Circular business model for the reuse of industrial oils and ecological cleaning in SMEs: feasibility study and sustainable entrepreneurship

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Abstract*– The growing demand for industrial maintenance in small and medium-sized enterprises (SMEs) generates significant amounts of hazardous waste, including used hydraulic oils and chemical degreasers, which are often discarded without reuse or recovery strategies. This study evaluates the technical, economic, and environmental feasibility of a circular business model for the reuse of industrial oils through dialysis and the substitution of conventional degreasers with ecological reusable products in SMEs. The methodology comprises four phases: diagnosis of the current state, technical-operational viability analysis, economic-financial viability analysis, and circular business model proposal. The results show that oil dialysis extends the useful life of hydraulic oil by 60% to 75%, reducing new oil consumption by 37.5% to 43.3% and generating net annual savings of $4,754 for two equipment, plus $1,900 in degreasers, totaling $7,441.5 annually. Environmentally, the model reduces hazardous waste generation by more than 50%. It is concluded that the circular business model is technically, economically, and environmentally viable, replicable in other SMEs in the region, and contributes to the development of sustainable entrepreneurship ecosystems.

Keywords*-- Circular economy, SMEs, Hydraulic oil dialysis, Ecological degreasers, Sustainable business model.

I. Introduction

The traditional linear economic model based on "take, make, dispose" has generated unsustainable pressure on natural resources, increasing waste generation and greenhouse gas emissions. In this context, the circular economy emerges as a regenerative paradigm that seeks to minimize resource input and waste generation through the design of products and processes that keep materials in use for as long as possible [1]. This approach is founded on principles such as redesign, reuse, recycling, remanufacturing, and extending product life through maintenance, with the aim of increasing the added value of goods through different circular configurations [2].

In the industrial sphere, maintenance plays a strategic role in the transition towards circular models. Repair, refurbishment, and maintenance activities have been identified as key sectors for the circular economy due to their economic and social importance. The integration of preventive maintenance with management tools such as 5S and standardization can significantly reduce waste in manufacturing processes by improving efficiency and minimizing unnecessary material use [3]. Complementarily, waste management programs in companies often include preventive maintenance as a measure to minimize waste generation, maximize reuse and recycling, and reduce environmental waste disposal [4].

However, small and medium-sized enterprises (SMEs) face specific barriers to adopting circular economy practices in their maintenance operations. The lack of understanding of the benefits of circularity, structural financing limitations, and value chain imbalances prevent companies from capturing the returns from circular initiatives [5]. In the industrial maintenance sector, used hydraulic oil and conventional chemical degreasers represent two significant sources of waste that can be addressed through circular strategies but are currently underutilized.

Preventive maintenance, while essential to ensure equipment availability, involves repairing, replacing, and maintaining components, generating waste such as replaced parts, used lubricants, and other materials that can no longer be used after maintenance tasks [6]. Additionally, the process of scrapping old machines as part of condition-based preventive maintenance is a direct source of waste generation in industrial environments [7]. This situation shows that the scrapping of old machines and the lack of strategies for reusing fluids and components represent a missed opportunity for circularity [8].

Previous research has addressed the relationship between maintenance and the circular economy from various perspectives. A mathematical model of optimal control policy for preventive maintenance with inventory, maintenance, and backlog costs has been developed, demonstrating that there are cases where the optimal policy is dominated by the effect of hedging points or switching points, providing suggestions for operational decision-making [6]. In the field of waste management, it has been demonstrated that the Lean Six Sigma approach allows managing the waste generation rate and improving throughput rate through waste reduction [7]. Furthermore, a model has been presented that combines tools such as SLP, 5S, method standardization, and preventive maintenance for waste reduction in non-metallic mineral manufacturing, achieving a 58.8% reduction in material waste and demonstrating that preventive maintenance reduces machine stops and waste [3]. Likewise, the integrated optimization problem of condition-based preventive maintenance and production rescheduling with old machine scrap has been addressed, demonstrating the superiority of its approach compared to other maintenance policies and rescheduling strategies [8].

