EPDs can serve not only as tools for transparent environmental communication but also as strategic instruments for improving production processes and guiding sustainable product development. By analyzing life cycle data, the paper highlights how EPDs support informed decision-making across the value chain—from manufacturers to end users.

2. Materials and Methods

This study aims to consolidate existing knowledge within the traditional ceramic industry by identifying prevailing environmental trends and outlining potential future directions. The analysis focuses on four representative product categories - clay bricks, roof tiles, ceramic tiles, and sanitary ware – using EPDs sourced from One Click LCA and the International EPD System [19]. To complement and contextualize the findings, relevant scientific and technical literature is also reviewed.

Special attention is given to key environmental indicators, including Global Warming Potential (GWP) from fossil sources and total GWP (expressed in kgCO$_{2e}$), as well as total fresh water and energy use. These parameters are examined within the scope of the product`s life cycle stages from cradle to gate, encompassing Module A1 (raw material supply), Module A2 (transport to the manufacturing site), Module A3 (production process), Module A4 (transport to the construction site), and Module A5 (product assembly). The assessment of roofing tiles, ceramic tiles, and sanitary ware is conducted using One Click LCA, which applies a consistent internal database. In contrast, clay bricks are analyzed based on EPDs published within the International EPD system, which allows for variable data sources depending on the practitioner. These life cycle stages are prioritized due to their well-documented contribution to the overall environmental impact of ceramic products, particularly in terms of energy consumption and emissions [20]. To enable consistent comparison across product sub-groups, a functional unit of 1 kg is applied throughout the analysis.

2.1. The Importance of Using the Same Software in Comparisons

Comparability between EPDs for similar products is essential for enabling informed decision-making on environmental performance [12,22]. However, such comparisons are only valid when all relevant rules, requirements, and methodological instructions are consistently applied [11,23]. The selection and availability of input data play a critical role, and discrepancies between inventory databases can significantly affect results. Using different platforms for the same product is problematic, as each may incorporate manufacturer-specific processes and assumptions that hinder integration into LCA calculations. Moreover, newer standards often require extensive datasets, which can be difficult to manage and may introduce distortions [17,23,24].

Until 2024, EPD development largely followed the General Programme Instructions (GPI) and PCRs of the International EPD system. With the emergence of platforms like One Click LCA-now part of EPD Hub (as of 2025), there have been notable improvements in data collection, analysis, and verification. These tools offer enhanced analytical capabilities that support greater consistency and transparency in EPDs.

International standards such as ISO 14025 and EN 15804 are foundational to ensuring comparability. SRPS ISO 14025 provides a globally recognized framework for Type III EPDs, mandating standardized LCA data, independent verification, and consistent reporting [11,12,25]. PCRs under this standard define strict criteria for comparing products within the same category, including alignment in functional units, system boundaries (modules considered), data quality, and impact categories. EN 15804, tailored for construction products, provides sector-specific requirements that adopt a full life cycle approach. Its latest update [26] introduces additional impact categories and stricter reporting rules, reinforcing the standard’s robustness. It also allows sub-building level comparisons, provided that functionality, excluded materials and processes, and intrinsic product characteristics are consistently defined. For EPDs utilizing information modules—typical for construction products with an A1-D modular framework under EN 15804 [15,26] and ISO 21930 [27], it is essential that the environmental impacts of excluded life cycle stages are either minimal or that data for these stages align within reasonable uncertainty limits.

Despite these frameworks, comparing EPDs across platforms like One Click LCA and the International EPD System remains challenging due to differences in scope, methodology, and data transparency. Variations in assumptions, data sources, and missing process-specific details (e.g., raw materials composition and firing temperature) can strongly influence results. Geographical and temporal contexts further complicate comparability [14,25].

Using the same software and database is therefore essential for reliable LCA-based comparisons. Different tools may apply distinct algorithms, impact assessment methods, and boundary definitions, leading to substantial variations, even for identical products [22,24]. For example, one platform may include transport emissions while another omits them, resulting in divergent carbon footprints [24,28]. Müller et al. [29] found that software choice alone can cause up to 30% variation in the carbon footprint.

The growing emphasis on standardization in LCA, reinforced by ISO 14044, underscores the need for consistent methodologies and transparent data sources. Without such consistency, the credibility and utility of EPDs in guiding sustainable choices are significantly diminished [21].

3. Results and Discussion

3.1. One Click LCA for Traditional Ceramic Products EPDs

3.1.1. Roofing Tiles

The declarations for clay roof tiles produced in England, Portugal, and Serbia, taken over from the One Click LCA, were issued in 2024 and are valid until 2029 (Figure 1). The documents discuss different clay roof tiles crafted entirely from natural materials. Analysis of modules A1- A3 reveals that the case study in Portugal records the highest CO_2-equivalent fossil and total emissions (Figure 1a), Serbia 1 involves the most energy-intensive process (Figure 1b), and England exhibits the greatest water consumption. These variations arise from multiple factors, including the raw materials utilized, the overall production process, and the types of fuels employed. Besides, the program operator-related issues may influence the results [25]. A linear relationship between GWP, water consumption, and total energy usage is seen in Portugal`s case study. On the contrary, in Serbia, the roof tiles analyzed are produced by two facilities, and it is seen that one system spends less energy but leaves a higher GWP footprint. This is strongly related to the fuels being used and the energy loss by the production system, especially the kiln. Conversely, Serbia 1 shows a lower GWP despite higher non-renewable energy consumption, which may initially appear contradictory. However, this outcome likely stems from the predominance of lower-carbon energy sources such as natural gas [30], higher thermal efficiency in the production process, and the implementation of emission control technologies that reduce greenhouse gas output per unit of energy consumed. These factors decouple energy use from GWP impact and highlight the importance of considering both energy quantity and quality in environmental assessments. Therefore, it is seen that more detailed EPDs are necessary to ensure that comparisons yield thorough and meaningful conclusions.

