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Feasibility study of a reuse scenario for end-of-life tire granules: A case study of Tunisia

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Abstract

The growing accumulation of used vehicles has intensified global concerns regarding unused waste, particularly end-of-life tires. A major challenge in existing recycling practices lies in the contamination of tire granules with residual rubber, which limits their transformation into clean and economically valuable secondary materials. This study addresses this gap by examining an innovative technology designed to convert contaminated granules into a reusable raw material suitable for multiple industrial applications. The research specifically explores the integration of these granules into the production of gym mats as an alternative to their conventional use in artificial turf systems. Life cycle analysis was employed to compare the environmental performance of the proposed process with existing practices. The findings indicate a notable reduction in environmental burdens when granules are repurposed as additives in mat production. To evaluate long-term sustainability, the study also analyzed the financial feasibility of the recycling system through cost-benefit analysis and derived economic performance indicators from the life cycle results. The outcomes demonstrate that the process yields favorable economic returns and supports the long-term viability of the technology. These results suggest that the valorization approach can be effectively replicated in various contexts and scaled with supportive policy measures, offering a pathway toward more sustainable management of tire waste.

Keywords: circular economy; cost-benefit analysis; environmental assessment; recycling technology; tire waste management.

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1. INTRODUCTION

The recycling of used tyres is a major challenge in many developing countries, particularly in Tunisia. The management of ELT is becoming a crucial issue for the protection of the environment and public health as the number of vehicles on the road continues to increase. Focusing on the situation in Tunisia, this research paper examines the specific challenges of scrap tyre recycling in developing countries. In addition, the recycling of used tyres offers significant economic and environmental opportunities that remain largely untapped in developing countries.

However, recent studies have shown that recycling for material recovery yields lower impacts in global warming, particulate matter, and resource use than incineration or energy-recovery pathways (Maga et al., 2023). However, in order to fully exploit these opportunities, effective strategies for the management of scrap tyres need to be put in place (Khan et al., 2024). These strategies should take into account environmental, social, and economic aspects (Han et al., 2024).

LCA, as defined by ISO14040 and 14044, is a quantitative environmental assessment tool that examines the environmental impacts of a product or system throughout its life cycle using a multi-criteria approach. Cost-benefit analysis (CBA) is a process for the evaluation of the economic benefits of a decision in order to determine whether it is feasible. We will extend our LCA and CBA analyses in this article with specific objectives. Firstly, our LCA focuses on assessing the environmental impact of end-of-life tyres as part of the tyre recycling project in Tunisia. Furthermore, the use of recycled tyre-derived materials, such as crumb rubber and recovered carbon black, in new products offers significant value addition and supports circular economic initiatives (Banala et al., 2025). Second, our CBA assesses the social impact of scrap tyres, focusing on the economic performance, financial sustainability, and viability of a Tunisian company's scrap tyre recycling project.

Reviews of tire recycling technologies indicate that mechanical grinding, pyrolysis, and devulcanization have different trade-offs, emphasizing the need for integrated environmental and economic assessments before technology adoption (Laftah & Rahman, 2025). Our study emphasizes the integration of an innovative tire recycling technology as a means of encouraging the adoption of LCA and CBA by Tunisian businesses, especially in a developing country such as Tunisia, where these assessments are not always a priority. This document is structured as follows: The background to the process, the CBA, and the LCA are presented in Section 2. Section 3 presents the results of both analyses, while Section 4 considers the financial feasibility and economic performance of the process. Finally, section 5 presents some conclusions and suggestions.

1.1. Purpose of study

Against this background, our study aims to identify ways to improve the recycling of used tires in Tunisia, using LCA and CBA approaches. The purpose of assessing the environmental and social impacts of a product is the objective of the analyses discussed in this article, LCA and CBA.

2. METHOD AND MATERIALS

2.1. Data collection instrument

The present study used a case study method to collect and analyze data.

2.1.1. Case study context

The process of shredding end-of-life tyres (ELT) takes place in several stages. First, a separator removes the steel wires from the tyre ring. Next, a knife is used to cut the tyres into 30 cm strips. The fragments are then transported to a shredder, where specialized machines first reduce them to a size of 5-8 cm, then to about 2 cm, and finally to less than 1 mm. A sieve is then used to separate the rubber, steel wire, and nylon fibers according to their thickness. The final product, a homogeneous granular material, is measured and stored in large bags. This shredded material has a variety of applications, including infill for artificial turf football pitches (Fig. 1) and gym mats (Fig. 2).

