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Overcoming Barriers to the Implementation of Cleaner Production in Small Enterprises in the Mechanics Industry: Exploring Economic Gains and Contributions for Sustainable Development Goals

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Abstract: The purpose of this study is to evaluate the economic and environmental gains that result from the implementation of cleaner production in a small enterprise (SE) from the metal and mechanics industry, allowing for overcoming barriers and contributing to sustainable development goals. The research work builds on a case study that involved several data sources, including semi structured interviewing and non-participant observation. Data analysis involved the calculation of mass balance, building solid and liquid waste that were minimized in the process. The results suggest that cleaner production led to economic gains, by allowing for reduction in losses and promoting a better use of raw materials. It also led to environmental improvements by means of the implementation of a wastewater treatment station that allowed for the reuse of water in the manufacturing process. It was concluded that the economic gain in the project played a determinant role for the SE to overcome the barriers for the implementation of CP and leading to the reduction of the environmental impact in the abiotic, biotic, water and air compartments, as estimated with the Mass Intensity Factor. The study offers a timely and relevant contribution for the literature in the field, while offering insights for managerial practice, and the attainment of the Sustainable Development Goals defined by the United Nations Development Program.

Keywords: economy and environmental advantage; cleaner production barriers; cleaner production; metal mechanics industry; sustainable development goals

1. Introduction

Small enterprises (SEs), defined here as companies with an annual turnover \leq EUR 10 million [1], play an important role in the world Economy. Despite of the acknowledged importance of SEs, only recently they have started to receive adequate attention in the academic literature [2]. The socio-economic relevance of SE is attributed to several factors including its role in the promotion of social development and economic stability, that are fundamental to support political stability and job creation.

Several environmental problems that are associated with the operations of SE have been highlighted in recent years. In the specific context of the mechanics industry some of

them are deemed as complex given the high costs that are involved in any investments that are required to adopt clean technologies, as well as for the treatment and disposal of waste.

To a great extent, the management of SE is characterized by the prevalence of a short run perspective. Moreover, there is a substantial diversity in the flows of waste that are generated that requires the implementation of very differentiated strategies in order to implement any reduction and reutilization practices, therefore creating important managerial difficulties. In recent years, the economic development and the aggravation of environmental problems has been triggering the pursuit of solutions to address such challenges faced by SEs. These enterprises aim for cost effective solutions to reduce their environmental impact, and therefore engage on activities that allow the reengineering of their products and processes in order to make them more efficient in the utilization of resources while reducing the volumes of waste [3,4].

The SEs operating in the mechanics industry act as suppliers for other economic activities across the value chain in several industries, such as the automotive sector and the construction industry. They are responsible for an important volume of negative impacts over the environment concerning the levels of pollution generated by their activities, as well as for their intense consumption of raw materials, and the risks associated with the disposal of production waste [5].

According to [6], one of the key challenges is the need to align the economic growth with the objectives of contributing to cleaner and sustainable environmental conditions. Against this background, the paradigm of Cleaner Production (CP) stands out as a strategy that is economically viable to reduce the environmental impact of production systems, offering superior performance for environmental protection and reducing the risks for humans by focusing on the reduction of the volumes of waste that are generated [7]. The core principle of CP is the efficient use of natural resources and energy, and the reduction of risks and impacts for humans and the environment throughout the life cycle of a product [8]. According to the perspective inscribed in the Sustainable Development Goals proposed by the United Nations, energy audits can increase the opportunities for companies to achieve higher standards of energy efficiency [9].

The implementation of CP practices leads to more competitiveness of SEs, increasing the quality of their products, and offering alternatives for achieving improvements in the environmental performance, reducing costs, and allowing for the creation of opportunities for new products development and new business opportunities [10]. The results achieved with CP can be assessed using the methodology proposed by [11] involving the monitoring of environmental indicators that must address relevant information, allowing for a better understanding of the production process impacts, and for the evaluation of the impacts of CP in the environmental performance of the company.

Despite the benefits that are attributed to CP, its rate of implementation is still modest in SEs. This is usually attributed to factors related to the lack of resources, and the limitations in decision making that are associated to the concentration of managerial responsibilities in the hands of the owners, and often to the lack of leadership capabilities [12]. Other limitations that are often advanced to explain the low implementation of CP in SEs include the lack of financial resources to invest in technologies for the reduction of waste and emissions, as well as the lack of qualified human resources and infrastructure problems [13,14].

