Overcoming Barriers for Adopting Cleaner Production: A Case Study in Brazilian Small Metal-Mechanic Companies

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Abstract: Small enterprises negatively affect the environment due to the inadequate disposal of manufacturing and raw material wastes generated in production processes; in addition, small enterprises do not often adopt adequate environmental practices due to barriers that include the lack of investment capacity. However, the adoption of cleaner production results in economic and environmental gains. The purpose of this study is to demonstrate how Brazilian small metal mechanical enterprises can identify and overcome barriers with the aim of implementing cleaner production. The research method used multiple cases with data collected by means of interviews and observations. The results allowed us to conclude that cultural and technical barriers negatively affect the adoption of cleaner production in the small enterprises studied. However, cultural and technical barriers can be overcome by means of economic and environmental gains as well as through investment in employee training and in the acquisition of more efficient machines and equipment.

Keywords: Cleaner production; overcome barriers; small enterprises; environmental practices

1. Introduction

Environmental problems caused by industries have increased and become a global concern; therefore, it is important to mitigate the consumption of non-renewable natural resources and environmental pollution caused by industrial processes. Industries have used cleaner production (CP) with the aim of minimizing the consumption of raw materials and environmental impacts. However, small enterprises (SEs) are still unable to adopt CP due to its high implementation costs.

CP is a preventive strategy applied into the production process for increasing productivity through a more efficient use of raw materials, energy, and water, thereby improving economic performance and reducing environmental impact [1]. Neto and Jabbour [2] concluded that CP concentrates on reducing raw material consumption and mitigating environmental impacts with the purpose of generating economic gains. Moreover, CP provides great contributions to the industrial sector, improving environmental performance and stimulating the pursuit of market advantages [3–6].

The barriers preventing the implementation of CP by SEs are related to various aspects including: the lack of financial resources [7,8], the lack of interest in environmental issues, the lack of capital for investment in environmental practices, and the lack of knowledge by the medium and high managers that impact the final treatment of the product. Also, there is no concern with minimizing the waste generated by the production system [9–12]. The difficulties for SEs in adopting CP increase when there is need to save time and money, and when there is no guarantee of financial return because SEs

often need short-term economic return. SEs tend to focus on productive processes while ignoring environmental factors [11,13–15]. Thus, SEs face several barriers to adopting CP and overcoming difficulties. Studies on the subject have indicated that the main barrier for adopting CP is the lack of capital for investments and the lack of knowledge about the opportunity of obtaining economic gains. However, there is a lack of studies showing that the adoption of CP resulted in economic gains while reducing environmental impacts. Considering all the above, the research question for this study was: Do economic and environmental gains allow Brazilian small metal-mechanic companies to overcome technical and cultural barriers when implementing CP?

The scientific literature contains few studies carried out on how to overcome barriers to implement CP. The studies identified addressed the issue in a qualitative way; as such, these works do not quantify economic results nor evaluate the environmental impacts of CP adoption. Silva et al. [9] presented qualitative alternatives to overcome the barriers when implementing CP by means of quality tools. Zilhy [16] considers motivational factors within organizations as pivotal in overcoming the barriers for implementing CP. He understands that motivation comes from external factors such as environmental authorities and clients. Vieira and Amaral [12] identified that the analysis, quality, accountability, and TRIZ tools aid the process of overcoming barriers when implementing CP. Hilson [17] concluded that the government should play a more active environmental role to overcome CP barriers. Yiping and Raymond [18] observed that strengthening environmental awareness and boosting the training for environmental practices at national, regional, and corporate levels are considered the main features to overcome the barriers for implementing CP.

The purpose of this study is to demonstrate how Brazilian small metal mechanical enterprises can identify and overcome barriers with the aim of implementing CP. Toward this end, multiple cases were developed in two Brazilian small metal-mechanic companies with the purpose of showing how barriers were identified, their causes and effects, economic and environmental analysis, their return on investment, opportunities for improvements in production processes, and the effective overcoming of barriers. SEs are relevant in the Brazilian economy and account for 27% of the gross domestic product (GDP). In addition, they employ 52% of the formal labor force and account for 40% of the total salary. The Brazilian SEs in the metal-mechanic sector has a 22.5% share in the Brazilian industry GDP contribution [19,20].

2. Methodology

A systematic review of the literature was performed via the Google Academic, Science Direct, Emerald, Scopus, and Scielo databases, using keywords: "cleaner production" and "overcome" and "barriers." Bardin [21] recommends selecting papers using keywords and then, based on this selection, analyze the articles and select those that are relevant to the study. Seventeen papers were selected for this study and five articles were considered relevant for the subject.