To get more detailed insights, the spent energy and water, and GWPs are studied in the same products separately through the modules A1- A5 (Figure 2). The most pronounced GWP contributions stem from the production phase (A3) and gate-to-site transport (A4). In both Portuguese case studies, total and fossil GWP values during A3 are the highest among the assessed regions, while Serbia 1 reports the lowest emissions in this phase (Figure 2a). The A4 module further accentuates Portugal`s elevated GWP, likely due to longer transport distances or less efficient logistics, whereas Serbia 2 exhibits the lowest transport-related emissions. Furthermore, the construction phase (A5) in England shows a notable GWP spike, suggesting material handling or installation practices with high carbon intensity.

Water use is most significant in phase A1 (raw material extraction and supply), followed by A3 (production). Portuguese factories lead in water use across both modules, indicating either water-intensive clay preparation or less efficient recycling systems (Figure 2b). This trend underscores the need for targeted water-saving interventions in upstream and manufacturing stages.

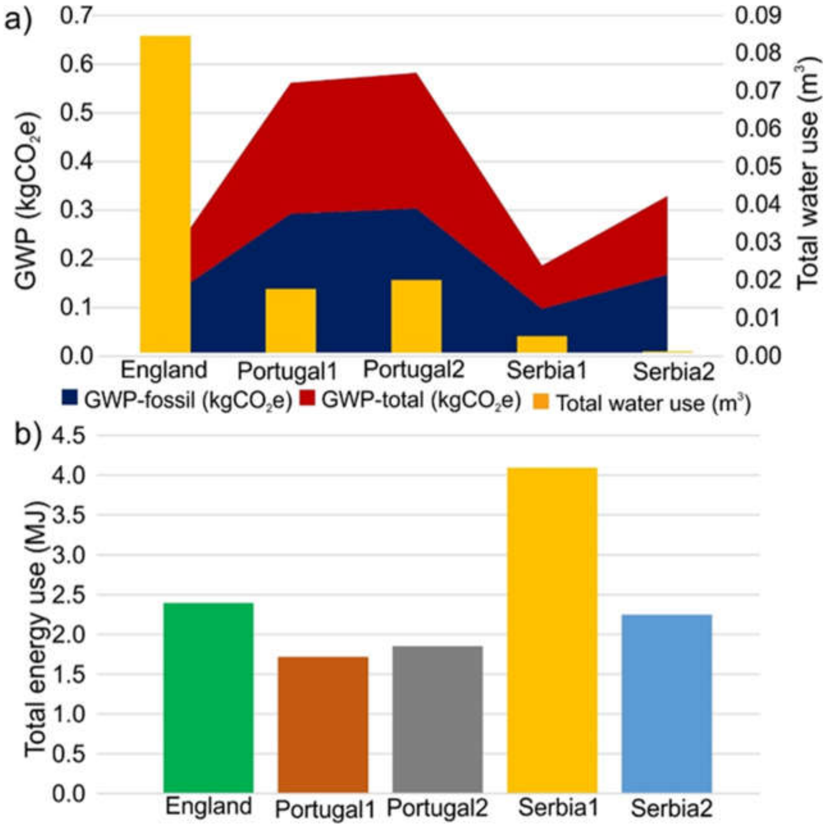

Figure 1. Modules A1-A3 in 1 kg of roofing tile: a) Equivalent CO_2 footprint and water consumption, and b) Energy use.

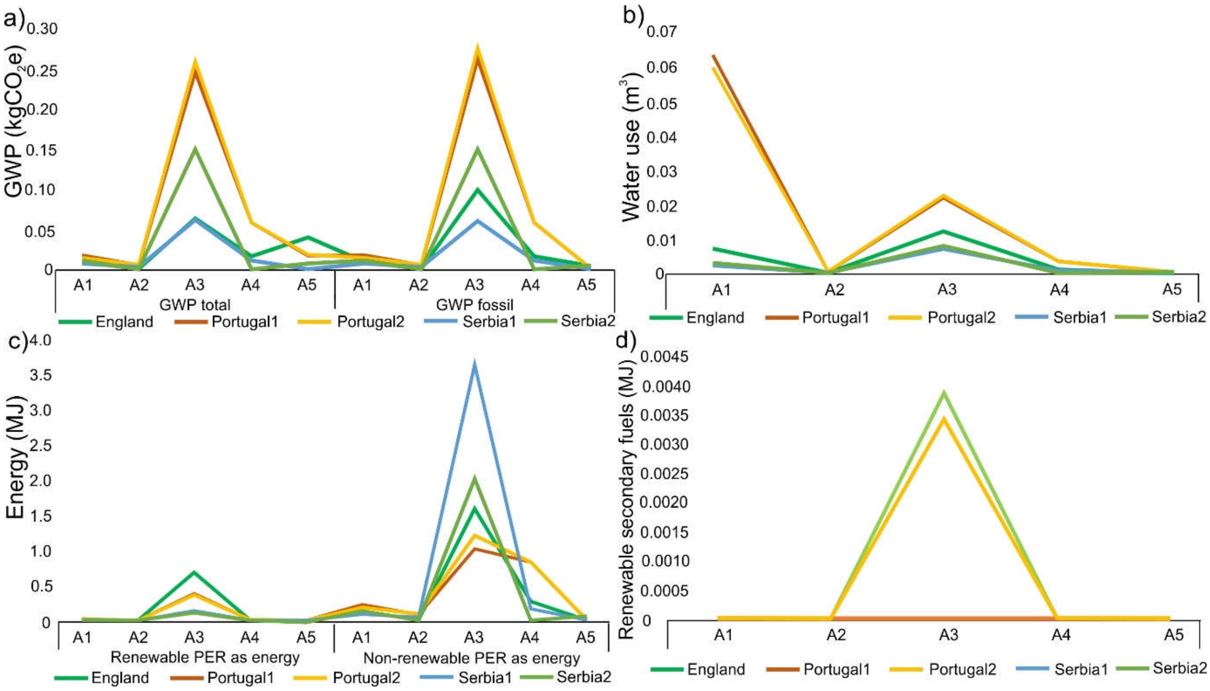

Figure 2. Modules A1-A5 in the production of 1 kg of roofing tile: a) Total and fossil GWP, b) Water use, c) Renewable and non-renewable PER energy, and d) Renewable secondary fuels (GWP - Global Warming Potential, PER – Primary Energy Sources).