Existing research about the implementation of CP in the metal and mechanics sector refers to the opportunity of achieving economic gains supported by the estimation of the returns on investment (ROI) [15,16]. In what concerns the minimization of the environmental impact, several studies mention the existence of evidence of improvements, despite not offering an explicit quantitative measurement for them [17,18]. Some studies use the mass balance method to determine and quantify the reduction in the consumption of raw materials and the reduction in waste. However, the studies do not offer quantitative data for the environmental impact [16,19]. Other studies offer data in relative terms to demonstrate the reductions in losses, but do not assess the environmental impact of such losses [5,20,21].

Only one study, conducted with a Brazilian SE in the metal mechanic sector, showed that the cultural and technical barriers have negative impacts for the adoption of CP. Such barriers can be overcome by economic and environmental gains through investments in the training of employees and in the acquisition of more efficient machinery and equipment [22]. However, this research did not identify any previous work addressing the SDGs by implementing environmental actions to overcome CP barriers. Sustainable development needs to become the key goal of environmental actions to overcome CP barriers. The SDGs aim to allow for meeting the needs of the society by means of an intelligent use of sustainable science [23,24].

This study subscribes to the need of assessing the environmental impacts at several levels, including biotic, abiotic, air and water as environmental actions for overcoming barriers for CP, and therefore contributing to attain the SDGs. Accordingly, the study assessed the reduction in the environmental impact building on the Mass Intensity Factor (MIF) instrument [25]. As such, the first research question of this study, is formulated as follows: How can the reduction in environmental impacts for the biotic, abiotic, air and water elements, lead to overcoming the barriers to the implementation of CP and contribute to attain the SDGs?

Another research gap that was identified concerns the lack of studies offering quantitative evidence about the process of overcoming the barriers for the adoption of CP, while connecting it with the SDGs. Existing work related to the barriers for the adoption of CP in SEs in the metal and mechanics sector usually refer to the SDGs but fail to address the economic, social and environment aspects with an equivalent depth [26]. Companies consider that the specific limitations of SEs are determinant for the ability to understand the barriers for the adoption of CP and highlight that such limitations affect the ability to access relevant knowledge and information for overcoming the barriers. A lack of understating of the benefits that result from the adoption of CP persists [14,27].

CP practices are attributed a great importance for the achievement of sustainable development [28]. The work of [29–31] concluded that CP practices lead to relevant economic and environmental results. SEs have a focus on production management problems, often disregarding environmental factors, due to the pressure they face for meeting short run objectives, together with the lack of resources [16,32]. These companies usually do not have enough human resources with the necessary technical capabilities, nor departments that are adequately focused on innovation [14,33]. Such factors are important for the identification of the barriers to the implementation of CP and are the key for pursuing alternatives for sustainable solutions for their products and processes [4,27,32]. Very often, SEs face financial difficulties that are associated with lack of knowledge about the returns on the investment. As such, the knowledge about the economic gains that could be achieved by SEs, would mitigate the financial barriers, and would contribute to the attainment of SDGs. This leads to the second research question of this study: How can economic gains lead to overcoming the barriers for the adoption of CP, and contribute to attain the SDGs?

As such, one of guiding objectives of this study was to evaluate the economic and environmental gains that resulted from the implementation of CP in a small enterprise in the metal and mechanics industry, allowing for overcoming barriers and contributing to the SDGs. It is important to highlight that there are few studies relating CP with the SDGs [9,23,26,28,29]. However, sustainable development must be considered as a key issue in the adoption of CP [34], particularly when it allows for extending the CP practices to the stakeholder community [35,36]. As aforementioned, existing studies focus in addressing the economic and environmental gains mostly from a qualitative perspective. Existing work builds on: cost–benefit analysis [37]; the improvement in the use of resources and the efficiency in materials [38]; the recycling and the reuse of waste [39]; the reduction in the consumption of raw materials and inputs and the minimization of the volume of waste generated [40–42]; the improvements in the use of resources [43,44]; the reduction of emissions [45,46]; and the adoption of clean technologies [47,48]. This is the first study that addresses economic and environmental gains and the overcoming of barriers for

the adoption of CP, while contributing to SDGs. The article is organized in five sections, including the introduction, a section devoted to the description of materials and methods, the results, a discussion and a conclusion.

