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CLEANER PRODUCTION IN AN AUTOMOTIVE SHEET MOLDING COMPOUND MANUFACTURING PROCESS: AN INDUSTRIAL CASE STUDY ON EDGE WASTE PREVENTION

PRODUÇÃO MAIS LIMPA EM UM PROCESSO AUTOMOTIVO DE FABRICAÇÃO DE SHEET MOLDING COMPOUND: ESTUDO DE CASO INDUSTRIAL SOBRE A PREVENÇÃO DE RESÍDUOS DE BORDA

PRODUCCIÓN MÁS LIMPIA EN UN PROCESO AUTOMOTRIZ DE FABRICACIÓN DE SHEET MOLDING COMPOUND: UN ESTUDIO DE CASO INDUSTRIAL SOBRE LA PREVENCIÓN DE RESIDUOS DE BORDE

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Abstract

This study describes a Level 1 Cleaner Production (CP) intervention implemented in an automotive Sheet Molding Compound (SMC) process in southern Brazil. An analysis of the annual pre-intervention production base of 1,247,327 kg identified an edge-loss rate of 8.7%, corresponding to 108,463.22 kg of material associated with manual edge trimming. The intervention consisted of deactivating five fiber feed tubes and installing four metal plates to prevent fiber buildup in the edge zone. According to company records, the revised configuration removed the operational need for manual trimming of this

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specific edge-waste stream. The study established a gross annual baseline of R$ 1,132,629.13 in avoidable raw-material and waste-management losses associated with the pre-intervention edge-waste flow. This amount does not represent net savings or a payback estimate because investment and maintenance costs were not available for disclosure. The study does not report post-intervention time-series data, disclosable numerical quality-test results, or life-cycle impacts. It documents a case-specific source-prevention intervention and its limitations under industrial confidentiality conditions.
Keywords: Cleaner Production; Source prevention; Sheet Molding Compound; Automotive industry; Eco-efficiency.

Resumo

Este estudo descreve uma intervenção de Produção Mais Limpa (PML) de Nível 1 implementada em um processo automotivo de Sheet Molding Compound (SMC) no sul do Brasil. A análise da base anual de produção pré-intervenção de 1.247.327 kg identificou uma taxa de perda de borda de 8,7%, correspondente a 108.463,22 kg de material associado ao corte manual das bordas. A intervenção consistiu na desativação de cinco tubos de alimentação de fibras e na instalação de quatro placas metálicas para evitar o acúmulo de fibras na zona de borda. Segundo os registros da empresa, a configuração revisada eliminou a necessidade operacional de corte manual desse fluxo específico de resíduos de borda. O estudo estabeleceu uma linha de base anual bruta de R$ 1.132.629,13 em perdas evitáveis de matéria-prima e gestão de resíduos associadas ao fluxo pré-intervenção. Esse valor não representa economia líquida nem estimativa de payback, pois os custos de investimento e manutenção não foram disponibilizados para divulgação. O estudo não apresenta série temporal pós-intervenção, resultados numéricos divulgáveis de ensaios de qualidade ou impactos de ciclo de vida. O artigo documenta uma intervenção específica de prevenção na fonte e suas limitações sob condições de confidencialidade industrial.
Palavras-chave: Produção Mais Limpa; Prevenção na fonte; Sheet Molding Compound; Indústria automotiva; Ecoeficiência.

Resumen

Este estudio describe una intervención de Producción más limpia (PML) de nivel 1 aplicada a un proceso automovilístico de Sheet Molding Compound (SMC) en el sur de Brasil. El análisis de la base anual de producción previa a la intervención, de 1 247 327 kg, identificó una tasa de pérdida de borde del 8,7 %, equivalente a 108 463,22 kg de material asociado al corte manual de los bordes. La intervención consistió en desactivar cinco tubos de alimentación de fibra e instalar cuatro placas metálicas para evitar la acumulación de fibra en la zona de borde. Según los registros de la empresa, la configuración revisada eliminó la necesidad operativa de realizar el corte manual de este flujo específico de residuos de borde. El estudio estableció una línea de base anual bruta de 1 132 629,13 reales brasileños en pérdidas evitables de materias primas y gestión de residuos asociadas al flujo

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previo a la intervención. Esta cantidad no representa un ahorro neto ni una estimación del periodo de retorno, ya que los costes de inversión y mantenimiento no estuvieron disponibles para su divulgación. El estudio no presenta series temporales posteriores a la intervención, resultados numéricos divulgables de ensayos de calidad ni impactos del ciclo de vida. El artículo documenta una intervención específica de prevención en origen y sus limitaciones bajo condiciones de confidencialidad industrial.