Serbia 1 demonstrates the highest reliance on non-renewable primary energy sources (PER), reflecting a fossil-dominated energy mix in ceramic production (Figure 2c). In contrast, renewable energy use remains marginal across all sites, with England showing the highest relative share, albeit still limited. This dispersity highlights the urgent need for energy transition strategies in traditional ceramics, especially in regions with high PER dependency. No use of non-renewable secondary fuels is reported across the studied factories, suggesting limited integration of industrial by-products or waste-derived fuels. While England reports the highest renewable energy input, its absolute contribution remains low.

Notably, Serbia 2 and Portugal 1 report the highest renewable secondary energy use in the assessed modules, reinforcing the call for decarbonization and diversification of energy sources (Figure 2d).

3.1.2. Ceramic tiles

The EPDs for ceramic tiles manufactured in the USA, Italy, and the United Kingdom, sourced from the One Click LCA, were issued in 2024 and remain valid until 2029. The documents encompass a range of wall and floor ceramic tiles composed entirely of natural raw materials, offering a comparative lens into the environmental performance of different production systems (Figure 3). Among the A1-A3 modules, the highest GWP footprint is attributed to the Italian factory producing engineered surface porcelain tiles of 6 mm thickness (ITA10 6 in Figure 3a), likely due to energy-intensive firing and surface treatment processes. In contrast, the remaining factories report GWP totals near the EPA benchmark of up to 0.6 kg CO_{2e}/kg tile [10], suggesting relatively optimized upstream and manufacturing stages.

Water consumption varies significantly across sites and product types, with no clear correlation to tile thickness. This variability may stem from differences in clay preparation, glazing, or water recycling practices. Notably, wall tile production emerges as the most water- and energy-intensive, consistent with prior findings [31].

Energy consumption profiles reveal substantial inter-factory differences. Some of the products from the USA exhibit up to 44% higher total energy use compared to other sites, regardless of tile thickness (Figure 3b). This elevated footprint is primarily driven by modules A4 (transport) and A5 (assembly), indicating longer supply chains or less efficient logistics and installation practices.

The average total energy demand across the studied cases is 7.69 MJ/kg of fired ceramic tile, which notably exceeds values reported by Alves et al. [32] and is more than double the 3.6 MJ/kg cited in Manrique et al. [33]. These discrepancies underscore the importance of contextualized energy data by production route, regional energy mix, and tile typology.

A key limitation in the reviewed EPDs is the lack of disclosure regarding the milling route (wet vs. dry), which poses a critical determinant of energy and water intensity in ceramic processing [31,34]. Furthermore, batch composition and raw material variability significantly influence firing temperature, sintering behavior, and overall resource demand [35]. Without this granularity, cross-factory comparisons risk oversimplification and may obscure actionable insights for process optimization.

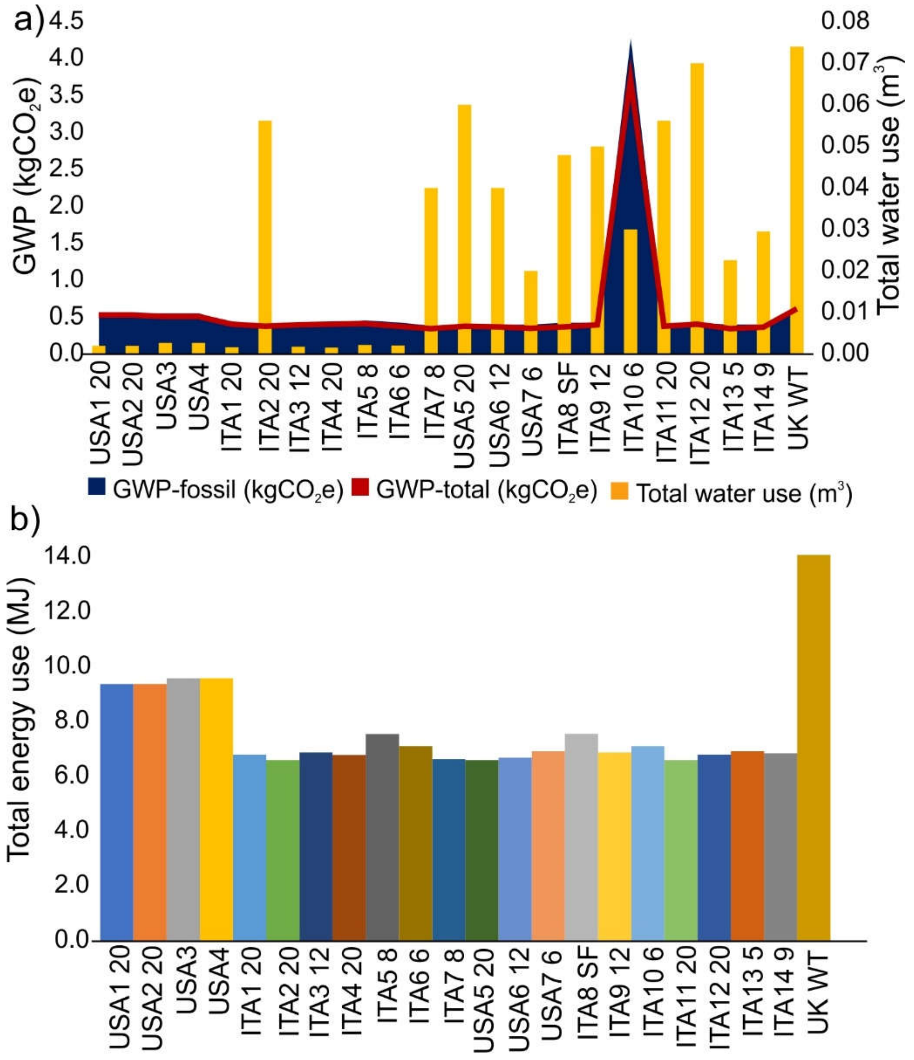

Figure 3. Modules A1-A3 in the production of 1 kg of ceramic tile: a) Equivalent CO_2 footprint and water consumption, and b) Water and energy use (USA – United States of America, ITA – Italy, UK – United Kingdom, SF – single-fired, WT – wall tiles, the number in the end is for the thickness).