The research method adopted consisted of using multiple cases in two small metal-mechanical enterprises. Multiple case studies are considered more convincing due to intra-case and inter-case analysis. Intra-case analysis consolidates the information of each case, and the inter-case analysis identifies patterns, thus providing elements for the development of theories [22]. Multiple-case studies require the use of techniques that facilitate the synthesis and understanding of data involving three activities: the analysis of data, the presentation of data, and its conclusion [23]. The collection of information comprises various sources such as documents, records, interviews, observation, and physical artifacts [24]. In this study, we adopted the records in archives, semi-structured interviews, and observations to present qualitative and quantitative data.

Initially, the respondents were contacted by telephone and were asked to participate in the interview. The researcher subsequently sent them a summary of the subject and the research protocol. Miles and Huberman [23] recommended the use of techniques that facilitate the understanding and summarization of results. For instance, the data collection instrument must be the same for all companies to allow for data comparison. The interviews took one hour and were carried out at the

companies. The respondent of small company "A" was the Industrial Manager, with a background in business administration and mechanical engineering, and he also had twenty years of experience in the metal-mechanical industry. In small company "B," the respondent was the Managing Partner, with a background in engineering production and business administration and twenty-six years of experience in the metal-mechanical industry. In the interview, the instrument for the identification of barriers established on the foundations of the literature (see Table 1) was shown and included the barriers and sub-barriers of CP. The respondents weighted the barriers in a scale from 1 to 8, using 1 for the barrier that impacts less negatively in the process of adoption of CP, and 8 for barrier that impacts more negatively.

Table 1. Barriers and Sub-barriers of the CP.

Barriers	Sub-Barriers	Authors
Economic	Economic restrictions for investments	Frijns and Vliet [25]; Shi et al. [7]; Hitchens et al. [26]; Hicks and Dietmar [27]; Mitchell [28]; Mittal and Sangwan [29]; Jabbour et al. [8]
	Limited resources	Hitchens et al. [26]; Van Hoof and Lyon [30]
	Costs for CP implementation	Shi et al. [7]; Graham and Van Berkel [31]; Jabbour et al. [8]
	Few commercial advantages	Shi et al. [7]; Siaminwet al. [32]; Graham and Van Berkel [31]
Financial	Lack of incentives	Frijns and Vliet [25]; Wang [33]; Shi et al. [7]; Koefoed and Buckley [34]; Silva et al. [11]
	Difficulties in accessing credits	Shi et al. [7]
	Difficulties in raising capital	Hitchens et al. [26]; Siaminwe et al. [32]; Silva et al. [11]
	High initial capital cost	Chiu et al. [35]; Shi et al. [7]; Koefoed and Buckley [34]; Daquino et al. [36]; Klewitz and Hansen [37]; Vieira and Amaral [12]
Cultural	Resistance to change	Frijns and Vliet [25]; Shi et al. [7]; Domingues and Paulino [38]; Koefoed and Buckley [34]; Severo and Olea [39]; Silva et al. [9]
	Little involvement	Van Berkel [40]; Klewitz and Hansen [37]; Vieira and Amaral [12]
	Education	Sisinno and Moreira [41]; Vieira and Amaral [12].
	Not knowing the benefits	Van Berkel [40]; Klewitz and Hansen [37]; Vieira and Amaral [12]
	Little environmental awareness	Frijns and Vliet [25]; Shi et al. [7]; Shi et al. [42]; Daquino et al. [36]
	Training in environmental education	Frijns and Vliet [25]; Shi et al. [7]; Geng et al. [43]; Mittal and Sangwan [29]; Silva et al. [9]; Silvestre and Silva Neto [44]; Daquino et al. [36]; Silva, Morales and Machado [11]; Abdulrahman et al. [45]
Technical	Emphasis at end of line	Frijns and Vliet [25]; Silva et al. [9]
	Lack of technical knowledge	Frijns and Vliet [25]; Shi et al. [7]; Hamed and El Mahgary [46]; Domingues and Paulino [38]; Severo and Olea [39]; Mittal and Sangwan [29]; Silva et al. [9]; Silvestre and Silva Neto [44]; Daquino et al. [36]; Silva, Morales, and Machado [11]
	Lack of technical information	Shi et al. [7]; Hitchens et al. [26]; Silva et al. [9]; Silvestre and Silva Neto [44]; Vieira and Amaral [12]
	Lack of time for management	Frijns and Vliet [25]; Domingues and Paulino [38]; Silva et al. [9]; Silvestre and Silva Neto [44]
	Lack of skilled labor	Shi et al. [7]; Siaminwe et al. [32]; Oliveira and Alves [15]; Graham and Van Berkel [40]; Shi et al. [42]; Silva et al. [9]; Daquino et al. [36]; Silvestre and Silva Neto [44]; Klewitz and Hansen [37]; Severo et al. [10]
Technological	Infrastructure issues	Shi et al. [7]; Shi et al. [42]
	Obsolete machinery and equipment	Dasgupta [47]; Hitchens et al. [26]; Genget al. [42]; Mittal and Sangwan [29]; Daquino et al. [36]; Daquino et al. [36]; Silvestre and Silva Neto [44]
	Lack of money for technological improvement	Wang [33]; Domingues and Paulino [38]; Silvestre and Silva Neto [44]