Palabras clave: Producción más limpia; Prevención en la fuente; Sheet Molding Compound; Industria automotriz; Ecoeficiencia.

1. Introduction

Automotive manufacturing demands high productivity while controlling material losses, rework, and waste. In SMC production, fiber distribution must suit molding, and incomplete edge zones often need trimming before molding. This study examined such issues at a Brazilian automotive parts manufacturer.

How can a specific SMC manufacturing setup be changed to prevent fiber-contaminated edge strips while achieving operational acceptance according to the company's quality-assurance release records?

This article aimed to document the intervention, quantify the pre-intervention edge-loss baseline, and report the available operational, economic, and environmental information. The study does not assess statistical process capability, post-intervention temporal stability, life-cycle impacts, or economic payback because the required detailed records were not available for publication.

The economic scope of this study is limited to quantifying the gross annual baseline of raw-material and waste-management losses associated with the pre-intervention edge-waste stream. The study does not calculate net savings, return on investment, or payback because investment, maintenance, and other implementation costs were not available for disclosure. The technical scope is limited to reporting the operational acceptance indicated by the company's pilot-batch release and quality-assurance records.

This study offers a practical and methodological contribution by documenting a Level 1 Cleaner Production intervention aimed at preventing a specific material-

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loss stream. It also discusses the use of aggregated industrial data to report an industrial case while preserving confidentiality. The study does not quantify environmental performance, life-cycle impacts, or effects on competitiveness.

2. Literature Review

2.1 Cleaner Production and Prevention at the Source

Cleaner Production reduces resource use, emissions, and waste by changing products, processes, and practices, unlike waste management strategies after production. The intervention was classified as Level 1 Cleaner Production, changing the process to prevent specific edge waste (Figueiredo, 2004; Fagundes, 2015).

Cleaner Production offers benefits like resource efficiency, lower costs, and sustainability (Araújo, 2004). These should link to available indicators. This study focuses on recorded edge loss mass and its cost as primary indicators, not estimated environmental reductions.

In the hierarchy of industrial environmental strategies, Level 1 Cleaner Production (CP)—focused on process modification and prevention at the source—surpasses traditional end-of-pipe or secondary recycling approaches in terms of eco-efficiency, since it eliminates environmental liabilities even before they physically materialize (Krauklis et al., 2021). In high-volume manufacturing processes for the automotive sector, where raw material consumption and off-edge waste represent both severe financial losses and high energy footprints (Dér et al., 2022), Level 1 surgical interventions constitute the most advanced standard of operational eco-innovation.

2.2 Resource Efficiency and Competitiveness

Materials that are purchased, processed, and discarded without becoming the intended product represent both an environmental burden and a production cost. Cost analysis is important because raw materials, labor, transportation, and final disposal may all be associated with the same avoidable condition in the process (Bomfim and Passarelli, 2008; Cheng and McNamara, 2000; Simon, Bilstein, and Luby, 2008). In this case, the study included raw material losses and disposal costs

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in the calculation of the total annual loss.

The imperative to reduce weight and optimize structure in the modern automotive industry has increased the relevance of reinforced composites, such as Sheet Molding Compound (Wazeer et al., 2023). Forming and cutting sheets produce significant industrial waste, increasing disposal costs and raw material loss. Linking loss management with operational and logistics cost accounting is essential to show the economic viability of manufacturing sustainability.

2.3 Manufacturing of Sheet Molding Compound (SMC) and Composite Materials

Composite materials combine a matrix and reinforcement to achieve properties unavailable to single materials. SMC is prepared by making a base paste, adding chopped glass fibers, and wrapping in plastic for storage under controlled conditions. This method is popular for quick cycles and producing complex components (Fette et al., 2016).

Fiber distribution is fundamental and seen as a process modification, not just a waste disposal change, requiring a pilot test, traceability, operational adjustments, and quality verification.