3.1.3. Sanitary ware

The EPDs obtained via One Click LCA for sanitary ware items (sinks, toilets, bidets, etc.) reveal that the Swiss ceramic industry exhibits the highest consumption of energy and water, resulting in the most pronounced GWP across the assessed systems (Figure 4). The elevated GWP is particularly evident in modules A1 and A5, suggesting both resource-intensive material sourcing and carbon-heavy installation practices.

In module A1, substantial inputs of water, renewable energy, and non-renewable primary energy resources (PER) are recorded, reflecting the upstream burden of raw material extraction and preparation. Notably, the total energy demand reported in these EPDs surpasses values documented in the Ecoinvent database for a comparable Italian sanitary ware production system, which utilized a more diversified energy mix – including grid electricity, photovoltaic generation, and natural gas [36]. This discrepancy underscores the importance of regional energy infrastructure and process transparency in shaping the environmental profile of ceramic products. It also highlights the need for harmonized reporting of energy sources and water use to enable meaningful cross-country comparisons and targeted sustainability interventions.

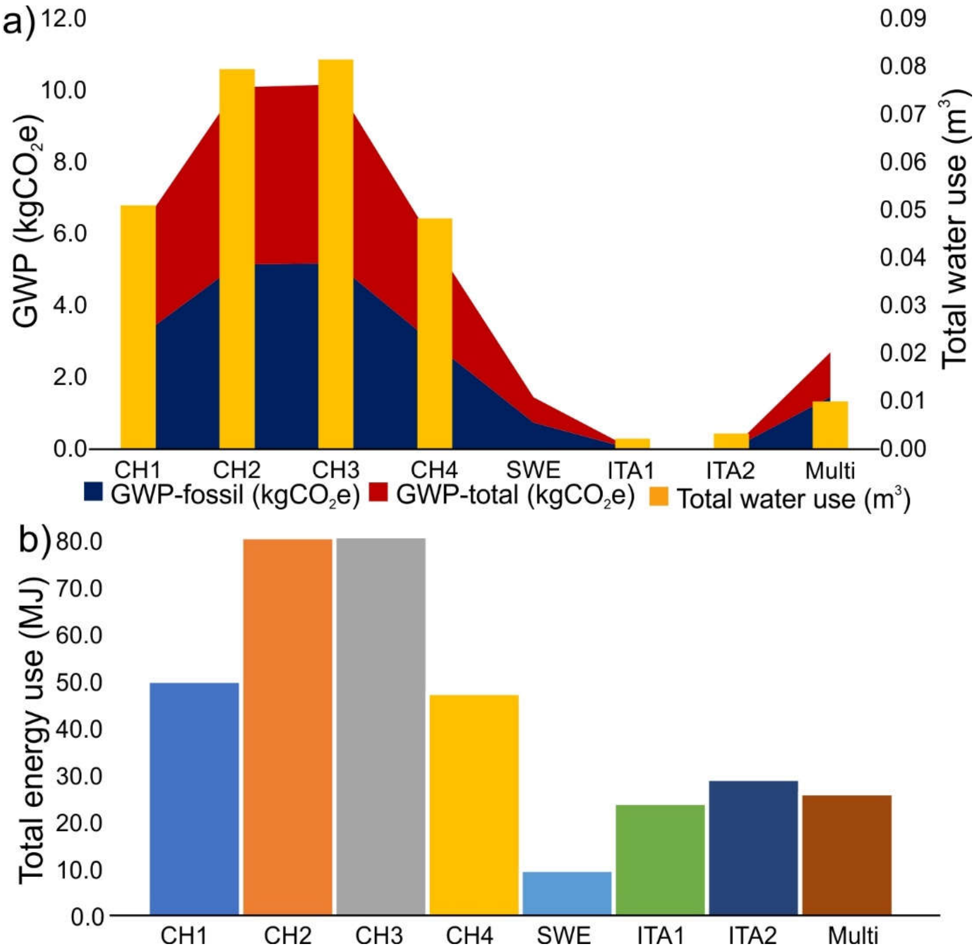

Figure 4. Modules A1- A3 in the production of 1 kg of sanitary ware: a) Equivalent CO$_2$ footprint and water consumption, and b) Water and total energy use (CH – Switzerland, SWE – Sweden, ITA – Italy, Multi – multiple countries by the same company).

3.2. International EPD System for Traditional Ceramic Products EPDs

3.2.1. Clay Bricks

Among the recently analyzed EPDs, the highest GWP was recorded for Denmark (DK7), where gas-fired periodic kilns are used-highlighting the carbon intensity of intermittent firing cycles and fossil-based energy inputs (Figure 5). This was followed by Turkey (TR), associated with hand-shaped brick production, and Germany (GER2), both of which also exhibit elevated GWP values, likely due to traditional forming techniques and fossil-dominant energy mixes.

Moderate GWP levels were observed in Denmark (DK6) for bricks without voids in pet-coke-fueled tunnel kiln, and in India (IN) for hand-molded bricks, suggesting partial mitigation through kiln efficiency or regional energy factors.

In contrast, Denmark sites DK8, DK9, and DK10, which utilize biogas-fired kilns for bricks without voids, demonstrate some of the lowest GWP values in the dataset-underscoring the decarbonization potential of renewable thermal energy sources.

A notable limitation in the reviewer EPDs is the inconsistent reporting on GWP-fossil, which impedes precise attribution to fossil fuel combustion. However, cases where high total energy consumption coincides with low GWP – as seen in several biogas-fired systems – suggest substantial integration of clean or renewable energy sources. This reinforces the importance of transparent energy source disclosure and module-level granularity in future EPDs to support robust benchmarking.