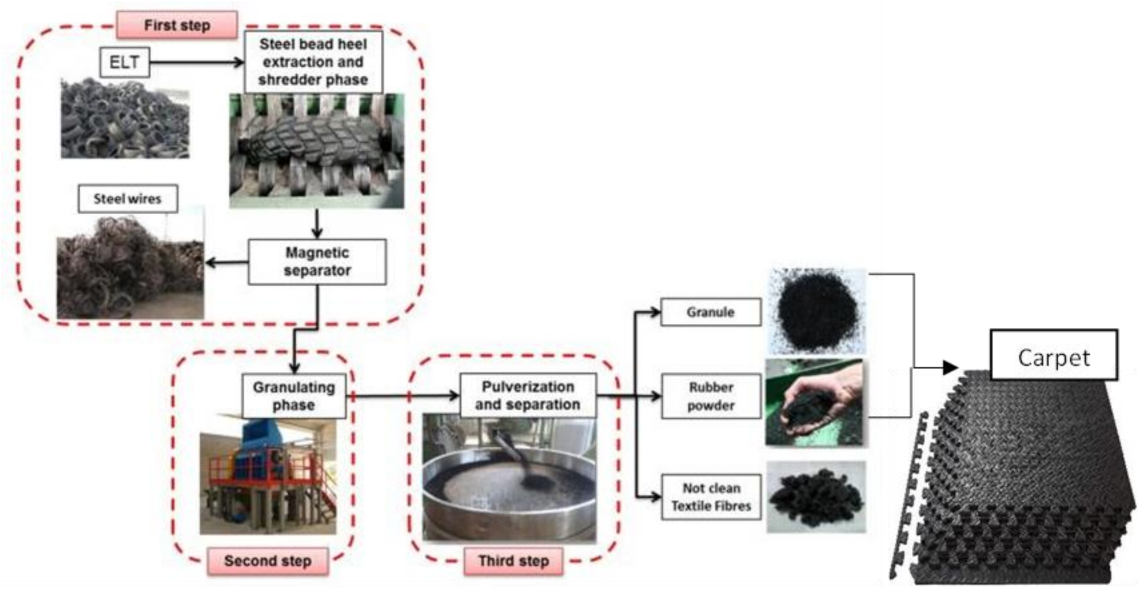
Figure 1

Synthetic turf infill scenario

Source: Brahem Recycling Company

Figure 2

Carpet production scenario



Source: Tunisian Tire Recycling Company

2.2. Cost-benefit analysis: framework

The Carpet CBA, as defined by Kelman (1981) as a simple method for systematically evaluating a production decision, is the second assessment used to assess the viability of the tyre textile fiber treatment and recycling project. The purpose of CBA is to evaluate a project's impact on societal welfare by juxtaposing its ''positive externalities'' (benefits) against its ''negative externalities'' (costs). Key CBA principles entail the quantification of both costs and benefits in monetary terms to facilitate a straightforward comparative analysis, ensuring that the ''Economic Net Present Value'' (ENPV) of benefits surpasses the ENPV of costs, and employing a differential approach by evaluating the project scenario against a baseline scenario without the intervention. Further procedural details are available in the guidelines referenced above. Context description and objective definition are outlined in the introduction and previous section, while the financial and economic analyses are presented in the subsequent sections of this document.

