

Implementing circular economy evaluation of implications related to an innovative waste to resource management scenario

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Abstract

Circular Economy (CE) has the potential to enhance eco-performance and contribute to sustainable development by recovering and valorizing waste and residues. However, a comprehensive methodology to measure CE transition and progress is lacking. This study investigates the implications of CE implementation in the industry, focusing on Spent Bleaching Earth (SBE) residue valorization in brick manufacturing. Life Cycle Assessment (LCA), Circular Indicators, and Economic Advantage compare a CE-oriented strategy with a business-as-usual approach for SBE management. Results suggest that while the environmental benefits of the CE approach may not be immediately clear, it offers significant economic benefits, with annual savings in the thousands of euros. Resource scarcity is also positively influenced, with a 20% reduction in total waste generated. The research Degree Thesis suggests that integrating SBE repurposing in the ceramic industry offers a viable avenue for advancing CE within industrial contexts, providing insights into potential methodologies for implementation.

Keywords: Circular economy; CE implementation; Life Cycle Assessment; Spent Bleaching Earth; Resource Valorization.

Introduction

With global population growth and industrial expansion putting increasing pressure on natural resources and ecosystems, the prevailing linear production model, characterized by the 'take-make-use-dispose' approach, has proven to be problematic in terms of economic, social, and environmental sustainability [1]. In Europe, industries account for over 20% of CO₂ emissions, high water and energy demand, and generate more than half of the continent's waste. Globally, only 8.6% of the resources annually fed into the economy are recycled back into society [2]. The Circular Economy (CE) emerges as a promising solution to mitigate waste generation, enhance resource efficiency, and promote sustainable development [3], [4]. Today, practical implementation of CE requires a framework and indicators for monitoring and reinforcing positive loops [5]. However, a comprehensive methodology for monitoring CE transition and progress is still lacking, and existing analyses often rely on isolated views that overlook the multifaceted nature of the CE paradigm [6], including social impacts [7].

This Degree Thesis preliminarily explores the effects of implementing a CE strategy in a case study within the manufacturing sector in Italy. Spent Bleaching Earth (SBE) is a production residue of vegetable oil refining, containing 20-40 wt% residual oil and presenting significant disposal challenges, including environmental deterioration (e.g., leaching, groundwater pollution), risk of self-ignition, and increasingly stringent policy restrictions. Traditionally considered a nuisance, SBE has been managed as waste, often through costly solvent extraction treatments [8]. Between 2019 and 2021, the company Sfridoo S.r.l. implemented an industrial symbiosis (IS) initiative for alternative SBE management, promoting its reuse as a by-product in brick manufacturing. IS practices are recognized as key strategies to support transition towards CE [9], and in this context, the SBE generate by a waste producer can find valuable applications in the ceramic industry as a pore-forming agent [10], [11].

Methods

The study assessed the implications of the IS practice across three main perspectives characterizing the circular paradigm: environmental impact, resource scarcity, and economic benefit [6]. Environmental performance was evaluated using the Life Cycle Assessment (LCA) methodology [12], focusing on the Global Warming Potential (GWP) impact category to compare two alternative options for the management of 1 ton of SBE (FU) following a CE strategy (CE-S) or a business-as-usual approach (BU-S) (Figure 1).

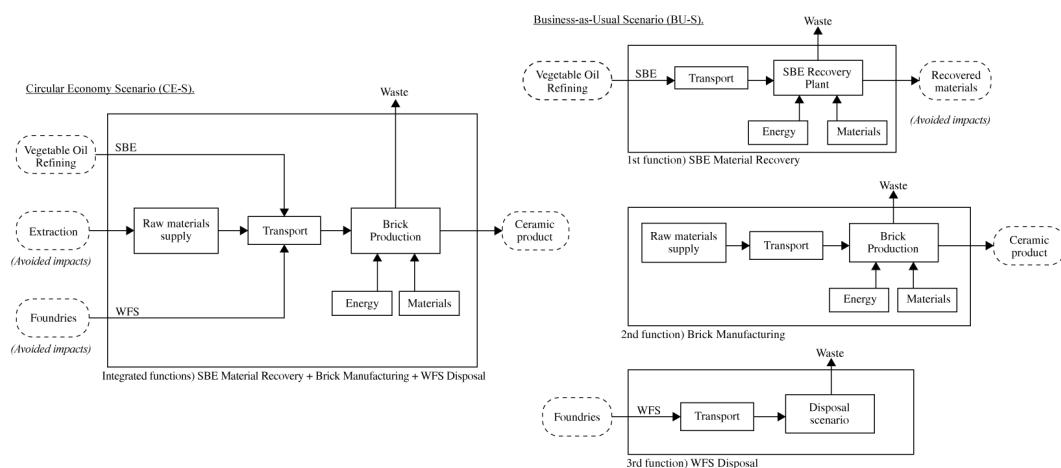


Figure 1. LCA System Boundaries: Comparative Analysis of CE and BU Scenarios for SBE Management

System boundaries were expanded to include all relevant processes and functions [13]. The SimaPro 9.2.0.1 software and Ecoinvent 3.7.1 database licenced to the Dept. of Industrial Chemistry of the University of Bologna have been used to model the system, which has been designed to integrate scientific knowledge, territorial features, market requirements, legal constraints, and industrial stakeholder habits [14]. Avoided impact analysis as well as uncertainty, contribution and sensitivity analysis were also performed

to test model robustness. Simple and understandable Circularity Indicators (C-indicators) were developed based on literature [15], [16], [17] to provide insights into resource scarcity and inform business decisions [18]. These indicators have been categorized into two groups based on the system level they focus on (Table 1). The Economic Advantage was quantified to offer suggestions on the financial implications for the original waste producer. This is defined as the sum of the value generated by selling the residue and the savings related to waste disposal and transportation, reduced by the new cost (if any) from the alternative management strategy. Data acquisition was mainly based on public-available papers and supplemented by primary information from by the companies involved. This has been intended to simplify the LCA labour-intensive procedure given the preliminary investigation scope.