Table 1. *Cont.*

Barriers	Sub-Barriers	Authors
Regulation	Unawareness of regulations	Dasgupta [47]; Hitchens et al. [26]; Siaminwe et al. [32]; Koefoed and Buckley [34]; Mittal and Sangwan [29]
	Difficulties in complying with regulations	Gombault and Versteege [48]; Hilson [49]; Hitchens et al. [26]; Siaminwe et al. [32]; Van Berkel [40]
	Loose oversight and poor enforcement of environmental standards	Hilson [17]; Shi et al. [7]; Mittal and Sangwan [29]
	Little money to meet the regulations.	Wang [33]; Hilson [17]; Hilson [49]; Van Berkel [40]; Domingues and Paulino [38]
Governmental	Motivation policies	Frijns e Vliet [25]; Shi et al. [7]; Siaminwe et al. [32]; Mitchell [28]; Koefoed and Buckley [34]; Shi et al. [42]
	Support policies for CP	Frijns and Vliet [25]; Mitchell [28]; Koefoed and Buckley [34]; Domingues and Paulino [38]; Daquino et al. [36]; Daquino et al. [36]
	Unaware of incentives	Siaminwe et al. [32]; Shi et al. [42]
Organizational	Environmental awareness	Shi et al. [7]; Van Berkel [40]
	Managerial competence	Shi et al. [7]; Hitchens et al. [26]; Siaminwe et al. [32]; Silva et al. [9]; Daquino et al. [36]; Daquino et al. [36]; Abdulrahman et al. [45]; Jabbour et al. [8]
	Employee involvement	Frijns and Vliet [25]; Silva et al. [9]; Daquino et al. [36]; Daquino et al. [36]; Jabbour et al. [8]
	Incorrect allocation of resources	Domingues and Paulino [38]
	Environmental priority	Frijns and Vliet [25]; Wang [33]; Shi et al. [7]; Hitchens et al. [26]; Mitchell [28]; Silva et al. [9]; Daquino et al. [36]; Jabbour et al. [8]
	Company culture	Hitchens et al. [26]
	Market pressures by CP	Shi et al. [7]; Shi et al. [42]
	Motivation of managers	Hitchens et al. [26]; Van Hoof and Lyon [30]; Silva et al. [9]

The respondents appraised the level of importance of the barriers and sub-barriers using the GUT matrix tool considering three main aspects: severity (S), urgency (U), and tendency (T). The grade 5 was utilized to address the most striking barriers, and grade 1 was used for the least impactful ones. Kepner and Tregoe [50] developed the GUT matrix tool to analyze the priorities of the problems in the organizational or personal scope in terms of severity, urgency, and tendency. Severity refers to the impact of the problem on people, results, processes, and organizations. Urgency is related to the time available or necessary to solve a problem. Tendency regards the potential of growth, the evaluation of the tendency of growth, and reduction or disappearance of the problem. The GUT matrix tool is easy to apply, and the calculation is done by multiplying the assigned values.

$$BF = S \times U \times T \tag{1}$$

The product of this multiplication is named the barrier factor (BF), which in comparison with other barriers, will indicate whether it is the most urgent. The results are compiled as a ranking of barriers according to their impact in order to guide the company's decision when implementing CP.

Additionally, a cause and effect diagram was developed to find alternatives for overcoming barriers. The diagram is based on the literature and it is presented in Table 2. The diagram was used to analyze complex problems with the aim of indicating alternatives for overcoming barriers mentioned on the interview and observed in the production system.

Table 2. Cause and Effect Analysis.