2.3. CBA: methodological choices

Some preliminary methodological choices have been made in order to carry out a CBA: The analysis takes into account a reference period of 25 years to evaluate the ecological and social impacts at the time the program is set up, as well as its results afterwards. A 25-year period is also in line with the European Commission's recommendations on CBA. In its 'Guide to CBA of investment projects', the European Commission (EC) proposes a waste management case study where the ''residual value'' is defined as nil, assuming that at the end of the operational period the machinery and equipment will have reached almost all of its capacity and the commercial value will be nil (Boesch et al., 2014). Countries in economic crisis, such as Tunisia, are heavily indebted and can no longer invest in long-term, high-return projects, and are simply making quick savings, as recommended by foreign lenders, without any real assessment of the domestic economy. Political elites focused on short-term elections are not in favor of medium and long-term projects with deferred returns. Small projects and the short term are favored, while populist and electoral rhetoric does the rest. IMF and World Bank suggest high discount rates for indebted poor countries, up to 15% for countries like the Philippines, Pakistan, and Mali. For Tunisia, the international organizations apply discount rates of 10-12%. However, these developing countries have an increased need for low discount rates to legitimize long-term loans and sustainable public investment in areas such as education, health, infrastructure, and others. At 3% in France, 3.3% in Germany, or 3.5% in the US. Controversies over the precise value of a fair discount rate have resulted in the use of a different rate, 11 %, to discount costs and benefits.

2.4. Life cycle assessment

The LCA is the initial analysis carried out to assess the viability and practicality of the proposed tyre scrap processing and recycling process. Following the standard LCA, this analysis assesses the impacts of all activities associated with the process throughout its life cycle. The results of this analysis first give a good idea of the new treatment process's environmental performance compared to the reference process. They are then used in the LCA to assess the feasibility of the suggested procedure. The first three stages of the LCA analysis are presented in the following subsections : (i) elaboration of the purpose and scope to define the aims and underlying assumptions ; (ii) collection of relevant ''Life Cycle Inventory'' (LCI); and (iii) evaluation of the LCI to measure the impacts. The fifth section deals with the interpretation of the results, which is the final step.

2.4.1. LCA: defining objectives and scope of application

The present research aims to assess and compare the ecological impacts of two ELT scenarios to determine the "best option" based on key parameters. The definition of the functional unit chosen is that of one ton of non-reusable used tyres from the collection point. The analysis takes a "door-to-door" approach, covering all activities related to a given phase of the tyre life cycle, from cleaning to end-of-life, including all stages of transport. Exclusions include (i) secondary processing (such as factory operations), (ii) production of transport vehicles, (iii) transport-related loss and inefficiency, and (iv) production of fiber processing plants and materials. The reason for the last exclusion is that the equipment has a much longer lifetime than that considered for the one-ton functional unit. According to Favi et al. (2016), the impact of mechanical engineering on the overall LCA can be assumed to be minimal, as indicated by other studies on LCA of manufacturing and milling processes.

2.4.2. LCA: life cycle assessment inventory

The main focus of LCA is to break down the entire life cycle into elementary stages. LCA uses input-output analysis to identify input and output flows. There are two main categories of Life Cycle Inventory (LCI) data: primary and secondary. Primary information, measured using equipment parameters, covers the fiber treatment process, pellet production, and transport. Interviews with senior industry executives involved in the different scenarios analyzed provide data on the production of bituminous conglomerates. In addition, a customized electricity generation mix was developed using data from various energy market regulators, and electricity supply and generation were included in the secondary data. The assessment of the ecological impact of the incinerator was based on the principles of the Boesch study (Boesch et al., 2014). The Boesch model covers grate incineration, various flue gas cleaning methods, waste heat recovery for electricity and steam generation, recovery of metals from waste slag and ash, and residue landfill. It should be emphasized that the Boesch model can be adapted to individual installations and locations.

Table 1

Inventory data : synthetic turf

Description	Value
electricity kwh	96.1538
big bag KG	1.98
transport km	120
truck terrain total tkm	108
total sand tone	2.775
Products avoided	
textile fibre in tonnes	0.1
wire in tonnes	0.16
Virgin EPDM in tonnes	0.5
chalk in tonnes	2

Source : Brahem Recycling Company

Table 2

Inventory data : carpet production

Description	Value
Electricity kwh	72.8205
Glue in tonnes kg	0.002266
Products avoided	
textile fibre in tonnes	0.1
wire in tonnes	0.16
virgin polyurethane in kg	1

Source : Tunisian Tyre Recycling Company

2.4.3. LCA: impact of life cycle analysis

Using specific characterization models, "Life Cycle Impact Analysis" (LCIA) defines the environmental impacts from the results of the Life Cycle Inventory (LCI) (Theregowda et al., 2015). The environmental impacts are calculated using the ReCiPe midpoint LCIA method - hierarchical version (H) - Europe (Huijbregts et al., 2017). To account for this, this study uses the intermediate impact categories of human health (HH) and resource quality (RA), and the final damage categories of ecosystem quality (ED), according to the internationally recognized ReCiPe (H) method (Goedkoop et al., 2009). All Kyoto Protocol greenhouse gases are included in the ReCiPe (H) midpoint climate impact category, using global warming potentials from the IPCC Fourth Assessment Report with a 100-year time horizon (IPCC, 2007).