2. Materials and Methods

According to [49], the case study method is adequate when the research question is ample and complex, and the existing knowledge is insufficient. Likewise, case study is recommended when the phenomena to investigate cannot be addressed outside of its natural context. As such, case studies allow for exploratory research in a domain for which the number of studies is still limited. Case study allows for the development of contributions to theory development, building on empirical observation.

The evidence for a case study can be derived from several sources, including documents, archival data, interviews, direct observation, participant observation and physical artefacts [49]. Accordingly, and building on the research questions that were put forward, a case study was conducted allowing to shed light into the subject with an applied case and allowing for a rich understanding of the phenomena [49]. The sources of evidence used in the study included: archival data, semi-structured interviews and nonparticipant observation. These methods allowed for the collection of qualitative and quantitative data [50]. The semi-structured interview was conducted with the production manager and supervisor of the company. Interviews are considered key instruments for the conduction of case studies [51,52]. Observation was conducted in the production process. The desk research resorted also to the electronic archives supplied by the company, referring to elements such as the volumes of waste, the consumption of raw materials, the costs associated with waste disposal and related information, therefore offering valuable data to complement the information collected in the interview, and allowing for gathering qualitative and quantitative data [53].

The study was conducted in a Brazilian SE belonging to the metal and mechanics sector. This company was chosen in face of some peculiar characteristics: it had implemented several CP practices that allowed the researchers to explore their effect on the economic and environmental areas and it allowed the investigators complete access to the data required to perform the necessary studies and analyses.

In the field research, a first phase involved asking the respondents to attribute a weight to rate the relative importance of the barriers identified in the literature (Table 1). The barriers with higher importance were rated with 10 points.

Table 1. Barriers to the implementation of CP.

Barriers	Rating Attributed by the Specialist	Concept	References
Economic and financial	10	Lack of economic resources for investing in environmental actions	[3,13,14,27,30,46–48]
Cultural	9	Lack of knowledge and difficulties in accessing information	[14,18,27,30,32]
Governmental	2	Public policies for the implementation of CP	[3,14,27,30,31,46]
Organizational	2	Risk of survival of the enterprise	[3,14,27]
Technical	10	Lack of professional capabilities	[3,10,13,27,30–32,46,47]
Market	1	Low perceptions from customers, suppliers, and competitors about the adoption of CP	[10,27,30,31]
Social	2	Lack of social awareness	[14,30]
Behaviour	3	Lack of commitment	[3,13,27,32]
Technologic	10	Obsolete equipment and tools	[3,13,32,48]

Source: Adapted with permission from [22].

After the data collection phase, the next stage involved the evaluation of the economic and environmental results of the implementation of CP, to address the proposed research questions. The instruments used to evaluate the economic and environmental results, as recommended by [34,54–59] followed the methodology for the environmental evaluation of the implementation of Eco efficiency tools in industrial operations. A first step involved the collection of data to identify the reduction in waste and emissions, by means of a mass balance method, offering detail about the materials and the components and calculation of the Total Saved Materials (MTE). The data about the waste and emissions allowed for measuring the economic and environmental results. Next, the mass balance was computed with the purpose of identifying economic gains. Returns were also calculated for any investments made. The evaluation of the environmental gain followed using the Equation (1) for Mass Intensity Factors (MIF). For this purpose, the study considered the Mass (M) and the Intensity Factor (IF), using Equation (2) next for obtaining the Mass Intensity per Compartment (MIC). It measured the reduction in the environmental impact for each abiotic compartment (w), biotic (x), water (y), air (z) and other (n...). This allows for the quantification, using Equation (3) of the reduction in the total impact, Mass Intensity Total (MIT) that brings together all the MICs.

$$\text{MIF} = M \times \text{IF} \quad (1)$$

$$\text{MIC} = (w + \text{IF})(x + \text{IF})(y + \text{IF}) \quad (2)$$

$$\text{MIT} = (\text{MIC}_w + \text{MIC}_x + \text{MIC}_y + \text{MIC}_z + \text{MIC}_n \dots) \quad (3)$$

The values for MIF presented in Table 2 represent the intensity factors used in the study, according to the specified by the relevant entity [60].

Table 2. Intensity Factor for the Materials addressed in the study.