2.4 Industrial Waste and Limits of Environmental Claims

Efficient industrial waste management involves accurate classification, documentation, secure transport, and proper disposal. The study classified the edge trimmings as Class I waste in the company's process. This article retains this information as the classification adopted in the case records but does not present it as an independently verified classification, since the technical report, composition report, or current regulatory assessment could not be included for disclosure.

The main environmental benefit is cutting waste from edge trimmings, lowering transportation and disposal needs. Evaluations of broader effects on energy use, greenhouse gases, or entire life-cycle impacts were not performed and thus fall outside this study's scope.

It should be noted that classifying the material as Class I waste relies solely

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on the company's operational records and is not an expert assessment or an independent analysis presented in this study. Additionally, the environmental benefits mentioned are limited to the direct flow of raw materials and the removal of related logistics, without encompassing full greenhouse gas inventories or life-cycle energy analyses.

Empirical research in advanced manufacturing often faces challenges due to industrial confidentiality and protecting trade secrets (Fagundes, 2015). Modern research supports using aggregated data and standardized metrics of material losses to share technological knowledge securely. This approach also maintains the validity of industrial interventions based on empirical evidence.

3. Methodology

3.1 Research Design and Case Context

This applied industrial case study includes a process improvement and a before-and-after comparison. The case was conducted at an automotive products manufacturer located in southern Brazil, using a Sheet Molding Compound (SMC) production line. The company and the detailed configuration of the product and equipment are not identified, as the study involves industrial confidentiality.

In accordance with standards of scientific integrity and CNPq Ordinance No. 2.664/2026, we hereby declare that the generative artificial intelligence tool Perplexity Pro (accessed in 2026) was used solely as technical support in preparing this manuscript, specifically to: (i) assist in refining the text with grammatical and stylistic improvements; (ii) support the logical organization of the manuscript's sections and the harmonization of titles and subtitles; (iii) review terminological consistency among the concepts addressed; and (iv) help create schematic visual elements, as described by the authors (Figures 1–2). The tool was not used to generate original scientific ideas, unpublished data, or texts without human validation and citation. It did not replace authors' contributions. All responsibilities—like methodology, data collection, analysis, waste reduction, economic gains, interpretation, and manuscript writing—were solely by the authors, who verified all facts and are responsible for the work's scientific accuracy and integrity.

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The study utilized descriptive records, production forecasts, unit characteristics of the coils, loss estimates, cost records, a pilot batch, and post-implementation observations, which were presented in aggregate form in this article. The company's detailed identity, equipment design, product specifications, quality records, investment costs, and time-series records are kept confidential to preserve anonymity and trade secrets.

3.2 Data Sources and Confidentiality Protocol

The data used in this manuscript include information such as aggregate annual production, unit coil weight, coil width, edge loss width, loss percentage, annual loss volume, raw material loss cost, disposal costs, and intervention setup costs. The study also described a traceable pilot test, subsequent adjustments, and the implementation of the revised machinery configuration.

To protect anonymity and trade secrets, the company name, internal material codes, detailed machinery dimensions, detailed product specifications, exact time-series records, detailed quality test results, and the investment costs of the intervention are not disclosed. The three categories of SMC are therefore identified as White, Green, and Black categories, without reproducing the internal codes. This choice preserves category separation and company confidentiality.

3.3 Calculation of the Pre-Intervention Loss Base

The pre-intervention edge-loss rate was calculated using Equation (1):

$$\text{Edge-loss rate (\%)} = (\text{Annual mass of edge trimmings} / \text{Annual production mass}) \times 100 \quad (1)$$

The baseline year saw 108,463.22 kg of edge trimmings and 1,247,327.00 kg of production mass. The relationship is given by Equation (2):

$$(108{,}463.22 / 1{,}247{,}327.00) \times 100 = 8.6965\% \quad (2)$$

The result was rounded to 8.7%, representing an annual pre-intervention loss baseline, not a monthly average, post-intervention rate, or process stability

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evidence.

Raw-material loss and disposal costs, including dumpster rental, transport, and final disposal, were summed across three categories to establish the gross annual baseline of the edge-waste stream. They do not indicate net savings, ROI, or payback.

3.4 Intervention and Validation of the Pilot Batch

The intervention involved deactivating five fiber feed tubes and installing four metal plates at the machinery's ends to prevent fiber buildup in the edge zone, which previously needed cutting. The five tubes were chosen because fibers toward the edge caused the composite-free band. Details about the plates' positions, sizes, material grade, and mounting methods are confidential and not disclosed.