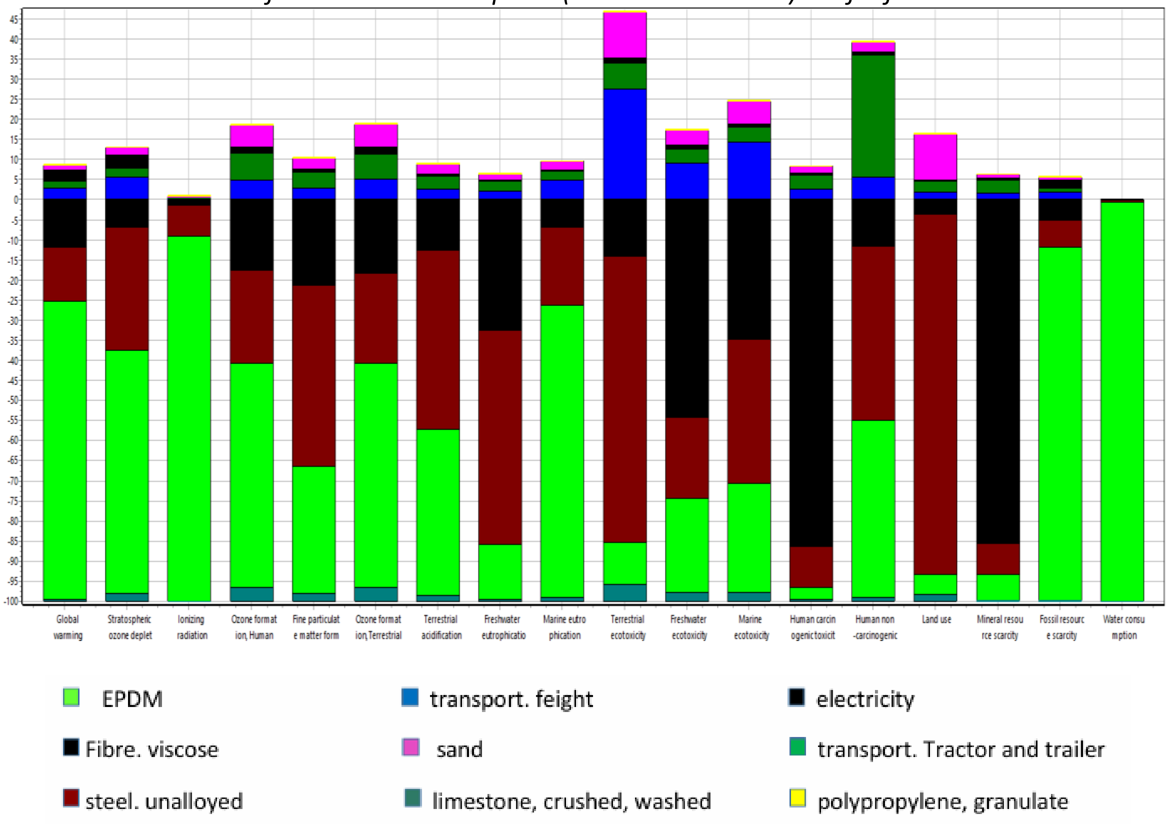
3. RESULTS

3.1. LCA: Life cycle interpretation

A comparison between the two scenarios considered (Figures 5 and 6) reveals that the carpet production scenario is more ecologically viable according to several "Impact Categories", in particular for the two "Impact Categories": AP and GWP. If only the other two impact categories (ionizing radiation and water consumption) are considered, an improvement in the ecological impact is noted. However, according to the CBA methodology, GWP and AP are the Impact Categories to be used in the financial and economic analysis. The results indicate that significant savings can be made by choosing a closed-cycle ELT grain when the GWP impact category is considered. The total impact is reduced from 2236.6015 kg CO2eq in the grass filling scenario to 5825.2287 kg CO2eq in the carpet manufacturing