In the field of hydraulic system cleaning, an adaptive intelligent turbulent flushing system based on Reynolds number and the viscosity-temperature characteristics of the flushing solvent has been developed, demonstrating that the system can stably control the cleanliness of hydraulic components through adaptive adjustment of the turbulent flow state of the flushing solvent [4]. Similarly, the operation of the oil supply system of steam turbines before and after maintenance has been analyzed, showing that filter modernization reduced solid particles in the oil by 5.8 times, and that the purified oil achieved purity class six to seven according to GOST 17216-2001 [9]. An optimized flushing method for the lubricating oil system of a 1000 MW unit in China has also been presented, demonstrating that flushing optimization provides a good guarantee for the safe and reliable operation of the unit and generates good economic benefits [10]. Additionally, a new technology has been developed for cleaning diesel engine lubrication systems using used motor oil without draining it from the engine crankcase, demonstrating that the introduction of ammonium hydroxide into used engine oil allows the removal of almost all types of contaminants and increases the service life of freshly refilled oil [11]. The effects of contamination of biobased hydraulic fluids with mineral oil have been analyzed, finding that the degree of deterioration correlates not with the amount of mineral oil added, but with the amount of metals introduced through the mineral oil's additives, and changes in quality control, product documentation, and standardization have been recommended [12].

In the field of circular economy applied to hydraulic components, the importance of recycling and reusing components in hydraulic drive equipment has been analyzed, noting that in this field the importance of recycling and reuse has occupied a significant place, making it much easier to successfully apply the principles of the circular economy and reduce raw material consumption and pressure on existing resources [13]. Likewise, the enablers of the circular economy in manufacturing organizations have been analyzed, identifying awareness of the circular economy, technological knowledge, legislative and consumer demand, and managerial readiness to develop products or brands that utilize the circular economy as key enablers [14]. The potential of integrating circular economy principles into facility maintenance and management towards sustainable development has also been explored, demonstrating that the circular economy offers a valuable framework for creating a sustainable, low-carbon future in facility management [15]. Research in the Basque Country on SMEs in the machinery and equipment sector identified ecodesign, eco-innovation, and resource recovery as key elements in their business models, demonstrating how the circular economy improves competitiveness by creating new business lines, reducing costs, and optimizing processes [5].

More recently, the state of the art in obsolescence management during the crucial maintenance phase and in the context of circular economy principles has been explored, identifying strategies that include traditional replacement methods, remanufacturing, and system complexity reduction, demonstrating their effectiveness in extending asset lifespans and optimizing maintenance practices [16]. Research has also been conducted on how historical failure and maintenance records can be used to estimate future failures and prescribe advances in scheduled preventive interventions, achieving average savings between 17% and 24% in maintenance costs [17]. Fifty-one cases of AI-enhanced digital twins in maintenance have been analyzed, identifying studies dedicated to opportunistic preventive maintenance designed to minimize penalties for production interruptions through efficient scheduling [18]. A detailed taxonomy of energy system maintenance has been presented, dividing preventive maintenance into routine (calendar-based), risk-based, and usage-based [19]. Likewise, a prescriptive analytics framework has been proposed to optimize intelligent preventive maintenance strategies in railway infrastructure using graph convolutional networks [20], and a digital twin framework has been proposed for smart tunnel maintenance, enabling a transition from manual scheduling to an effective preventive maintenance system based on 3D real data analysis [21].

Despite these advances, a knowledge gap is identified in the integration of a circular business model specifically oriented to SMEs that combines the reuse of industrial oils through dialysis processes and the substitution of conventional degreasers with ecological products. This gap is particularly relevant in the Latin American context, where SMEs face structural barriers to the adoption of circular practices [5].

The main motivation for this research arises from the need to provide SMEs in the industrial sector with a practical and economically viable tool for the implementation of circular economy practices in their maintenance operations. The high volume of used industrial oils and chemical degreasers generated by maintenance activities represents a significant opportunity for reuse and waste reduction, generating economic and environmental benefits for companies.

The novelty of this research lies in the integration of a circular business model that combines: (i) the reuse of industrial oils through a dialysis process that allows purification and restoration of the oil to its usable state, extending its useful life and reducing the purchase of new oil; (ii) the substitution of conventional chemical degreasers with biodegradable ecological products, reducing the environmental impact of cleaning processes; (iii) a scalable and replicable business model for SMEs, based on circular maintenance as a service (Maintenance-as-a-Service); and (iv) a regional approach that contextualizes the results in the Latin American context, generating a replicable model for other SMEs in the region.