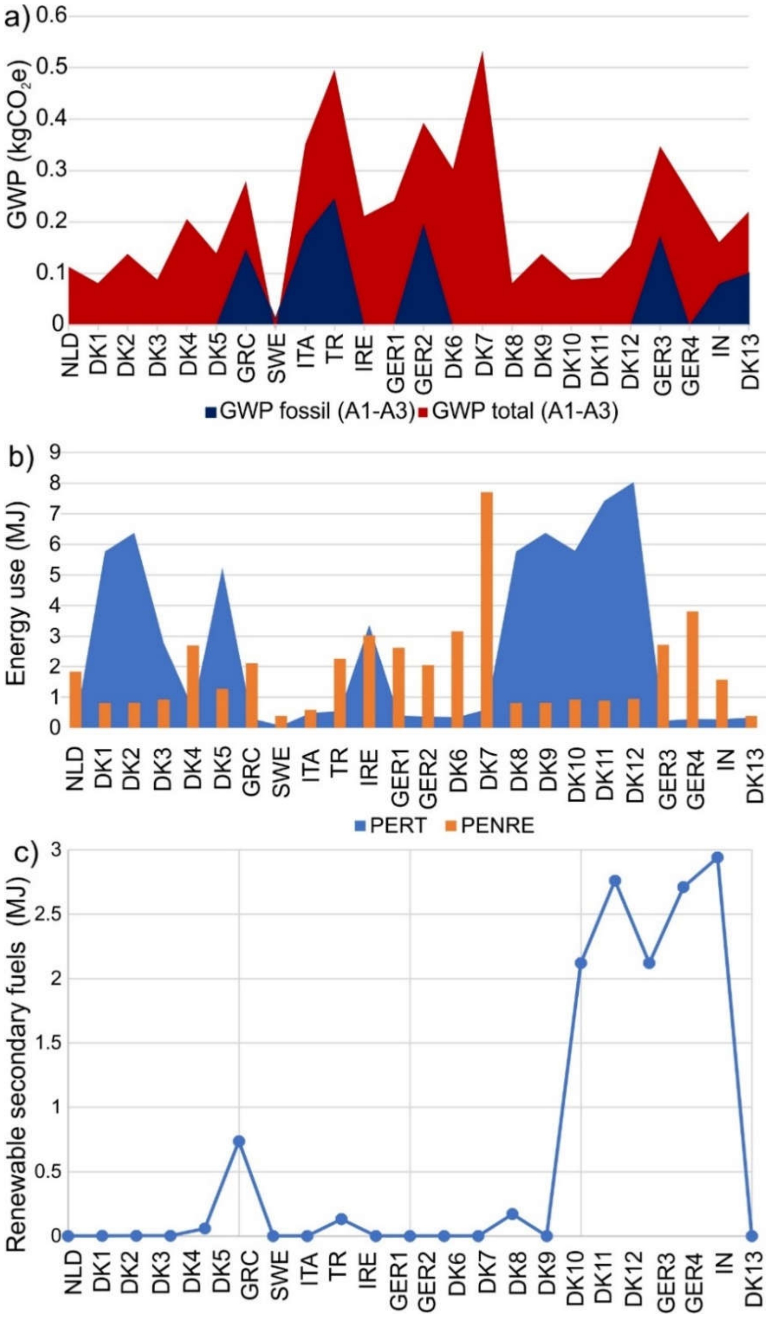

Figure 5. Modules A1- A3 in the production of 1 kg of clay bricks: a) Equivalent CO_2 footprint (GWP fossil not given for most of the cases), b) Renewable primary energy resources as energy (PERT) and non-renewable

primary energy resources (PENRE), and c) Renewable secondary fuels (NLD – Nederland, DK – Denmark, GRC – Greece, SWE – Sweden, ITA – Italy, TR – Turkey, IRE – Ireland, GER – Germany, IN - India).

Renewable primary energy resources (PERT) and non-renewable primary energy resources (PENRE) displayed contrasting patterns in most cases, with industries utilizing high PERT showing low PENRE usage (Figure 5b). However, in certain instances, the levels of energy derived from renewable and non-renewable sources were comparable, as observed in Sweden (SWE), Italy (ITA), Ireland (IRE), and Denmark (DK13). Some industries, particularly in Denmark, have already incorporated substantial renewable energy sources, resulting in significantly lower GWPs. Compared to findings in the literature, where approximately 21.6 MJ was expended per kilogram of clay bricks [33], the current data revealed considerably lower energy consumption. Notably, India (IN), Denmark (DK11), and Germany (GE4) recorded the highest usage of renewable secondary fuels.

3.3. Discussion and Summary

The studied EPDs from the One Click LCA software showed logical and known trends in GWP fossil, GWP total, and total energy use (Figure 6), which once again proves their validity [31,34].

To enable the comparison of EPDs, establishing a standardized platform would be beneficial. Such a comparison would be particularly valuable for analyzing the environmental impacts of industries globally and identifying strategies to mitigate them. Achieving this would require additional data, such as the proportion of organic matter and carbonates in raw material mixtures, and precise information on energy sources used and their quantities. Renewable energy sources (e.g., solar, wind, or hydro) can significantly reduce GWP, even if energy use is high. If the factory uses clean energy, this might explain the relatively low greenhouse gas emissions. Factories with optimized processes, such as advanced heat recovery systems or lean manufacturing practices, might balance high energy use with low carbon emissions. Furthermore, pre-processed raw materials or external suppliers with lower environmental impacts could explain the reduced carbon emissions.