The research involved a traceable pilot batch, defect inspections, adjustments to operating standards, and permanent implementation after company approval. The information authorized for disclosure indicates that the pilot batch was released through the company’s internal quality-assurance process after the process adjustment.

Numerical results for basis weight, thickness, fiber content, fiber distribution, mechanical properties, sample size, acceptance limits, and rejection rate were not available in a publishable format and are part of the company’s confidential quality system. Therefore, this study does not independently demonstrate equivalence of product quality before and after the intervention. It reports operational acceptance based on the company’s pilot-batch release records and the absence of operational deviations reported by its quality-assurance system.

3.5 Interpretation of Productivity and Environmental Results

The operational implications of the intervention are interpreted qualitatively rather than as quantified productivity gains. According to company records, manual edge trimming and the associated handling of the specific edge-waste stream were no longer required. Because cycle-time, productivity, ergonomic, and safety data were not available for disclosure, the study does not quantify changes in operational

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performance.

The environmental interpretation is limited to three levels: (i) the pre-intervention edge-waste flow identified in the company records; (ii) the waste-management activities associated with that specific flow; and (iii) broader environmental benefits that remain unquantified because no life-cycle assessment was conducted.

4. Results and Discussion

4.1 Production and Waste Generation Prior to the Intervention

The study covered three anonymized SMC categories. Annual production was 673,342 kg (White), 413,727 kg (Green), and 160,258 kg (Black), totaling 1,247,327 kg. Losses were 58,551.48 kg, 35,976.26 kg, and 13,935.48 kg, totaling 108,463.22 kg. Therefore, the annual volume of edge loss corresponds to approximately 8.7% of the annual production base, consistent with the calculation based on unit width.

Table 1 presents aggregated (annual) data regarding production, edge loss volume, and the cost of raw material loss

Table 1: Annual production, volume of edge loss, and cost of raw material loss.

Anonymized category	Annual production	Annual edge loss	Annual cost of raw material loss
White	673,342.00 kg	58,551.48 kg	R$ 562,094.19
Green	413,727.00 kg	35,976.26 kg	R$ 350,768.54
Black	160,258.00 kg	13,935.48 kg	R$ 137,264.46
Total	1,247,327.00 kg	108,463.22 kg	R$ 1,050,127.19

Source: Data provided by the company.

The three categories had the same reported unit width and edge-loss width. The aggregate edge-loss rate was calculated from the total annual edge-loss mass divided by the total annual production mass, as presented in Section 3.3. The resulting 8.7% rate is an annual pre-intervention baseline and should not be interpreted as a comparison of performance between products or as a post-intervention rate.

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4.2 Monthly Production Basis

The study also presented a monthly production forecast used to establish the annual baseline. These figures describe the production volume prior to the intervention and are reproduced without extrapolating the post-intervention loss rate.

Table 2 presents a monthly production forecast.

Table 2. Monthly production forecast.

Month	Production
January	74,545 kg
February	81,369 kg
March	94,887 kg
April	107,411 kg
May	110,243 kg
June	110,642 kg
July	127,297 kg
August	141,165 kg
September	137,082 kg
October	115,910 kg
November	91,782 kg
December	54,994 kg
Annual total	1,247,327 kg

Source: Data provided by the company.

The monthly figures show variation in production volume and possible product mix during the pre-intervention baseline period. Post-intervention monthly waste records, lot-level information, quality-rejection data, and production-volume data were not available for publication. Therefore, this study does not estimate a post-intervention waste rate, does not test a before-and-after difference, and does not demonstrate temporal stability of the process improvement.

4.3 Disposal Costs and Annual Total Loss

Disposal costs include dumpster rental, transportation, and disposal fees;

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Table 3 lists yearly expenses.

Table 3. Annual disposal costs.

Cost Component	White	Green	Black	Total
Dumpster rental	R$ 1,608.00	R$ 1,608.00	R$ 1,608.00	R$ 4,824.00
Transportation	R$ 7,200.00	R$ 3,600.00	R$ 1,800.00	R$ 12,600.00
Final Destination	R$ 35,130.89	R$ 21,585.76	R$ 8,361.29	R$ 65,077.94
Total allocation	R$ 43,938.89	R$ 26,793.76	R$ 11,769.29	R$ 82,501.94

Source: Data provided by the company.