The purpose of this study is to determine the technical, economic, and environmental feasibility of implementing a circular business model for the reuse of industrial oils and ecological cleaning in industrial sector SMEs, as well as to

identify the barriers and opportunities for its adoption in the Latin American context.

The contribution of this research is threefold. At the theoretical level, it contributes to the existing body of knowledge on circular economy applied to maintenance in SMEs, integrating concepts of oil dialysis, ecological cleaning, and circular business models. At the practical level, it offers SMEs a viable and replicable business model for implementing circular practices in their maintenance operations, generating economic savings and environmental benefits. Finally, at the regional level, it generates a replicable model for other SMEs in the region, contributing to the development of sustainable entrepreneurship ecosystems and strengthening local capacities in the circular economy.

The article is structured in five sections. Following this introduction, Section 2 presents the methodology employed for the development of the business model. Section 3 presents the results of the feasibility study. Section 4 discusses the findings. Finally, Section 5 presents the conclusions and recommendations of the study.

II. METHODOLOGY

The methodology for the development of the circular business model is structured in four phases, ensuring a systematic, reproducible approach oriented towards value generation for SMEs. The workflow is illustrated in Fig. 1.

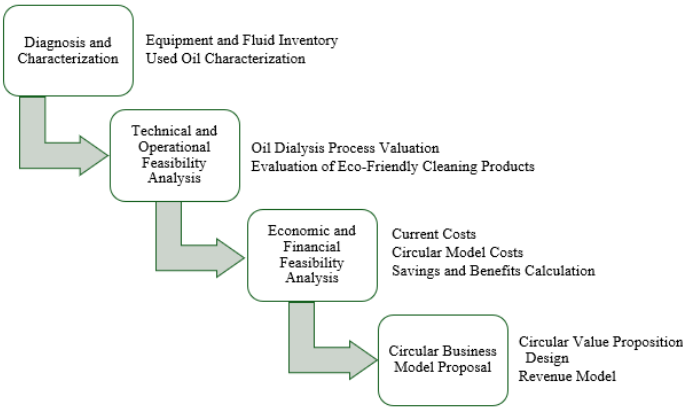


Fig. 1. Proposed methodology for the circular business model in SMEs.

2.1. Diagnosis and Characterization of the Current State

The first phase consists of gathering baseline information on the SME's hydraulic and lubrication systems, as well as current cleaning and maintenance processes. This phase is based on identifying points in the product life cycle where value is reduced or destroyed, allowing the diagnosis of opportunities for circular improvement.

Inventory of equipment and fluids: A detailed inventory is conducted of all equipment using hydraulic oil or lubricants, including:

- Type of equipment (presses, elevators, hydraulic systems, compressors, etc.)
- Oil tank capacity (gallons)
- Type and specification of oil used
- Oil change frequency (operating hours or time)
- Annual volume of used oil generated
- Current cost of purchasing new oil and disposing of used oil

Characterization of used oil: Oil samples are taken at the critical change point (approximately at 2,000 operating hours) for laboratory analysis, determining:

- Solid particle contamination level (ISO 4406 standard)
- Water content
- Viscosity
- Acidity level (neutralization number)
- Presence of wear metals

Characterization of current cleaning processes: The products and methods currently used for component cleaning are identified:

- Type of degreaser used (conventional chemical or ecological)
- Monthly consumption volume
- Product cost
- Waste disposal method
- Estimated environmental impact

Material and waste flow mapping: A flow diagram is developed representing the current cycle of oils and cleaning products, identifying:

- Material inputs (new oil, degreasers)
- Outputs (used oil, cleaning waste)
- Losses and waste in the process
- Opportunities for closing cycles

2.2. Technical and Operational Viability Analysis

The second phase evaluates the technical feasibility of implementing the oil dialysis process and substituting degreasers with ecological products, based on the principles of the circular economy that seek to keep products and materials in use for as long as possible.