Causes	Effects	Authors
Economic	Little money for investments	Hitchens et al. [26]; Hicks and Dietmar [27]
	Little money for training	Shi et al. [7]; Daquino et al. [36]
	Little money to buy less polluting raw material	Hitchens et al. [26]
	Little money for voluntary actions for environmental improvements	Van Berkel [40]; Van Hoof and Lyon [30]
Financial	High interest and short-term loans	Shi et al. [7]; Silva et al. [11]
	Unaware of government-subsidized financing for environmental actions	Siaminwe et al. [32]
	Unawareness of public and private partnerships to obtain resources directed toward environmental actions	Hitchens et al. [26]
Technical	Lack of control in the management of waste and emissions causing economic losses with fines	Hitchens et al. [26]; Van Berkel [40]; Domingues and Paulino [38]
	Lack of specialized professionals to correctly apply resources to environmental actions that allow for economic gains	Shi et al. [7]; Silva et al. [9]; Severo et al. [10]
Technological	Use of obsolete machines and equipment that generate more waste and greater consumption of raw material, causing economic losses	Dasgupta [47]; Genget al. [42]; Mittaland Sangwan [29]; Silvestre and Silva Neto [44]
Cultural	Resistance to changes, making environmental actions difficult	Shi et al. [7]; Domingues and Paulino [38]; Severo and Olea [39]; Silva et al. [9]
	Unawareness of possible economic, environmental, and health gains for workers	Van Berkel [40]; Vieira and Amaral [12]
	Disinterest for environmental problems	Van Berkel [40]; Klewitz and Hansen [37]
	Little environmental awareness	Frijns and Vliet [25]; Shi et al. [7]; Shi et al. [42]; Daquino et al. [36]
Regulation	Non-compliance with environmental regulations, resulting in fines	Hilson [49]; Hitchens et al. [26]; Siaminwe et al. [32]; Van Berkel [40]
	Little knowledge of regulations, resulting in non-compliance	Dasgupta [47]; Hitchens et al. [26]; Koefoed and Buckley [34]; Mittal and Sangwan [29]
	Penalties for damages to the environment.	Gombault and Versteege [48]; Hilson [49]; Van Berkel [40]
Governmental	Non-involvement in environmental campaigns that make it possible to obtain economic resources	Siaminwe et al. [32]; Shi et al. [42]
	Lack of knowledge of economic incentive policies for environmental improvement actions	Frijns and Vliet [25]; Domingues and Paulino [38]; Daquino et al. [36]
Organizational	Non-understanding of environmental actions that can generate economic gains	Hitchens et al. [26]; Van Berkel [40]; Silva et al. [9]; Jabbour et al. [8]
	Little involvement of managers	Van Hoof and Lyon [30]; Silva et al. [9]
	Little effort to reduce waste that generates economic losses	Frijns and Vliet [25]; Silva et al. [9] Daquino et al. [36]

The existence of raw material waste was identified in the interview and in the observation of the production process. Based on this analysis, a feasibility study to reduce waste and emissions was carried out, making it possible to quantify economic and environmental gains. For the economic assessment, the return on investment (ROI) based on a cost reduction was calculated considering the minimization of waste and the predictable investment associated with this cost reduction. For the environmental assessment, the mass balance was developed by means of a weighing of the total

material economized (TME) using the mass intensity factors tool (MIF), according to Ritthoff et al. [51], and considering mass (M) and Intensity Factor (IF).

$$\text{MIF} = \text{Mass (M)} \times \text{Intensity Factor (IF)} \tag{2}$$

Table 3 presents the IFs used for the environmental impact calculations in accordance with the Wuppertal Institute [50].

Table 3. Intensity Factors of Materials.

Component	Specification	Abiotic M.	Biotic M.	Water	Air
Stainless steel	18% Cr, 12% Ni	14.43	-	205.13	2.83

Source: Wuppertal Institute [50].

In addition, the mass intensity per compartment (MIC) was calculated to measure the reduction of environmental impact in the abiotic, biotic, water, and air components according to the following equations:

$$\text{MIC}_{\text{abiotic}} = \sum \text{MIF}_{\text{abiotic}} \tag{3}$$

$$\text{MIC}_{\text{biotic}} = \sum \text{MIF}_{\text{biotic}} \tag{4}$$

$$\text{MIC}_{\text{water}} = \sum \text{MIF}_{\text{water}} \tag{5}$$

$$\text{MIC}_{\text{air}} = \sum \text{MIF}_{\text{air}} \tag{6}$$

Thus, the mass intensity total (MIT) was accounted by means of the sum of the components, according to Equation (7):

$$\text{MIT} = \sum \text{MIC}_{\text{abiotic}} + \sum \text{MIC}_{\text{biotic}} + \sum \text{MIC}_{\text{water}} + \sum \text{MIC}_{\text{air}} \tag{7}$$

3. Results and Discussion

Flowchart Analysis for Cleaner Production Deployment

The small company "A" is located in São Paulo, Brazil, has 20 employees, and manufactures sieve-size screens and metal filters. Its production process comprises of sectors for receipt, raw material stock, screen manufacturing, stamping, welding, packaging, finished product stock, and shipment, as depicted in Figure 1. The small company "B" is located in Campinas, São Paulo, has 30 employees, and manufactures vibratory feeders. Its production process consists of receiving and stocking the raw material, cutting, bending, welding, assembly, testing, finished product stock, and shipment (Figure 1).