Table 1. Novel C-indicators for evaluating IS performance from a resource perspective.
Author's elaboration based on [15], [16], [17].

Level of analysis	C-indicator	Description
<i>Company level (micro level)</i>	Recycled material procurement (% of input material)	Percentage of Secondary Raw Materials (SRMs) and by-products coming from other industries that are used in the production process of brick manufacturing
	Waste generation capacity (% of intended product)	Express the amount of waste generated per ton of intended product produced by the Oil Refinery
<i>Symbiotic system level (meso level)</i>	Total waste generation (kg/ton of product)	Amount of waste generated by the companies participating in the industrial symbiosis for producing their products
	Extraction intensity (kg/ton of product)	Total amount of mineral resources purchased by companies each year that derive from mining activities

Findings

The IS initiative set by Sfridoo between 2019 and 2021 is a Repurposing activity (R7) where SBE, a discarded product, is used in a distinct production cycle and with a different function [19]. The transition from waste to by-product extends the lifecycle of SBE, allowing it to serve first as an adsorbent in its "virgin state" and then as a pore-forming agent in its "spent state" after use. Additionally, SBE inclusion increased the use of other waste streams used by the brick furnace into the ceramic blend like Waste Foundry Sand (WFS) and displaced other materials like sawdust and tuff. The CE approach also revealed system multifunctionality, with SBE recovery, brick manufacturing, and WFS disposal managed by the same actor. In contrast, the traditional scenario (BU-S) involved three separate entities to deliver the same output.

– Performances of SBE management following different scenarios

The carbon footprint of managing 1 ton of SBE under a CE-S was slightly higher (3%) compared to the traditional approach (5,419 vs. 5,239 kg CO₂ eq. respectively, Figure 2).

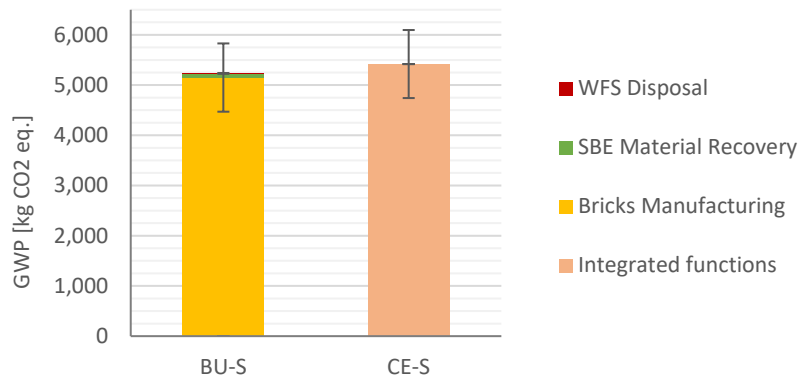


Figure 2. Comparative analysis of functions contribution to the GWP of the scenarios

Despite this, the LCA results do not determine with certainty which scenario is more environmentally advantageous looking at the GWP impact category only. The analysis reveals that avoided impacts, particularly when recovered products displace more impactful goods, can significantly alter this outcome. However, in this case study, the larger emissions associated with the firing step in brick manufacturing, the primary emissions source common to both scenarios, buffered these benefits and potentially overshadowed the variables directly influenced by the CE strategy [20]. Conversely, the economic benefits of SBE conversion from waste-to-resource are significant. Following a CE approach, reclassifying the residue as a by-product reduces management costs of 1 ton to 19.83€, an 83% reduction compared to the initial disposal costs of 116.67€ per ton under the BU-S scenario, with potential annual savings based on the waste producer’s production trends of about 116,200€. Resource scarcity is also positively impacted, as adopting the CE strategy led to a 15% increase in recycled material usage and a 48% reduction in waste from the Refinery, while overall waste generation decreased by nearly 20%, and resource extraction was reduced by 4%.

Discussion/Conclusion

This study assessed the impact of a IS initiative that transforms Spent Bleaching Earth (SBE) from traditional waste into a valuable by-product. The strategy showed strong contributions to two out of three key perspectives of the CE framework—resource scarcity and economic benefit—while presenting trade-offs in the environmental impact. While the environmental advantages were not definitive, the approach resulted in reduced resource extraction and substantial cost savings.

Key findings emphasize the importance of LCA in evaluating CE practices, revealing both potential environmental benefits and drawbacks. The reliance on the GWP indicator alone may not fully capture environmental impacts, highlighting the need for a more holistic and standardized approach. Additionally, reclassifying production residues as by-products instead of waste offers clear economic advantages, such as cost reduction and increased profitability. However, the study has limitations, including the potential

impact of seasonality on data accuracy and the absence of consideration for social impacts, rebound effects, and economic impacts on the waste treatment and brick manufacturing systems.

The results are context-specific and may vary in different settings. The practical implications suggest that SBE management is a crucial resource. Based on earlier estimates [21] and global vegetable oil consumption data from 2019/2020 [22], SBE generation can be estimated between 2.4 and 3.2 million tons per year. This largely unexplored material warrants further investigation within various production cycles, including brick manufacturing, to foster material circularity and minimize waste generation. In conclusion, the research advocates for integrated, interdisciplinary approaches, and standardized methodologies, and further studies to fully assess the environmental, economic, and social implications of IS practices. These steps are essential for CE effective implementation in industrial contexts and to drive a cultural shift from waste-to-resource.

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