Evaluation of the oil dialysis process: The oil dialysis process is based on the principle of purification through filtration and contaminant separation. The following aspects are evaluated:

- Available technology: Mobile or fixed dialysis equipment, with processing capacity according to the SME's demand (e.g., 50-200 gallons/day).
- Operating parameters: Heating temperature (60-80°C), vacuum pressure (approximately 27" Hg), processing flow rate.
- Quality criteria: ISO 4406 cleanliness level $\leq$ 18/16/13, water content $\leq$ 100 ppm, viscosity within the specified range.
- Processing capacity: Volume of oil that can be treated per cycle and per day.

- Infrastructure requirements: Space, electrical connections, storage system for treated oil and contaminants.

Evaluation of ecological cleaning products: A comparative evaluation of biodegradable industrial degreasers available on the market is conducted, considering criteria such as:

- Cleaning effectiveness (ability to remove grease, oil, and dirt)
- Biodegradability (mineralization ≥ 60% of the product)
- Absence of aggressive solvents and volatile organic compounds (VOCs)
- Safety for the operator and surfaces
- Cost per gallon
- Availability and supply logistics

Operational process design: A standardized procedure is established for:

- Oil dialysis: Equipment connection, heating, vacuum application, filtration, recirculation, and parameter monitoring.
- Ecological cleaning: Preparation, application of ecological degreaser, dwell time, removal, drying, and safe waste disposal.

Identification of technical barriers: Technical barriers to implementation are identified and documented:

- Existing infrastructure limitations
- Need for staff training
- Equipment and fluid compatibility
- Dialysis equipment maintenance requirements

2.3. Economic and Financial Viability Analysis

The third phase evaluates the economic viability of the circular business model, considering current and projected costs as well as expected benefits.

Estimation of current costs (Linear Scenario): Current costs associated with maintenance and cleaning are calculated:

- Annual cost of purchasing new oil
- Annual cost of disposing of used oil as hazardous waste
- Annual cost of conventional degreasers
- Annual labor cost for oil changes and cleaning
- Cost of machine downtime for corrective maintenance
- Waste treatment and regulatory compliance costs

Estimation of costs for the circular model (Proposed Scenario): Costs for the new model are projected:

- Investment in dialysis equipment (or cost of the dialysis service)
- Dialysis equipment operating cost (energy, filters, maintenance)
- Cost of ecological degreasers
- Labor cost for the dialysis process and ecological cleaning
- Laboratory analysis cost (sampling and certification)
- Staff training cost

Calculation of savings and benefits: Savings and benefits of the circular model are calculated:

- Savings from reduced new oil purchases: Dialyzed oil is reused, reducing new oil purchases by an estimated percentage (70-80%).
- Savings from reduced disposal costs: Used oil is reused, reducing disposal costs as hazardous waste.
- Savings from extended equipment lifespan: Clean oil reduces component wear, extending the lifespan of pumps, valves, and cylinders.
- Environmental benefit: Reduction of hazardous waste and CO_2 emissions.
- Image benefit: Positioning the SME as a sustainable company.

Financial indicators: The following indicators are calculated to evaluate economic viability:

- Net Present Value (NPV): Sum of discounted cash flows minus initial investment.
- Internal Rate of Return (IRR): Discount rate that makes NPV equal to zero.
- Payback Period: Time required to recover the initial investment.
- Equivalent Annual Cost (EAC): Annualized cost of the project.

2.4. Circular Business Model Proposal

The fourth phase consists of designing a scalable and replicable business model to offer the circular maintenance service to SMEs, based on circular economy principles that emphasize design for longevity, repairability, and recyclability.

Design of the circular value proposition: The value proposition of the circular business model is defined:

- In situ oil dialysis service: Purification of hydraulic and lubricating oil at the SME's facilities, extending its lifespan and reducing new oil purchases.
- Supply of ecological degreasers: Substitution of conventional chemical products with biodegradable and safe alternatives.
- Waste management: Reduction of hazardous waste and regulatory compliance.
- Training and advisory: Training maintenance personnel in circular practices.

Revenue model: A pay-per-use or annual contract model is proposed with the following components:

- Fee per gallon of processed oil: Cost per gallon of dialyzed oil.
- Fee per operating hour: Cost per hour of dialysis equipment use.
- Fee for laboratory analysis: Cost of sampling and oil quality certification.
- Fee for ecological degreaser supply: Cost per gallon of product.
- Membership or annual contract fee: Access to priority services and discounts.