In the interview process, it was identified that the SEs have few economic resources for investment, use obsolete equipment, and their professionals have low technical qualifications. This finding was corroborated by Deitos [52], who pointed out that SEs have a simple organizational structure, small portfolio of products, limited financial resources, and workers with a low skill level. It was also observed that the researched SEs are unaware of opportunities for obtaining economic gains by means of the implementation of CP, and these companies are not aware of the environmental impacts caused by the end of pipe treatment.
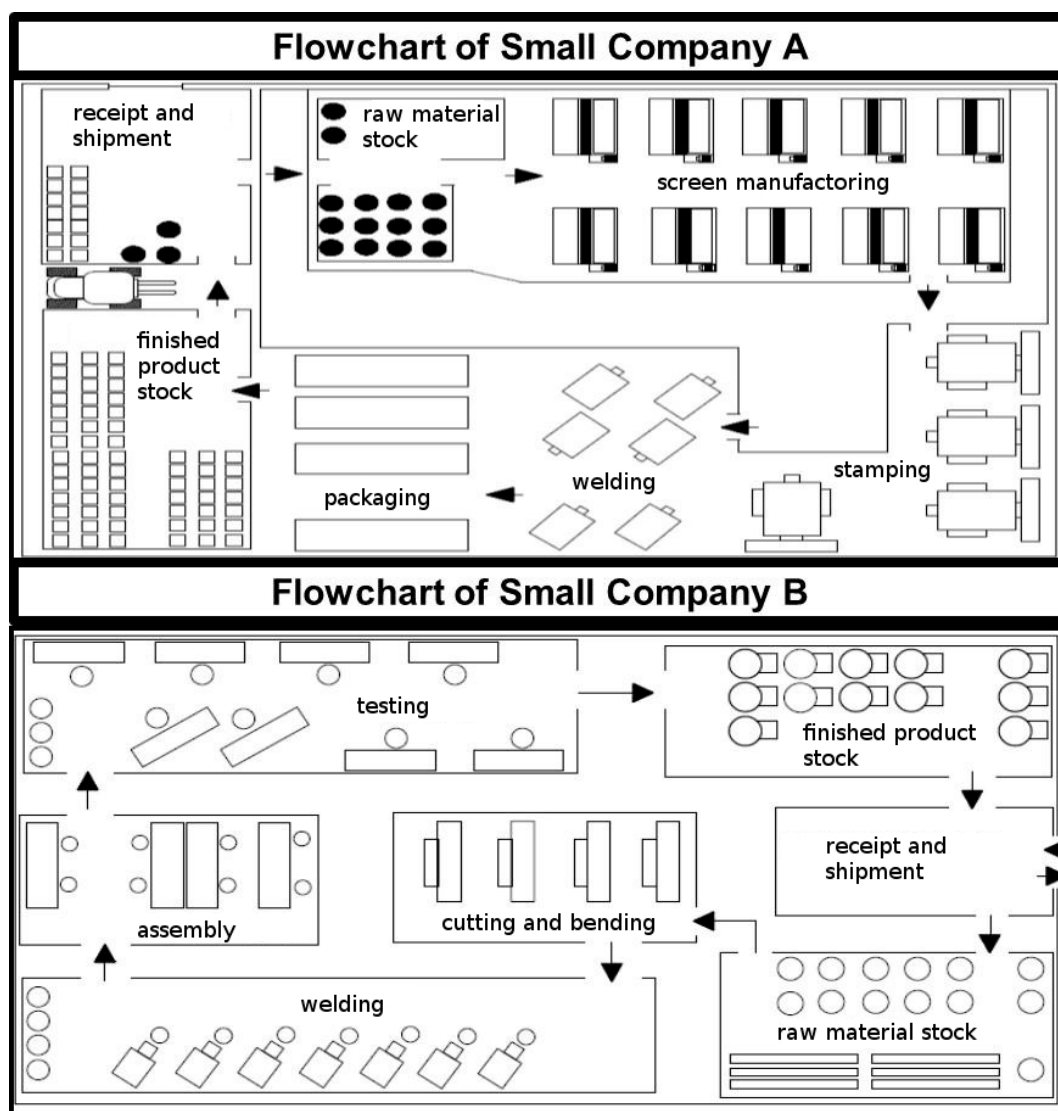
Figure 1. Flowchart of the manufacturing process of small companies "A" and "B."