scenario. For the lawn filling scenario (Fig. 3), the negative effects are only partly offset by the ecological advantages of avoiding the use of EPDM for the lawn filling (system extension model). For the carpet manufacturing scenario, the overall effect depends mainly on the granulate production. The glue used in the production of pneumatic mats and the energy consumption of the equipment are the main contributors to the GWP of the reuse scenario. From the findings for the AP effect category (Fig. 4), the same considerations can be roughly derived. The difference between the two scenarios is less (5.0603394 kg SO2eq compared to 21.248249 kg SO2eq), and the implementation of the carpet manufacturing scenario has a lower environmental impact.

Figure 3

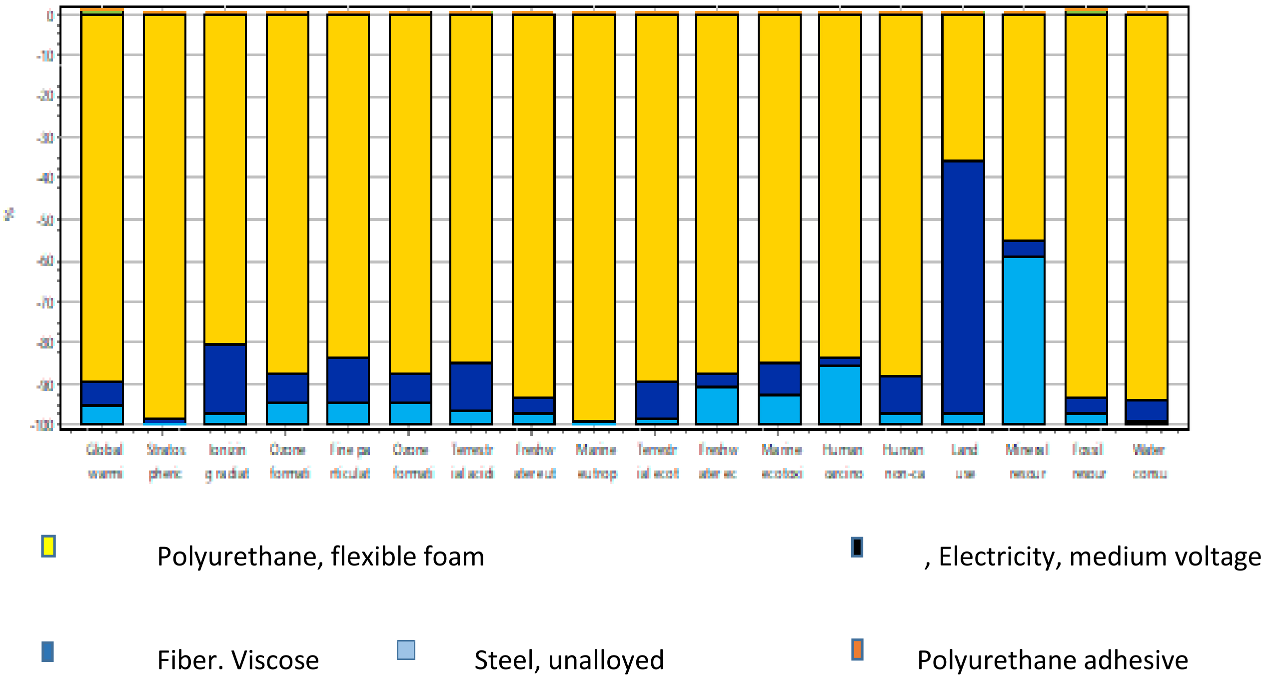
Characterization of environmental impacts (CML 2001 method): turf infill scenario