Service cost structure: Operating costs of the business model are defined:

- Cost of acquiring and maintaining dialysis equipment
- Cost of inputs (filters, energy, ecological products)
- Cost of specialized technical personnel
- Logistics and travel costs
- Laboratory analysis cost
- Administrative and marketing costs

Target customer segments: SME segments with the greatest potential are identified:

- Metallurgical sector: SMEs with hydraulic systems in presses, lathes, and heavy machinery.
- Agro-industrial sector: SMEs with hydraulic equipment in irrigation systems, harvesters, and processing.
- Transport and logistics sector: SMEs with vehicle fleets and cargo equipment.
- Mining sector: SMEs providing mining services with hydraulic equipment.

Implementation and scaling strategy: A gradual implementation strategy is proposed:

- Pilot phase: Implementation in 2-3 SMEs in a specific sector (e.g., mineral storage) to validate the model, measure results, and adjust parameters.
- Expansion phase: Expansion of the service to other sectors and regions, establishing strategic alliances with suppliers of equipment and ecological products.
- Scaling phase: Creation of a network of circular maintenance services at the regional or national level.

Key Performance Indicators (KPIs): Indicators are defined to measure the success of the model:

- Oil reuse rate: (Volume of dialyzed oil / Total volume of used oil) × 100
- Reduction in new oil consumption: (1 - Volume of new oil purchased / Historical volume) × 100
- Reduction in hazardous waste generation: (1 - Waste generated / Historical waste) × 100
- Annual economic savings: (Current cost - Circular model cost) in USD
- Customer satisfaction level: Satisfaction survey of SMEs served
- Customer retention rate: Percentage of SMEs renewing the annual contract

III. Results

This section presents the results of the feasibility study for the circular business model for the reuse of industrial oils and ecological cleaning in SMEs. The calculations are based on real data on consumption, costs, and operating times provided by companies in the sector, and are presented in comparative tables that allow visualizing the economic and operational benefits of the proposed model.

3.1. Hydraulic Oil Cost Analysis

Case 1: Front Loader

The front loader has a hydraulic oil capacity of 75 gallons. In the current scenario, the oil change is performed every 2,000 operating hours, which is approximately 4 months of work (considering 15 hours of daily operation). The cost of hydraulic oil is $12 per gallon.

Table 1.
Comparison of scenarios for front loader

Concept	Current Scenario	Circular Scenario (Proposed)
Oil capacity	75 gal	75 gal
Hours between changes	2000 h	3500 h
Time between changes	4 meses	7 meses
Oil changes per year	3	1.7 (≈2)
Annual consumption of new oil	225 gal	127.5 gal
Annual cost of new oil	$2,700	$1,530
Savings in oil purchase	----	$1,170 (43.3%)
Downtime per change	7 h	7 h (menos)
Number of stops per year	3	1.7 (≈2)
Annual downtime hours	21 h	11.9 h
Downtime cost ($65/h)	$1,365	$773.5
Savings in downtime costs	-----	$591.5 (43.3%)
Total annual savings per equipment	-----	**$1,761.5**

Note: The circular scenario includes an oil dialysis process every 1,000 hours, which extends the useful life of the oil from 2,000 to 3,500 hours.

Case 2: Container Crane

The container crane has a hydraulic oil capacity of 250 gallons. In the current scenario, the oil change is performed every 2,500 operating hours. The cost of oil is $12 per gallon.

Table 2.
Comparison of scenarios for container crane

Concept	Current Scenario	Circular Scenario (Proposed)
Oil capacity	250 gal	250 gal
Hours between changes	2500 h	4000 h
Time between changes	5 months	8 months
Oil changes per year	2.4	1.5
Annual consumption of new oil	600 gal	375 gal
Annual cost of new oil	$7,200	$4,500
Savings in oil purchase	---	$2,700 (37.5%)
Downtime per change	10 h	10 h (less)
Number of stops per year	2.4	1.5
Annual downtime hours	24 h	15 h
Downtime cost ($120/h)	$2,880	$1,800
Savings in downtime costs	---	$1,080 (37.5%)
Total annual savings per equipment	---	**$3,780**

3.2. Degreaser Analysis

In a typical workshop, the monthly consumption of conventional degreaser is 100 gallons, with a cost of $3.5 per gallon. The reusable ecological degreaser costs $5 per gallon, but it can be reused during the same month without needing to be discarded.