The study reported a raw material loss cost of R$ 1,050,127.19 and disposal costs of R$ 82,501.94, totaling R$ 1,132,629.13 annually as the total loss.

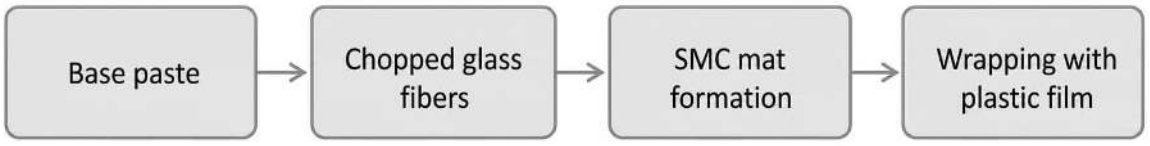
The annual overall loss reflects a baseline of avoidable losses, not a net annual saving, since the investment and maintenance costs of the intervention could not be disclosed.

In financial terms, R$ 1,132,629.13 reflects gross raw material losses and avoided disposal costs, not net revenue or final savings. Investment and maintenance costs were not disclosed, preventing payback calculation.

4.4 Process Intervention

Figure 1 illustrates the simplified flowchart of Sheet Molding Compound (SMC) manufacturing.

Figure 1. Simplified SMC manufacturing flowchart (the diagram is conceptual and not to scale).



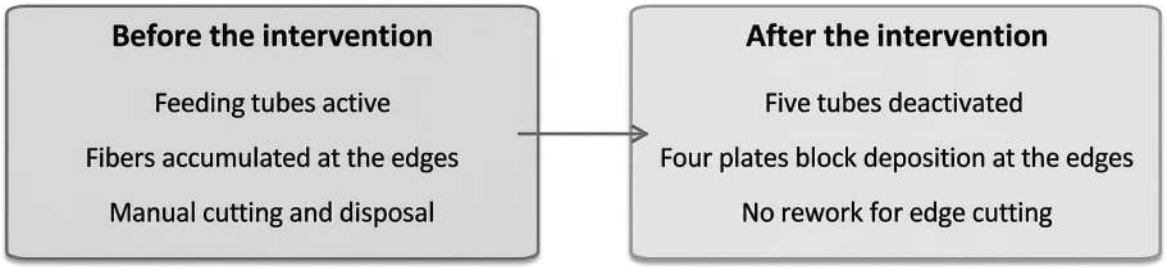
Source: Data provided by the company.

Visualizing this flowchart identified the source of the edge scrap problem, forming the basis for the proposed intervention. Figure 2 shows a conceptual 'before' and 'after' view.

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Figure 2. Conceptual representation of the intervention (not to scale).



Source: Data provided by the company

The flowchart identified the edge scrap source, forming the foundation for intervention, as shown in Figure 2, labeled ‘before’ and ‘after’. The aim was to prevent edge waste creation rather than recycling it after production, aligning with Level 1 of Cleaner Production.

4.5 Quality and Productivity Results

The company’s records show the revised configuration was accepted through internal quality assurance. Numerical data on basis weight, thickness, fiber content, strength, stability, mold filling, finish, sample size, thresholds, and rejection rate are not provided due to confidentiality. Accordingly, the study does not provide an independent quantitative demonstration of unchanged product quality.

According to company records, the revised configuration removed the operational need for manual edge trimming and the related handling of the specific edge-waste stream. Because cycle-time, productivity, ergonomic, and safety data were not available for disclosure, the study does not quantify operational-performance gains.

4.6 Environmental and Economic Interpretation

The documented pre-intervention material baseline is the annual edge-waste flow of 108,463.22 kg. The calculated economic baseline is the sum of raw-material loss and disposal costs, totaling R$ 1,132,629.13 per year. This amount represents gross avoidable losses associated with the pre-intervention edge-waste stream and does not represent realized net savings, net revenue, return on investment, or

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payback.

The study does not claim that all waste generated by the SMC process was eliminated. Losses associated with startup, cleaning, formulation changes, film, paste, non-conforming material, or other sources were not quantified. The intervention was intended to prevent the edge-waste stream associated with the fiber-contaminated strip, and the company's operational records indicated acceptance of the revised configuration. The study does not provide a quantified post-intervention waste rate or evidence of temporal stability.