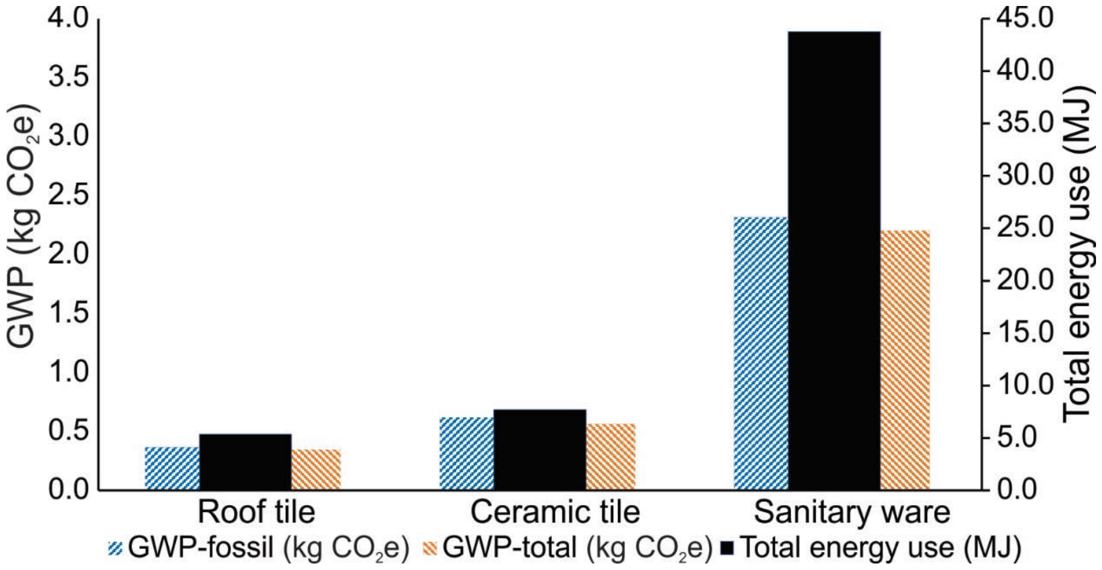

Figure 6. One Click LCA average values in clay roof tile, ceramic tile, and sanitary ware production (GWP – Global Warming Potential).

An approximate benchmark range in the context of EPDs would refer to a reference point or standard used to evaluate and compare the environmental performance of products. Benchmarks are typically derived from aggregated data, industry averages, or best practices and would serve as a guide to assess whether a product performs better, worse, or on par with others in its category. Some data in this regard are already available in the literature, but presenting a wider range and in some unified quantities would be feasible.

Clay roof tiles typically have a GWP of 4.4 t CO_2e per 100 m², depending on the energy source and manufacturing process [37], Table 1. Production energy for clay roof tiles is approximately 52.7 MJ per 100 m² or 2.1 – 2.4 MJ/kg [34], with possible variations based on kiln efficiency [37]. Clay bricks generally have a GWP of 0.07 to 0.34 kg CO_{2e} per 1 kg of brick, influenced by firing temperatures and fuel types [38]. Energy consumption ranges widely from 0.5–5.0 MJ/kg, depending on kiln technology (e.g., tunnel kilns are more efficient than clamp kilns) [31,38–40]. Ceramic tiles have a GWP of approximately 1.0–1.5 kg CO_2e per m², depending on the glazing and firing processes. Energy intensity is around 5–7 MJ/kg, with higher values for glazed tiles due to additional processing [34,41]. Water use can range from 1.0–2.0 m³/t, with significant variations based on the production method [42]. Sanitary ware products typically have a GWP of 1.15–2.6 kg CO_2e per 1 kg, depending on the complexity of the product. Energy consumption is estimated at 8.0-30.6 MJ/kg, with higher values for intricate designs. Water use is around 7.73 l/kg, with opportunities for reduction through closed-loop systems [34,36,43,44]. Sanitary ware exhibits the greatest environmental impact overall due to its complex shapes, multiple firing stages, and higher energy requirements. While literature provides partial benchmarks (Table 1), a broader, unified dataset is needed for robust evaluation.

Table 1. Product-Specific Benchmarks.

Product Type	GWP Range	Product Type	Water Use (m³/t or l/kg)
Clay Roof Tiles	~4.4 t CO_2e/100 m²	2.1–2.4 MJ/kg	—
Clay Bricks	0.07–0.34 kg CO_2e/kg	0.5–5.0 MJ/kg	—
Ceramic Tiles	1.0–1.5 kg CO_2e/m²	5–7 MJ/kg	1.0–2.0 m³/t
Sanitary Ware	1.15–2.6 kg CO_2e/kg	8.0–30.6 MJ/kg	~7.73 l/kg

[1] Tables may have a footer.

5. Conclusions

This study provides a cross-platform assessment of Environmental Product Declarations (EPDs) for ceramic construction products regulated under the Construction Products Regulation (CPR), including sanitary ware, ceramic tiles, clay bricks, and clay roof tiles. By integrating datasets from One Click LCA, the International EPD System, and supporting literature, the research identifies systemic disparities in environmental performance across product categories and reporting infrastructures.

A key contribution lies in quantifying the elevated environmental burdens of sanitary ware and ceramic tiles, driven by energy-intensive, multi-stage production processes. In contrast, clay bricks and roof tiles exhibit lower impacts due to simpler manufacturing routes and reduced thermal energy demand. These findings emphasize the central role of energy sourcing and process design in shaping the carbon footprint of ceramic products.

Beyond product-level insights, the study exposes structural limitations in current EPD practices, including:

- Fragmented reporting formats and insufficient process-level detail,
- Lack of harmonized benchmarks across platforms,
- Limited transparency regarding kiln technologies, firing temperatures, and energy mixes.

To enhance the credibility and market relevance of EPDs, the study recommends:

- Aggregating and normalizing data across multiple declarations to establish representative industry baselines and identify energy-intensive hotspots,
- Developing tailored Product Category Rules (PCRs) that reflect ceramic subtype specificities and enable meaningful benchmarking,
- Advocating for harmonized reporting standards that mandate detailed disclosures of energy sources and process parameters.

These measures are critical for improving cross-platform comparability, accelerating low-carbon innovation, and informing policy frameworks that support sustainable market transitions. As the ceramic industry advances toward carbon neutrality, the decarbonization of thermal processes and integration of renewable energy emerge as strategic levers for impact reduction.

Despite limitations due to restricted access to proprietary process data—often withheld for confidentiality—the study offers a transparent and policy-relevant framework for interpreting EPDs within a fragmented reporting landscape. The ongoing evolution of standards and life cycle databases further underscores the urgency of sector-specific harmonization to bridge the gap between academic research, industrial practice, and policy implementation.

Ultimately, this work contributes to the energy–environment discourse by delivering a data-driven critique of current EPD methodologies and proposing actionable pathways for improving environmental communication, market alignment, and decision-making in the ceramic construction sector.