4. The Analysis of the CP Barriers

The results, presented in Table 4, indicate that cultural, technical, and economic/financial barriers impacted both small companies "A" and "B." This finding indicates that these three barriers were common in the small companies that were studied. The main barrier to be overcome was the economic/financial one because when a small company has economic gains, it is possible to invest in training for employees, as well as buy machines and equipment. References [11,43] corroborate these results by considering that investment in training improves the skill level of workers. Also, the research works of Van Berkel [39] and Silvestre and Silva Neto [44] highlighted that the existence of technical barriers cause the absence of skilled labor to develop, which motivates studies on improving processes and products.

The CP barriers indicated in the two SEs were related to the lack of interest and lack of environmental awareness of the shareholders and stakeholders, as well as the lack of knowledge regarding the opportunity of obtaining economic gains. It should be noted that economic gains are achieved by investing in training, acquisition of clean technologies, and overcoming the barriers indicated. These findings are corroborated with References [30,53,54]. They concluded that the disinterest of businesspeople and stakeholders occurs due to a lack of knowledge of the economic and environmental benefits of CP adoption, which generates a resistance to change. Therefore, the results

of this study are relevant to the research community and to the organizational practice because it empirically shows how to identify the main barriers faced by SEs and the means for overcoming cultural and technical barriers for adopting CP.

Table 4. Matrix GUT.

Barriers of the Small Company "A"	Likert Analysis	S	U	T	Weighting	Barriers of the Small Company "B"	Likert Analysis	S	U	T	Weighting
Economic	6	5	4	3	60	Economic	6	3	3	3	27
Financial	5	3	3	3	27	Financial	7	3	3	3	27
Cultural	8	4	5	5	100	Cultural	5	4	3	3	36
Technical	7	4	4	4	64	Technical	8	5	3	3	45
Technological	4	4	3	2	24	Technological	4	4	3	2	24
Regulation	3	3	1	1	3	Regulation	2	2	2	2	8
Government	2	2	1	1	2	Government	3	3	1	1	3
Organizational	1	3	3	1	9	Organizational	1	1	1	1	1

5. Economics Assessment

In the small enterprise "A," a loss of raw material of around 54% in the process of cutting the stainless-steel screens for the manufacturing of the sieves was identified. Twenty-five hundred kilograms of stainless-steel screens were manufactured per month with the cost of US$21.62 per kg for the manufacturing of 5000 sieves. For each sieve, 0.225 kg of screen was required, resulting in a monthly expense with stainless steel screens of US$54,054.05. The loss of stainless-steel screens amounted to 1375 kg per month and its sale for external recycling resulted in an economic gain of US$1121.62.

With the implantation of CP, the inversion of the process of stretching the screen was suggested, which involved executing the stretch after the welding of the fabric in the rim. The screen could be cut in the diameter of the rim for the weld, with no need for leftovers, which reduced the monthly loss from 1375 kg to 250 kg, representing a minimization of monthly losses by 1125 kg and annual losses by 13,500 kg. This change required an investment of US$5405.41 in the manufacturing process for the purchase of a manual hydraulic press with a capacity of 10 tons to promote the stretching of the screen after welding in the rim, and a further US$1675.68 for the development and acquisition of auxiliary devices. The results indicated an economic gain of US$280,864.86 per year due to the better use of the screens while reducing waste. This finding shows a reduction in the total consumption of stainless-steel screens from 2500 kg to 1375 kg per month for the manufacture of 5000 sieves, thereby reducing the total consumption of stainless-steel screens by 44.2%.

The ROI was calculated by considering the investment in the manufacturing process of US$5405.41 plus US$1675.68 totaling US$7081.09 and obtaining the return of the capital invested in less than one month. After the amortization of the capital invested, the small company "A" started to make profit of US$196,818, as shown on Table 5.

The small company "B" produced 200 trays for vibratory feeders per month, using 3.3 tons of stainless-steel sheets for this purpose. The loss of raw material in the manufacturing process was identified as 300 kg per month, which was sold as external recycling for US$243.24. After the adoption of CP, the amount of waste was reduced to 100 kg per month through the reuse of stainless-steel sheet wastes for making washers. It should be noted that the company buys 100,000 washers per month, equivalent to 200 kg, with a cost of US$918.92 monthly. After the proposed change, the monthly losses were reduced from 300 kg to 100 kg, minimizing the loss by 200 kg per month and 2400 kg per year, equivalent to 66.6%.

Table 5. Economics Assessment.