Source: By Simapro

Figure 4

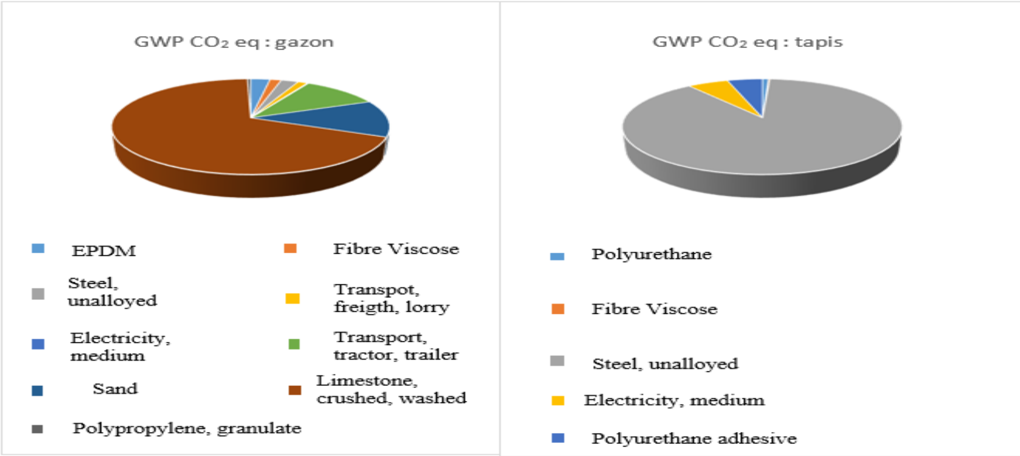
Characterization of environmental impacts (CML 2001 method): carpet production scenario



Source: By Simapro

Figure 5

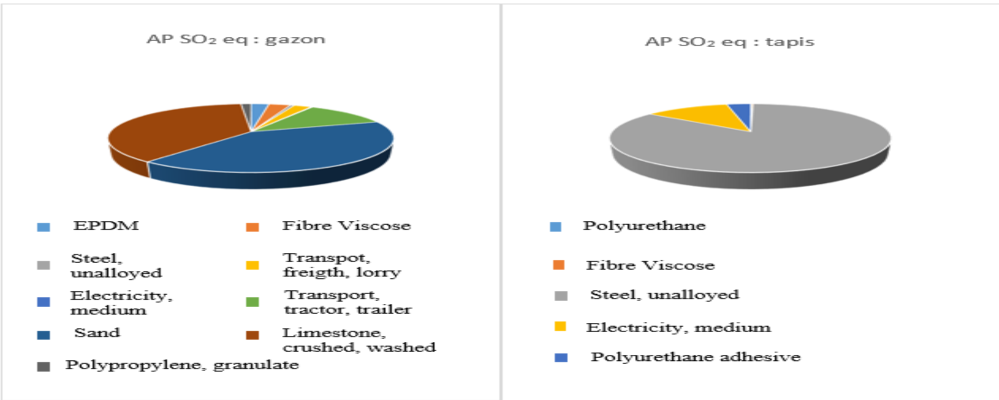
Detailed comparison of grass infill and carpet production scenarios in terms of GWP



Source: By Simapro

Figure 6

Detailed comparison of the grass infill and carpet production scenarios in terms of AP



Source: By Simapro

3.2.CBA: Financial analysis

Figure 7

Costs and benefits of tire shredding and transport

Activity : tire shredding		
Machinery (initial investment)	92381.5 € + 323335.25 €	Cost
Building	negligible	Cost
Energy : machine consumption	120 kW/h	Cost
Personnel	1.14 €/h	Cost
Pellets (granules)	156 tonnes / month	Cost
Big bags	30 € each (capacity : 2.8 m^3 one large bag contains 1 tonne of granules)	Cost
Activity : transport		
Load capacity (articulated truck)	3.5 tonnes	Cost
Number of journeys	8/ month	Cost
Cost of a journey	90 €	Cost
textile fiber sales	31.2 tonne/ month (150 € / tonne)	benefit

Source: Brahem Recycling Company

Figure 8

Costs and benefits of carpet production

Activity : carpet production		
Machinery (initial investment	73904 €	Cost
Building	Negligible	Cost
Energy	22720 Kw/month	Cost
Personnel	9h/jour (225 €/month)	Cost
Maintenance	Negligible	Cost
Saving (thanks to lower grain aquisition costs)	5076.8 €	Benefit