Author Contributions: Conceptualization, M.V.V. and T.S.Š.; methodology, M.V.V.; formal analysis, M.V.V.; investigation, M.V.V.; resources, M.V.V., T.S.Š. and Z.R.; data curation, M.V.V. and T.S.Š.; writing—original draft preparation, M.V.V. and T.S.Š.; writing—review and editing, M.V.V., T.S.Š. and Z.R; visualization, M.V.V.; supervision, Z.R.; funding acquisition, M.V.V. and Z.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Ministry of Science, Technological Development, and Innovation of the Republic of Serbia, grant number 451-03-136/2025-03/200012. The authors gratefully acknowledge the networking support provided by COST Action CA23157 European Network for Multiple View Life Cycle Sustainability Assessment (MultiViewLCSA). Milica Vidak Vasić funded the Article Processing Charge (APC).

Data Availability Statement: The data are sourced from https://manage.epdhub.com/ and https://environdec.com/home.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Cerame – Unie Activity Report, 2024. Available at https://www.canva.com/design/DAGYPvvCOUI/15sCuf7vYdE7f2FVnlTgdA/view?utm_content=DAGYPvvCOUI&utm_campaign=designshare&utm_medium=link&utm_source=editor#1 (accessed on 12/02/26).
2. Ceramic Roadmap to 2050, 2021. Available at https://www.ceramicroadmap2050.eu/chapters/continuing-our-path-towards-climate-neutrality/ (accessed on 12/02/26).
3. Del Rio DDF, Sovacool BK, Foley AM, Griffiths S, Bazilian M, Kim J, Rooney D (2022) Decarbonizing the ceramics industry: A systematic and critical review of policy options, developments and sociotechnical systems. Renew Sust Energ Rev 157:112081. https://doi.org/10.1016/j.rser.2022.112081
4. Wang R, Lei H, Liu S, Ye X, Jla J, Zhao Z (2021) The redistribution and migration mechanism of nitrogen in the hydrothermal co-carbonization process of sewage sludge and lignocellulosic wastes. Sci Tot Environ 776:145922. https://doi.org/10.1016/j.scitotenv.2021.145922
5. Heat Values of Various Fuels, https://world-nuclear.org/information-library/facts-and-figures/heat-values-of-various-fuels
6. Dolotovskij IV (2022) Energy-efficient vertical kiln for the firing of ceramic, In: Radionov, A.A., Gasiyarov, V.R. (eds) Proceedings of the 7th International Conference on Industrial Engineering (ICIE 2021). ICIE 2021. Lect Notes Mech Eng. https://doi.org/10.1007/978-3-030-85233-7_50
7. Yangin-Gomec C, Dalkılıç K, Perendeci A, Güngörmüşler M, Somorin T, Roussel J, Varol M, Ramos A, van Hullebusch ED, Trubetskaya A, Kazanc F, Vasić M, Akan AP, Ugurlu A, Marchetti J, Balasundararajan V, Kikas T (2025) Thermochemical processing of organic wastes for sustainable valorisation and energy recovery: A review of recent contributions to the field. Biomass Bioenerg 201:108122. https://doi.org/10.1016/j.biombioe.2025.108122.

8. Zhou Y, Qin C. (2017) Energy efficiency evaluation of a shuttle kiln based on field test. Adv Mechan Eng 9(4). https://doi.org/10.1177/1687814017699095
9. Radojević Z, Vasić MV (2023) Negative impacts of petroleum coke as an energy source in the brick-making industry. Build Mater Struct 66:2300010R. https://doi.org/10.5937/GRMK2300010R
10. EPA, Understanding Global Warming Potentials, 2025. https://www.epa.gov/ghgemissions/understanding-global-warming-potentials
11. Del Borghi A, Moreschi L & Gallo M (2020) Communication through ecolabels: how discrepancies between the EU PEF and EPD schemes could affect outcome consistency. Int J Life Cycle Assess 25:905–920. https://doi.org/10.1007/s11367-019-01609-7
12. Del Borghi A (2013) LCA and communication: Environmental Product Declaration. Int J Life Cycle Assess 18:293–295. https://doi.org/10.1007/s11367-012-0513-9Title of Site. Available online: URL (accessed on Day Month Year).
13. Arellano-Vazquez DA, Moreschi L, Del Borghi A, Gallo M, Islas Valverde G, Mayorga Rojas M, Romero-Salazar L, Arteaga-Arcos JC (2020) Use of EPD System for Designing New Building Materials: The Case Study of a Bio-Based Thermal Insulation Panel from the Pineapple Industry By-Product. Sustainability 12:6864. https://doi.org/10.3390/su12176864
14. Carvalho JGRO, Cecchin D, de Azevedo ARG, do Carmo DF, Paes JL, Ferraz PFP, Hamacher LS, Costa KA, Rossi G, Bambi G. (2025) Life cycle assessment (LCA) in construction materials – Review. Agron Res 23(1):293–321. https://doi.org/10.15159/AR.25.041
15. SRPS EN 15804:2020 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products. https://iss.rs/sr_Cyrl/project/show/iss:proj:71094 (Serbian standard).
16. SRPS ISO 14025:2007 Environmental labels and declarations - Type III environmental declarations - Principles and procedures (ISO 14025:2006). (Serbian standard)
17. Bovea M.D., Ibáñez-Forés V., Agustí-Juan I. (2014) Chapter 7: Environmental product declaration (EPD) labelling of construction and building materials. Eds: F. Pacheco-Torgal, L.F. Cabeza, J. Labrincha, A. de Magalhães. Eco-efficient Construction and Building Materials. Woodhead Publishing, Pages 125-150. https://doi.org/10.1533/9780857097729.1.125.
18. Andersen S.C., Larsen H.F., Raffnsøe L, Melvang C (2019) Environmental Product Declarations (EPDs) as a competitive parameter within sustainable buildings and building materials. IOP Conf Ser: Earth Environ Sci 323:012145. https://doi.org/10.1088/1755-1315/323/1/012145
19. Eco Platform, https://www.environdec.com/home
20. Drpić A, Spasojević Šantić T, Radojević Z (2021) Environmental Product Declaration (EPD) for clay roof tiles-case study: Production Plant of Clay Roof Tiles in Republic of Serbia. IOP Conf Ser: Mater Sci Eng 1196:012031. https://doi.org/10.1088/1757-899X/1196/1/012031
21. Martfnez-Rocamora A, Rivera-Gómez C, Galan-Marfn C, Marrero M (2021) Environmental benchmarking of building typologies through BIM-based combinatorial case studies. Autom Constr 132:103980. https://doi.org/10.1016/j.autcon.2021.103980
22. Fnais A, Rezgui Y, Petri I, Beach T, Yeung J, Ghoroghi A, Kubicki S (2022) The application of life cycle assessment in buildings: challenges, and directions for future research. Int J Life Cycle Assess 27:627–654. https://doi.org/10.1007/s11367-022-02058-5
23. Michalak J (2024) Environmental assessment of construction products- challenges, priorities, and needs from producers’ perspective. A Review. Cem Wapno Beton 29(1):16-39. https://doi.org/10.32047/CWB.2024.29.1.2
24. Otero MS, Garnica T, Montilla S, Conde M, Tenorio JA (2023) Analysis of sectoral Environmental Product Declarations as a data source for Life Cycle Assessment, Buildings 13:3032. https://doi.org/10.3390/buildings13123032
25. Olamewaju OI, Enegbuma WI, Donn M, Oyefusi ON (2025) Assessment of environmental product declaration and databases: Towards ensuring data quality assurance practices. Environ Impact Assess Rev 112:107803. https://dol.orgl10.1016/j.elar.2024.107803