Investment	7081					
Depreciation Period (years)	10					
Annual Depreciation	708					
Annual Cost Reduction	280,865					
Annual Depreciation	−708					
Basis for Calculating Income Tax	280,157					
IRPJ + CSLL (Social Contribution on Profit)	30.0%					
Value of Tax + Annual CSSL	−84,047					
Annual Net Cost Reduction	196,110					
Annual Net Cost Reduction	196,110					
Annual Depreciation	708					
Annual Cash Generation	196,818					
Cash Flow	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Investment	−7081					
Annual Cash Generation		196,818	196,818	196,818	196,818	196,818
Total Cash Flow	−7081	196,818	196,818	196,818	196,818	196,818
ROI or TIR	2779.5% year					
Payback Discounted at 15% per year	0.05 year					

Besides the investment of US$1621.62 in tool acquisition, it was necessary to invest a further US$4054.05 for purchasing an eccentric press with the capacity of 12 tons for stamping the washers. The results show that the operational expenses rose with the implementation of CP due to increases in electric energy consumption and costs with labor. However, stainless steel scrap was reused at 200 kg per month, thereby representing a 67% reduction in disposal, generating savings of US$11,027.03 with an economic gain of US$21,264.86 per year.

For the ROI calculation, the investment of US$4054.05 in the purchase of a press and US$1621.62 in tools was considered, totaling US$5675.67, which resulted in a ROI of 264%. Thus, the small company achieved the return of the investment in less than seven months and after paying the investment and started to profit US$15,056.00 per year, as shown on Table 6.

Table 7 showcases the economic results before and after the CP implementation per year of small companies. The findings indicate that both small companies had economic gains with the implementation of CP, which resulted in the reduction of raw material consumption. The small company "A" invested US$7081.09 in the implementation of CP and it obtained an economic gain of US$196,818 per year by reducing the consumption of 13,500 kg of raw material. The small company "B" invested US$5675.68 for the reuse of the discards of stainless-steel plates and obtained an economic a gain of US$15,056.00 per year with a return on investment in less than seven months.

The fact that small companies generated positive economic results corroborated the studies conducted by Van Hoof and Lyon [30], which concluded that the implementation of CP in SEs contributes to economic benefits. It should be emphasized that this study innovated the method of evaluating the economic gain of the implantation of CP in SEs in the metal-mechanical sector, thereby concluding by means of empirical evidence that the actions directed toward environmental preservation generate profits. This innovation is important because this subject is little discussed in the literature in terms of practical application. Another contribution of this study was to use the ROI to overcome barriers when implementing CP at SEs, demonstrating that investments, when necessary, can be recovered in the short term. Moreover, the findings indicate that the achievement of economic gains by small companies led to the overcoming of the cultural and technical barriers of the SEs.

Table 6. Return on Investment small company B.

Investment	5676					
Depreciation Period (years)	10					
Annual Depreciation	568					
Annual Cost Reduction	21,265					
Annual Depreciation	−568					
Basis for Calculating Income Tax	20,697					
IRPJ + CSLL (Social Contribution on Profit)	30.0%					
Value of Tax + Annual CSSL	−6209					
Annual Net Cost Reduction	14,488					
Annual Net Cost Reduction	14,488					
Annual Depreciation	568					
Annual Cash Generation	15,056					
Cash Flow	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Investment	−5676					
Annual Cash Generation		15,056	15,056	15,056	15,056	15,056
Total Cash Flow	−5676	15,056	15,056	15,056	15,056	15,056
ROI or TIR	264.9% year					
Payback Discounted at 15% per year	0.56 year					

Table 7. Economic gain with the CP implementation.

Company "A"	Annual without CP	Annual with CP	Cost Reduction
Spent on stainless steel screens	US$648,648.64	US$356,756.76	US$291,891.89
Scrap stainless steel	US$13,459.46	US$2432.43	US$11,027.03
TOTAL "A"	US$635,189.18	US$354,324.33	US$280,864.86
		Economic gain = US$196,818.00	
Company "B"	**Annual without CP**	**Annual with CP**	
Spent on stainless steel sheets	US$165,405.40	US$165,405.40	Cost Reduction
Stainless steel scrap	US$16,540.54	US$5513.51	0
Waste with washers	US$12,972.97	0	US$11,027.03
Gain with scraps	US$2,918.92	−US$972.97	US$12,972.97
Labor	0	+US$675.68	US$1945.95
Electricity	0	+US$113.51	US$675.68
TOTAL "B"	US$192,000.00	US$170,735.14	US$113.51
		Economic gain = US$15,056.00	US$21,264.86

6. Environmental Assessment

Table 8 showcases the results of the environmental assessment of the companies based on the annual reduction of waste, representing a total material economized (TME) of 13,500 kg for small company "A" and 2400 kg for small company "B." The results demonstrate that the total reduction of the environmental impact of the small company "A" was 3,002,430.00 kg, with the reduction per component amounting to 194.805 kg in abiotic, 2,769,255 kg in water, and 38,205 kg in air. The reduction of waste in small company "B" was 533,736.00 kg, with the reduction per component amounting to 34,632 kg in abiotic, 492,312 kg in water, and 6792 kg in air.