Table 3.
Degreaser comparison

Concept	Conventional Degreaser	Reusable Ecological Degreaser
Monthly consumption	100 gal	100 gal (initial purchase)
Price per gallon	$3.5	$5.0
Monthly cost	$350	$500 (initial purchase)
Reusability	No	Yes (reused within the same month)
Monthly cost after reuse	$350	$0 (if 100% reused)
Annual cost (12 months)	$4,200	$500 (initial purchase) + replacement losses
Annual savings (estimated, with 30% replacement)		$4,200 - ($500 + $1,800) = $1,900

Note: The ecological degreaser, being reusable, only requires replacement of losses due to evaporation or drag, estimated at 30% monthly.

3.3. Savings and Benefits Projection

Annual savings per equipment, Table 4 summarizes the annual savings generated by implementing the circular model in the two pieces of equipment analyzed. Total annual savings for the two equipment amounts to $5,541.5, distributed between oil purchase savings ($3,870) and downtime cost savings ($1,671.5). The front loader contributes $1,761.5 annually, while the container crane contributes $3,780, showing that equipment with larger oil capacity generates proportionally higher savings.

Table 4.
Summary of annual savings per equipment

Equipment	Oil purchase savings	Downtime cost savings	Total annual savings
Front loader	$1,170	$591.5	$1,761.5
Container crane	$2,700	$1,080	$3,780
Total for 2 equipment	$3,870	$1,671.5	$5,541.5

Annual savings from degreaser substitution, Table 5 compares the annual cost of the conventional degreaser versus the reusable ecological degreaser. The conventional degreaser has an annual cost of $4,200, while the ecological one, being reusable, only requires an initial purchase and replacement of losses (estimated at 30% monthly), resulting in an annual cost of $2,300. This represents an annual savings of $1,900 for a typical workshop, in addition to significantly reducing the generation of hazardous waste.

Table 5.
Annual savings from degreaser substitution

Concept	Amount
Annual cost of conventional degreaser	$4,200
Annual cost of ecological degreaser (initial purchase + replacement)	$2,300
Annual savings from degreasers	$1,900

Total annual benefit for a typical SME (2 equipment + workshop), Table 6 consolidates the total annual benefit that a typical SME (with 2 pieces of equipment and a maintenance workshop) would obtain by implementing the circular model. Total savings amount to $7,441.5 annually, representing a significant impact on reducing operating costs.

Table 6.
Total annual benefit of the circular model

Component	Annual savings
Hydraulic oil (2 equipment)	$5,541.5
Degreasers (workshop)	$1,900
Total annual benefit	$7,441.5

3.4. Business Model Viability Analysis

Estimated cost of the dialysis service, The oil dialysis service includes processing the oil at the SME's facilities. The estimated cost is $1.5 per gallon of processed oil (includes labor, filters, energy, and mobile equipment transport).

For the front loader (75 gal), the dialysis cost per process would be:

- 75 gal × $1.5/gal = $112.5 per dialysis

For the container crane (250 gal):

- 250 gal × $1.5/gal = $375 per dialysis

Considering that the front loader requires approximately 2 dialyses per year and the container crane 1.5 dialyses per year, the annual cost of the dialysis service is $225 for the front loader and $562.5 for the container crane.

Comparing the total annual savings (without considering the dialysis cost) against the annual service cost yields a net annual savings of $1,536.5 for the front loader and $3,217.5 for the container crane. Together, the net annual savings for the two pieces of equipment amounts to $4,754.

Fig. 2 compares the total annual cost of the linear scenario (oil purchase + downtime costs) against the circular scenario (oil purchase + downtime costs + dialysis service) for the two pieces of equipment analyzed. The linear scenario has a cost of $14,145, while the circular scenario reduces this cost to $9,391, generating a net annual savings of $4,754.