The findings indicate that source prevention may reduce the material losses and waste-management activities associated with this specific edge-waste stream. However, the study does not quantify changes in energy use, greenhouse-gas emissions, transport emissions, life-cycle impacts, company-wide environmental performance, or market competitiveness. Those effects should be investigated in future studies using post-intervention monitoring and life-cycle assessment methods.

4.7 Contribution and Transfer Conditions

The scientific contribution of this case lies in documenting a source-prevention decision pathway for a similar SMC manufacturing line. The pathway involves identifying the mechanism causing edge waste, measuring the baseline material loss, testing a process change in a pilot batch, gaining approval through quality assurance, and implementing the revised setup under specific conditions.

This contribution isn't a universal machinery design or general performance claim for the automotive industry. Its transferability depends on similarities in fiber-feed setup, edge shape, product specs, quality needs, and production conditions. Under similar conditions, it can help practitioners and researchers identify opportunities to prevent waste streams at their source rather than managing them after creation.

This case contributes to industrial research discussions under confidentiality. Using anonymized categories and aggregated data enables reporting process improvements without revealing company identity, internal codes, detailed design,

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or confidential quality records. The study also notes that confidentiality limits the reproducibility of the mass balance, post-intervention data, quality validation, and economic assessment.

4.8 Limitations

Since the investigation focuses on one SMC line and intervention, its findings aren't generalizable to the whole automotive industry. Confidential details include equipment, product specs, quality records, costs, and operational data.

The 8.7% rate is based on combined annual and total pre-intervention data. It does not indicate a consistent monthly rate, a post-intervention rate, or a statistically proven decrease after implementation.

The company did not provide post-intervention time-series data, costs, or data for net-payback calculations. Consequently, the study does not present statistical-process-control results, an economic sensitivity analysis, return on investment, or payback.

The company's quality-assurance records indicate operational acceptance after the adjustment; however, the specific numerical quality-test results cannot be shared because of confidentiality restrictions. Therefore, the study does not independently demonstrate unchanged quality attributes before and after the intervention.

The study does not provide a complete process mass balance, an independent waste-classification assessment, or a life-cycle assessment. These limitations should be addressed in future research using disclosable before-and-after production, quality, material-flow, economic, and environmental data.

5. Conclusions

This industrial case study examined a Level 1 Cleaner Production intervention in an automotive Sheet Molding Compound manufacturing process. The annual pre-intervention production base was 1,247,327 kg, and the reported annual edge-waste mass was 108,463.22 kg. The resulting aggregate pre-intervention edge-loss rate was 8.7%. Raw-material loss costs totaled R$ 1,050,127.19, while disposal

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costs totaled R$ 82,501.94, resulting in a gross annual baseline of R$ 1,132,629.13 in avoidable losses associated with the identified edge-waste stream.

The intervention consisted of deactivating five fiber feed tubes and installing four metal plates at the equipment ends. According to company records, the revised configuration removed the operational need for manual edge trimming and the related handling of the specific edge-waste stream. The pilot batch received operational acceptance through the company's internal quality-assurance process. However, the study does not provide an independent quantitative demonstration that all product-quality attributes remained unchanged because the detailed quality-test results were not available for disclosure.

The findings are limited to the case studied. The reported economic value is a gross pre-intervention baseline of avoidable losses and does not represent net savings, return on investment, or payback. The study lacks a complete mass balance, post-intervention data, statistical proof of stability, independent waste classification, or life-cycle assessment.

The documented environmental result is limited to the specific waste stream and waste-management activities recorded. Broader impacts on greenhouse gases, energy, transport, life-cycle, and competitiveness were not quantified. Future research should use publishable data to assess mass balance, process stability, quality, economics, and life-cycle impacts.

Despite these limitations, the study provides a case-based contribution to Cleaner Production research in composite manufacturing. It documents how a specific edge-waste mechanism can be addressed through a preventive process modification and how aggregated industrial records can be used to quantify the associated material-loss baseline while preserving confidentiality. The findings are relevant to similar SMC operations, provided that transfer is preceded by technical assessment, pilot testing, and quality-assurance approval under local production conditions

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