Source: Tunisian Tire Recycling Company

Figure 9

Costs and benefits of grain application in synthetic turf

Activity : application of grains in artificial turf		
Machinery (initial investment)	40000 € + 19765.2 €	Cost
Building	Negligible	Cost
Energy	15km/h	Cost
Personnel	8h/jour (12 €/day)	Cost
Maintenance	Negligible	Cost
Savings (thanks to lower grain acquisition costs)	700 € / tonne	benefit

Source: Green Ars Company

The tables captured in figures 7, 8, and 9 summarize the costs and revenues associated with the processes treated. Turkey purchased 31.2 tons of recovered textile fibers, saving €168,295.92. In addition, 13.5 tons of synthetic turf cost €9,450. The buildings in Monastir (1,000 m²) and Sousse (3,000 m²) are already owned, with a zero-opportunity cost. ELT grains are replacing EPDM (€300/t as opposed to €1,000/t) and polyurethane (€300/t as opposed to €5,376.8/t), resulting in cost savings. Every day, 85 mats and 33 tons of tiles are produced to equip playrooms and sports halls. Revenue from carpet sales is not included in the analysis. Construction costs are negligible (only one 8 m² shredder), and maintenance is superfluous. Equipment to be replaced includes shredders (10-year lifespan, years 10 and 20) and carpet machines (15-year lifespan, year 15, zero residual value). The new machines are expected to reduce energy consumption by 10%, in line with Tunisia's target for 2023. Energy costs remain constant, in line with European directives that favor real rather than nominal prices.

3.3.CBA: Economic analysis

The estimation of the economic costs is based on the financial costs of the project. The CBA is inherently subject to assumptions and discretion, as it involves the monetization of intangible elements. Nevertheless, the consideration of these elements is essential in order to examine the benefits of the project (Wang et al., 2015). The economic and environmental benefits presented in Table 6 have been monetized in the economic analysis. When analyzing the production scenario for gym mats, a cost reduction equivalent to the difference between the market cost of 'ELT-based pellets' and the cost of natural polyurethane is observed. The environmental performance was measured by several indicators in the LCA analysis. However, for the economic analysis, only the ecological indicators for which an economic assessment had been carried out by the EC were taken into account. The avoided production of polyurethane in terms of GWP is approximately 5.8252287 tons of CO2eq per year, according to the LCA. The avoided acidification potential (AP) of the ELT fibers is 0.0212 tons of SO2 per year. The damage caused by SO2 per ton of emissions in 2023 is €730 (Peace et al., 2005). ''Given that future emissions are generally expected to have a greater impact than current emissions'' (Boesch et al., 2014), this figure may underestimate the cost of SO2 emissions. However, this is the latest estimation that comes from an official EC survey. In Greater Tunis, waste management is seen as an economic resource through the formalization and creation of composting and recycling channels, and the introduction of financial mechanisms to support private investment in recycling projects and composting units. This investment is viable: the ENPV is $29.1 million, the IRR is 27% and the benefit-cost ratio is 2.5 (Sherif and Fadi, 2014).

4. DISCUSSION

Financial viability is an essential condition for the feasibility of any project, particularly in the Tunisian context, where economic resources are often limited. A project achieves financial viability when there is no anticipated risk of a funding shortfall during the investment and operation phases. Projects in Tunisia frequently face specific economic challenges, including financial market volatility and budgetary limitations. Financial viability is assessed by analyzing input-output dynamics while taking into account the local economic environment. This study revealed a positive cash flow throughout the reference period, an essential factor in ensuring the continuity of the project. In theory, maintaining a positive cash flow - or at least zero - over the reference period is essential to ensure sustainable financial stability and effective planning. This is particularly relevant in Tunisia, where prudent management of financial resources can have a significant impact on project success. To transition from a financial analysis to an economic analysis, benefits and costs must be monetized, meaning they need to be estimated in monetary terms to calculate economic performance indicators.