Component	Specification	Abiotic	Biotic	Water	Air
Aluminium	Secondary	0.85	0	30.74	0.95
Aluminium chloride	AlCl ₃	8.61	0	110.63	1.15
Lead	Pb	15.6	0	0.00	0.00
Copper	Secondary-Cu	2.38	0	85.51	1.32
Nickel	Ni	141.29	0	233.34	40.83
Tin	Sn	8468.00	0	10,958.00	149.00
Water	H ₂ O	0.01	0	1.30	0.001
Lime	Virgin	1.44	0	5.56	0.03
Electrical power	Industrial	2.67	0	37.92	0.64
Chlorine	Cl ₂	3.84	0	10.9	1.09
Oil	Hu, 42.8 MJ/kg	1.36	0	9.7	0.02
Carbon steel	Secondary	8.14	0	63.67	0.44

Source: Adapted with permission from [60].

The data collected in the case study allowed for the presentation of economic results and motivated the company to continue to work towards overcoming the barriers to CP, while providing information for the evaluation of the reduction of its environmental impact.

3. Analysis and Discussion of the Case Study Evidence

The company addressed in the study is classified as a small enterprise, involving 68 direct employees. The company is located in the City of São Paulo, Brazil, and its Production is targeted to the automotive sector, white line appliances and big auto parts wholesalers. The company is an ISO 9001:2015 certified company, that produces blind rivets, solid tubular nucleuses and drawn wire, using cold forming with materials such as steel, carbon and aluminium. In what concerns the requirements for environmental legislation the company addressed in the study meets the prevalent standards regarding the disposal of contaminant waste, and the noise levels released by the manufacturing unit,

an aspect that was particularly relevant due to the proximity of the factory to an urban residential area. The findings exhibited in Table 1 suggest that the main barriers associated with the implementation of CP in this SE are related with the lack of economic resources for investing in environmental actions; the lack of qualification and training of the human resources; and the use of obsolete equipment and tools, leading to the generation of waste. It was also observed that cultural barriers have negative impacts for the implementation of CP due to the lack of knowledge and low employee awareness about environmental issues.

3.1. Process Analysis

The identification of the polluting load generated by the company involved multiple observations of the production processes devoted to the production of aluminium wire and aluminium and steel fasteners. The research work also involved the examination of administrative documents such as reports for the wastewater treatment plant, and documents concerning the control of waste disposal activities, for solids and liquid waste.

In the production process for the fasteners the components are made in aluminium by means of cold forming processes using drawing mills and horizontal presses. Each month, an average of 50 tons of steel wire and 12 tons of aluminium wire are used, for an average monthly production of 45 million fasteners. The loss in raw materials in these first stages of the production process was around 2 tons of steel and 0.8 tons of aluminium per month. The implementation of CP led to a reduction in the loss index to 1.3 tons of steel and 0.5 tons of aluminium per month. These materials were then stored adequately and sent for recycling, periodically.

The fabrication of the fasteners uses cutting oil that becomes impregnated in the surface of the components and is separated by means of spinning, with the purpose of being reused. Not all the oil is effectively removed in this first phase of cleaning, so the parts are next washed with hot degreasing so that they can proceed to thermal treatment and polishing. For a long time, all the effluents generated in the thermal treatment and polishing sectors were discarded in the public sewage. However, to meet the environmental legislation the company installed a Wastewater Treatment Station (ETE) providing a treatment for the wastewaters generated in the production process. For the implementation of the ETE the company invested about USD 59,000 including the costs for the project, equipment, and lab analysis, as well as in training and awareness programs for the employees.

The implementation of the wastewater treatment station, that aimed at achieving standard levels for the concentration of impurities in the residual waters—as specified by the prevalent legislation—involved several phases, including: (a) the conduction of treatability tests (Jar Test) to determine the volume of flocculants and coagulants, reducing the concentrations for metals, oils and grease; (b) the implementation of a separating box (for water and oils); (c) the implementation of a homogenising system with air; (d) the installation of a tank for the preparation of solutions; (e) the installation of tank for mixing and *pH* calibration; (f) the installation of a decanter tank for solid metals. The local environmental legislation establishes the following requirements for wastewaters that are discarded from the ETE: *pH* ranging between 6.0 and 10; temperature below to 40 °C; concentration of sediments up to 20 mL/L in nine hour testing using a Inhof cone; absence of grease and oils, a concentration of 150 mg/L of soluble substances in hexane; absence of explosive or flammable substances; absence of substances that can cause clogging in pipes; absence of any substances in concentrations that can be toxic for biological processes.