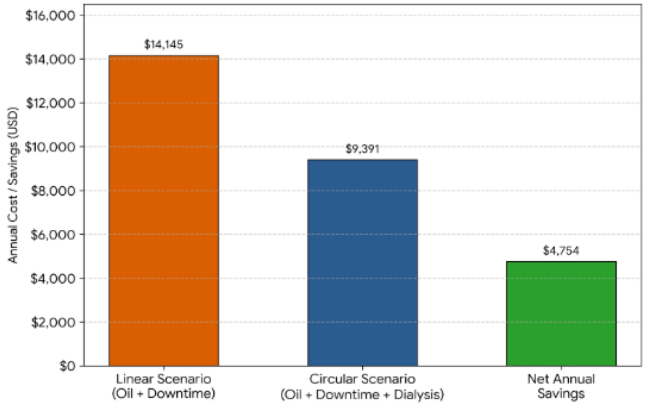


Fig.2 Comparación de escenarios: Lineal vs. Circular (2 equipos)

Fig. 3 breaks down the annual cost per equipment, comparing the linear scenario (oil purchase + downtime costs) against the circular scenario (oil purchase + downtime costs + dialysis). For the front loader, the cost is reduced from $4,065 to $2,528.5, while for the container crane, the cost is reduced from $10,080 to $6,862.5.

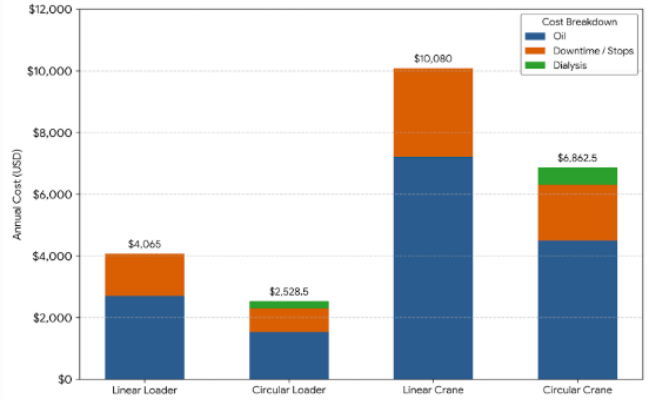


Fig. 3 Comparación de costos anuales por equipo (USD)

Fig. 4 compares the annual cost of the conventional degreaser ($4,200) against the reusable ecological degreaser ($2,300), showing an annual savings of $1,900 for a typical workshop

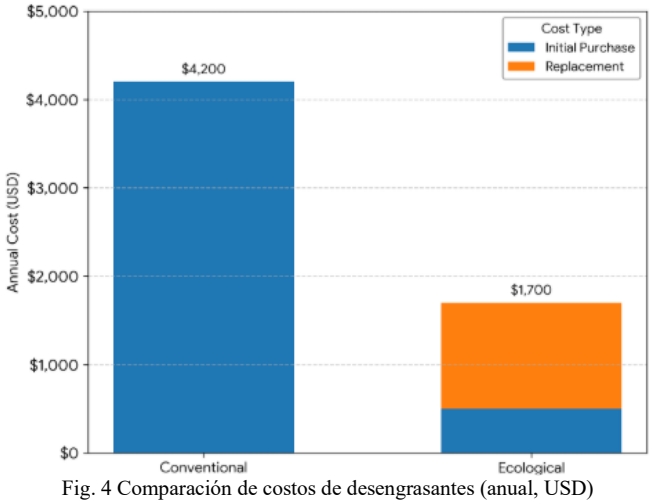


Fig. 4 Comparación de costos de desengrasantes (anual, USD)

IV. DISCUSSION

The results obtained confirm that the circular business model for the reuse of industrial oils and ecological cleaning is viable and generates significant benefits for SMEs. The implementation of the dialysis process allows extending the useful life of hydraulic oil by between 60% and 75%, reducing the frequency of changes and, therefore, the consumption of new oil. This lifespan extension is consistent with the principles of the circular economy, which seek to keep products and materials in use for as long as possible [1].