26. EN 15804:2012+A2:2019 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products. https://oneclicklca.com/en/resources/articles/en-15804-changes-epds?form=MG0AV3&form=MG0AV3
27. ISO 21930:2017 Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services
28. Konradsen F, Hansen KSH, Ghose A, Pizzol M (2024) Same product, different score: how methodological differences affect EPD results. Int J Life Cycle Assess 29(2):291-307. https://doi.org/10.1007/s11367-023-02246-x
29. Müller A, Harpprecht C, Sacchi R, Maes B, van Sluisveld M, Daioglou V, Šavija B, Steubing B (2024) Decarbonizing the cement industry: Findings from coupling prospective life cycle assessment of clinker with integrated assessment model scenarios. J Clean Prod 450:141884. https://doi.org/10.1016/j.jclepro.2024.141884
30. Gürsan C. and de Gooyert V. (2021) The systemic impact of a transition fuel: Does natural gas help or hinder the energy transition? Renew Sustain Energy Rev 138:110552. https://doi.org/10.1016/j.rser.2020.110552.
31. Vasić MV (2024) Techno-economic analysis in the service of traditional ceramic industry. The first review. Struct Integr Life 24(2):199-205. https://doi.org/10.69644/ivk-2024-02-0199
32. Alves CL, Miiller JOM, de Noni Jr. A, Heinrich S (2025) Challenges and opportunities for increase sustainability and energy efficiency in ceramic tile industry, Int J Appl Ceram Technol: el5097. https://doi.org/10.1111/ijac.15097
33. Manrique R, Vásquez D, Vallejo G, Chejne F, Amell AA, Herrera B (2018) Analysis of barriers to the implementation of energy efficiency actions in the production of ceramics in Colombia. Energy 143:575-584. https://doi.org/10.1016/j.energy.2017.11.023
34. BREF, 2007. EUROPEAN COMMISSION, Reference Document on Best Available Techniques in the Ceramic Manufacturing Industry. Available online at: https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/cer_bref_0807.pdf
35. Bačkalić Z, Vasić MV, Barta Holló B, Jovanović Dj, Sremac S, Awoyera P (2025). From lab to industry: Analysing the performance of ceramic batch modified with sodium silicate and phosphoric acid-based additive in ceramic floor tile production. Next Mater 8:100891. https://doi.org/10.1016/j.nxmate.2025.100891
36. Silvestri L, Forcina A, Silvestri C, Ioppolo G (2020) Life cycle assessment of sanitaryware production: A case study in Italy. J Clean Prod 251:119708. https://doi.org/10.1016/j.jclepro.2019.119708
37. Le A, Whyte A, Biswas WK (2019) Carbon footprint and embodied energy assessment of roof-covering materials. Clean Technol Environ Policy 21:1913–1923. https://doi.org/10.1007/s10098-018-1629-9
38. Olsson JA, Hafez H, Miller SA, Scrivener KL (2025) Greenhouse gas emissions and decarbonization potential of global fired clay brick production. Environ Sci Technol 59:1909−1920. https://doi.org/10.1021/acs.est.4c08994
39. Bureau of Energy Efficiency, 2022. https://beeindia.gov.in/sites/default/files/Brick_sector_Energy_Mapping.pdf?form=MG0AV3&form=MG0AV3
40. Akinshipe O, Kornelius G (2018) Quantification of atmospheric emissions and energy metrics from simulated clamp kiln technology in the clay brick industry. Environ Poll 236:580−590.
41. Ferrari AM, Volpi L, Pini M, Siligardi C, García-Muiña FE, Settembre-Blundo D (2019) Building a sustainability benchmarking framework of ceramic tiles based on Life Cycle Sustainability Assessment (LCSA). Resources 8:11. https://doi.org/10.3390/resources8010011
42. Dalsaniya HA, Bhatt NJ (2024) Water footprint analysis of ceramic tiles industry. Int Adv Res J Sci Eng Technol 11(4).

43. Desole MP, Fedele Gisario A, Barletta M (2024) Life Cycle Assessment (LCA) of ceramic sanitaryware: focus on the production process and analysis of scenario. Int J Environ Sci Technol 21:1649–1670. https://doi.org/10.1007/s13762-023-05074-6

44. Buonomo B, Manca O, Nardini S, Plomitallo RE, Gobio-Thomas L, Stojceska V (2025) Life cycle assessment of implementation of an innovative solar thermal technology in Italian ceramic industry. Therm Sci Eng Prog 61:103517. https://doi.org/10.1016/j.tsep.2025.103517