The reduction of the environmental impact related to the abiotic, water, and air compartments evidences the environmental gain in the organizational practice that the company obtained with the implementation of CP practices. The results of this study contribute toward addressing the research

gaps advanced by Strugariu and Heput [55], who mentioned that the adoption of CP results in the minimization of waste in the manufacturing process allowed for environmental gains. Other authors, namely Duan et al. [56], conducted a case study in China and presented only the mass scale without assessing the environmental impact; whereas Henriques and Catarino [57] discussed such results in percentage data. Both papers indicate the opportunity for future research regarding calculating the reduction of environmental impact through evidence in organizational practice. Thus, this study measured the environmental impact reduction in the abiotic, water, and air compartments after the adoption of CP practices. This feature is a relevant subject for science and organizational practice because of the opportunity to mitigate the generation of waste, as well as reducing the consumption of raw materials in the production system. In addition, the measurement of the environmental impact promoted the overcoming of cultural and technical barriers, because besides obtaining economic gain, it was possible to develop green marketing and create environmentally correct practices.

Table 8. Environmental assessment of companies for the stainless steel component.

Company	Waste before CP (kg/year)	Waste after CP (kg/year)	Compartments				Mass Intensity Total (MIT)
			Abiotic	Biotic	Water	Air	
"A"	16,500	13,500	194,805		2,769,255	38,205	3,002,265.00
"B"	800,600	2400	34,632		492,312	6792	533,736.00

7. Conclusions

SEs are important for the economy, and as such, they need to adopt CP environmental practices in the production system to minimize environmental impacts and achieve economic gains through reduced waste generation. This paper contributes to the literature on CP in SEs by presenting a path in the identification and overcoming of the barriers to its implementation. The studies that have approached the implementation of CP in SEs treat the subject in a qualitative way, which does not allow for the presentation of a simple and economically feasible path for SEs to implant CP in their processes. This study presents an innovative solution for SEs to overcome cultural and technical barriers in the process of implementing easy-to-understand CPs, presenting alternatives to overcome barriers by identifying causes and effects, and evaluating economic results by means of a balance mass and ROI. Moreover, it develops environmental assessment through material input per service unit (MIPS), allowing SEs to have an early view of the results, and thus contributing to reduce the economic difficulties that SEs may face. The proposed approach is an actionable stepwise process that can be kicked off in contexts with limited availability of resources (e.g., financial, time, etc.), and that for this reason can offer a good stepping stone for small companies to create awareness and initiate engagement with cleaner production objectives.

It was concluded that it was possible to overcome the cultural and technical barriers in SEs by contributing to the organizational practice and scientific research because of the economic and environmental gains obtained by the companies. The small company "A" earned US$196,818.00/year, with a reduction in environmental impact of 3002 tons/year. The small company "B" achieved an economic gain of US$15,056.00/year with an impact reduction of 533 tons/year, demonstrating that the economic and environmental gains allowed the Brazilian SEs of the metal-mechanic sector to overcome technical and cultural barriers in the process of CP implementation.

The following policy implications can be obtained from this study's findings. The results suggest that further incentives to the adoption of cleaner production practices should be included in the agendas of regional development agencies. In this case, regional bodies have a potentially greater impact and opportunities to deploy effective messages about the importance of cleaner production that can lead to changes in the practices of small companies, highlighting the benefits and promoting the visibility of good practices in comparable manufacturing contexts. Moreover, the information campaign to promote cleaner production should highlight the need to conduct comprehensive approaches in the assessment of the costs and gains of the implementation of cleaner production. For SEs, the technological changes

involved can represent substantial investments, that although having the potential to be overcome with gains and savings in the production process, can require some time for the full return and this may discourage such interventions in small manufacturing contexts. Eventually, local authorities may consider stimulating the development of targeted funding solutions to finance cleaner production initiatives in economic contexts where small companies are a very important part of the ecosystem.

The results of this study represent a scientific and practical advance in the identification and overcoming of barriers in the implantation of CP by SEs. However, this study considered only Brazilian SEs in the metal-mechanic sector. For future research, it is recommended to use the tools presented in this study in different industrial segments and countries. Furthermore, it is suggested that other researchers may propose new ways and present new approaches to overcome barriers when adopting CP.

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