In the case of the front loader, extending the oil life from 2,000 to 3,500 hours (75%) reduces annual new oil consumption by 43.3%, generating savings of $1,170 per year. For the container crane, extending from 2,500 to 4,000 hours (60%) reduces consumption by 37.5%, generating savings of $2,700 per year. These results are consistent with previous research that has demonstrated that purifying industrial oils through filtration and contaminant separation can significantly extend their useful life [9,11].

Additionally, the reduction in the frequency of oil changes decreases equipment downtime, generating additional savings in operating costs. For the front loader, the savings in downtime costs is $591.5 per year, while for the container crane it is $1,080 per year. This benefit is particularly relevant for SMEs, where equipment availability directly impacts business productivity and profitability [6].

In the cleaning area, substituting conventional degreasers with reusable ecological products generates annual savings of $1,900 for a typical workshop, in addition to significantly reducing the generation of hazardous waste. This result is consistent with findings from previous studies that have demonstrated that integrating circular practices into maintenance improves efficiency and reduces waste [3].

The business model viability analysis shows that the dialysis service costs $1.5 per gallon processed, resulting in an

annual cost of $225 for the front loader and $562.5 for the container crane. After deducting this cost, the net annual savings for the two pieces of equipment amounts to $4,754. This result demonstrates that the model is economically viable even considering the cost of the dialysis service.

The total annual benefit for a typical SME (with 2 equipment and a maintenance workshop) amounts to $7,441.5, representing a significant impact on reducing operating costs. This benefit is consistent with findings from research in the Basque Country, which demonstrated that the circular economy improves SME competitiveness by creating new business lines, reducing costs, and optimizing processes [5].

Environmentally, the circular model reduces hazardous waste generation by more than 50%, contributing to sustainability goals and regulatory compliance. This result is consistent with circular economy principles that seek to minimize waste generation and maximize reuse and recycling [2].

The implementation of the circular model involves operational and environmental risks that must be managed to ensure long-term sustainability. Table 7 presents the main risks identified, along with their mitigation strategies.

Table 7.
Operational and environmental risks of the circular model

Risk	Type	Mitigation Strategy
Dialysis equipment failure	Operational	Preventive maintenance; backup equipment
Cross-contamination of oils	Operational	Cleaning protocol; traceability record
Oil spill during dialysis	Environmental	Containment trays; spill kits
Improper waste disposal	Environmental	Management with authorized companies
Lack of trained personnel	Operational	Continuous training program

The proactive management of these risks allows guaranteeing service continuity, protecting the environment, and maintaining customer confidence in the circular model.

However, the study has some limitations. First, the calculations are based on data provided by a limited number of companies, so results may vary depending on the type of equipment, sector, and region. Second, the analysis does not consider the initial investment costs in dialysis equipment, which is relevant for the service provider. Finally, the study focuses on two specific equipment, so it is recommended to validate the results on a broader sample of SMEs.

IV. CONCLUSIONS

This study determined the viability of implementing a circular business model for the reuse of industrial oils and ecological cleaning in industrial sector SMEs.

Technical viability: The model is technically viable. The dialysis process allows extending the useful life of hydraulic oil by between 60% and 75%, depending on the equipment, without compromising its operational quality. Substituting conventional degreasers with reusable ecological products is technically feasible and reduces hazardous waste generation.

Economic viability: The model is economically viable. A typical SME with 2 equipment and a maintenance workshop can generate net annual savings of $4,754 in oil and downtime, plus savings of $1,900 in degreasers, totaling $7,441.5 annually.

Environmental viability: The model is environmentally viable. It reduces hazardous waste generation by more than 50%, contributing to regulatory compliance and sustainability goals.

Regional contribution: The model is replicable in other SMEs in the region, promoting the development of sustainable entrepreneurship ecosystems and strengthening local capacities in the circular economy.

Recommendations:

- For SMEs: It is recommended to implement the circular model, starting with a pilot on a high-demand piece of equipment to validate results before scaling to the entire fleet.
- For entrepreneurs: It is recommended to offer the dialysis service as a business model, complemented by the supply of ecological degreasers and training services.
- For regional government: It is recommended to promote incentive policies for the adoption of circular practices in SMEs, including subsidies for dialysis equipment and training in the circular economy.
- For future research: It is recommended to extend the study to more equipment, sectors, and regions, and to evaluate the impact of initial investment on the viability of the business model.

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