Figure 9

Monetizing project benefits

A) Reducing resource costs	Value
A_1) Economic value of recovered material	4680 €
A_2) Avoided cost of carpet production	168295.92 €
A_3) Avoided costs for artificial turf infill	9450 €
B) Avoided environmental externalities	**Value**
B_1) CO_2e emissions avoided by reusing ELT grains instead of polyurethane	524.2705 €
B_2) CO_2e emissions avoided by reusing ELT grains instead of EPDM	201.2941 €
B_3) SO_2 emissions avoided by reusing ELT grains instead of polyurethane	15.5112 €
B_4) SO_2 emissions avoided by reusing ELT grains instead of EPDM	3.694 €

In terms of annual economic benefits, the main contributions are as follows Recovery of textile fibers from ELT screenings, contributing €4 680; Avoided cost of carpet production, contributing €168295.92; Avoided cost of artificial turf infill: €9450; Avoided CO2eq and SO2eq emissions for the carpet production scenario (respectively 5.8252 tons CO2eq and 0.0212 tons SO2eq calculated with the LCA study), contributing €524,2705 and €15,5112 respectively in 2023 and increasing each year. Similarly, the avoided CO2eq and SO2eq emissions for the Refueling scenario (2.2366 t CO2eq and 0.005 t SO2eq, respectively, calculated with the LCA study) contribute €201.2941 and €3.694 in 2023 and increase each year. Avoided CO2eq and SO2eq emissions for the carpet production scenario (respectively 5.8252 tons CO2eq and 0.0212 tons SO2eq calculated with the LCA study), contributing €524,2705 and €15,5112, respectively, in 2023 and increasing each year. Similarly, the avoided CO2eq and SO2eq emissions for the Refueling scenario (2.2366 t CO2eq and 0.005 t SO2eq, respectively, calculated with the LCA study) contribute €201.2941 and €3.694 in 2023 and increase each year.

Table 3

Economic performance indicators

Discount Rate (%)	ENPV (€)	Ratio B/C (dimensionless)	TRE (%)
11	1007424.43	2.98	35.4

Where,

$$ENPV = PV(B) - PV(C) \qquad (1)$$

$$\mathrm{ENPV} = B0 - C0 + \frac{B1-C1}{1+i} + \frac{B2-C2}{(1+i)2} + \cdots + \frac{Bt-Ct}{(1+i)t} = 0 \qquad (2)$$

$$B/C = PV(B)/PV(C) \qquad (3)$$

As explained in Section 2.3, a discount rate of 11% was used for the analyses. Table 7 presents the results in terms of ''Economic Net Present Value'' (ENPV), ''Benefit Cost Ratio'' (B/C), and ''Economic Rate of Return'' (ERR) obtained. The ENPV is commonly used as a stand-alone indicator to assess the benefits and costs of a project. The basic rule is to accept any process with an ENPV greater than zero, as it indicates economic viability. In this article, the calculated value is positive over the observation period (ENPV = 1007424.43 €). Furthermore, the results of the B/C ratio prove that for both scenarios, every €1.00 of costs corresponds to more than €2.98 of benefits, which reinforces the feasibility of the project. Another important ''economic indicator'' is the ERR, which in this research is 35.4%. The ERR is typically used to assess the profitability of a project by comparing it with the discount rate (DR). The project should be funded if the ERR is equal to or greater than the DR. Here, the value obtained is considerably higher than the chosen discount rate (35.4% > 11%), providing further evidence of the economic viability of the project. Although the use of ERR remains controversial and some researchers advise caution in its application (Kelleher and MacCormack, 2004), these results strongly support the economic viability of this project.

5. CONCLUSION

End-of-life tires are one of the main sources of waste in the end-of-life vehicle sector. In this context, an LCA method was used to study the environmental impacts of recycling scrap tires. The results indicate a reduction in environmental impacts, specifically in Global Warming Potential (GWP) and Acidification Potential (AP), when ELT granulate is repurposed as a secondary raw material for sports hall mat production, as opposed to its use as infill for artificial turf on sports fields.

The CBA demonstrated the project's financial viability over the medium and long term, with high economic profitability (ENPV: €1007424.43; B/C ratio: 2.98), thereby justifying potential support from the Tunisian government. Key economic benefits include the valorization of textile fibers and cost savings from the substitution of EPDM and polyurethane. The proposed treatment and reuse process for ELTs exemplifies the effective application of CE principles.

Conflict of Interest: The authors have no competing interests to declare that are relevant to the content of this article.

Ethical Approval: The study adheres to the ethical guidelines for conducting research.

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