In the first phase, that was devoted to the data collection, an annual mass balance was estimated, building on the Mass (*M*) of solid residues, liquids and emissions generated in the manufacturing processes and in the wastewater treatment station (ETE), that were minimized with the implementation of CP. This allowed for the reduction in the environmental impact, as displayed in Table 3.

Table 3. Intensity Factors for the Materials used in the study.

Components	Classification	Local	Unit (Monthly)	Annual Waste (kg)
Aluminium	Secondary		0.3 mg/kg	0.003744
Aluminium chloride	AlCl ₃		0.3 mg/kg	0.003744
Lead	Pb		9.68 mg/kg	0.1208064
Copper	Cu		17 mg/kg	0.21216
Nickel	Ni	Wastewater Treatment Station (ETE)	11 mg/kg	0.13728
Tin	Sn		36 mg/kg	0.44928
Water	H ₂ O		192 m ³	1,920,000
Lime	Limestone		140 kg	1680
Electrical power	Kw		15 kw	180
Chlorine	Cl ₂		0.05 mg/kg	0.00624
Oil	Hu, 42.8 MJ/kg		20 kg	240
Steel	Secondary	Manufacturing process	700 kg	8400
Aluminium	Secondary	Manufacturing process	300 kg	3600

With the implementation of CP in the wastewater treatment system, the company was able to reuse the water in its manufacturing process, complementing the ETE with the implementation of the necessary units for the polishing. These included: systems for membrane filtration; chemical oxidation and disinfection to promote the separation between solid and liquid residues, by using continuous decanting for the precipitators, and also the correct destination for solid and liquid waste.

3.2. Economic Evaluation

The second phase of the study involved the conduction of the annual economic evaluation. To start with, an investment of about USD 35,000 was made in the manufacturing process to implement CP, as well as an in the wastewater treatment station of USD 15,400, for the acquisition of equipment for water reuse in the production system.

The data presented in Table 4 provides evidence about the increase that was registered in the operational expenses, due to the implementation of the wastewater treatment station. Such expenses are related to the increase in the use of chemicals for the treatment of the effluents, as well as for the energy consumption that is necessary to operate the pumps and the lab analysis that had to be subcontracted. The training of employees also involved an investment of about USD 5000, to guarantee the adequate capabilities to operate the ETE. To this end, the quality department also added the function of cleaning the system, the handling of chemicals, and the removing of the sludge that is generated in the process, for disposal. Quotation was done for subcontracting the lab tests for the residues, with the purpose of issuing the necessary documents for the transport and the disposal of the sludge. Meanwhile, a reduction in the consumption of water was observed, after the implementation of CP from a volume of 4320 m³/year to 2400 m³/year, resulting in a total of USD 44,856 of savings. This represented 58% of the water reuse in the production system. A gain of 66% was also observed due to the reduction in the waste of raw materials in the manufacturing of fasteners of steel and aluminium. The volume of such waste reductions was from about 24,000 kg each year to 15,600 kg, for the steel, and from 9600 kg to 6000 kg for the aluminium, leading to an overall gain of USD 78,000. As such, a total economic gain of BRL 112,031 was attained, as displayed in Table 4.

Table 4. Economic Gains from implementation of CP.

Items	Annual Expenditure—without CP (US\$)	Annual Expenditure—with CP (US\$)
Chemicals	1200	2640
Lime	180	180
Activated carbon	180	180
Sand	600	600
Electrical power	960	1440
Human resources	7200	7200
Lab tests	3000	11,904
Disposal certificate	1000	1000
Transport of waste	600	600
Destination	2496	2496
Water	106,800	61,944
Total for ETE	124,216	90,184
Gains/capital for ETE		34,031
Waste—steel	84,000	54,000
Waste—aluminium	144,000	96,000
Total Manufacturing	228,000	150,000
Gains/Capital Manufacturing		78,000
Economic Gain		112,031

The measurement of the return on investment for the implementation of CP took into account the investment in the manufacturing process—USD 35,000; the investment in the wastewater treatment station—USD 15,400; and the investment of USD 5000 in training, adding up to USD 55,400, considering a 10-year depreciation. The estimation also considered the reduction that was observed in the annual costs—USD 112,031—and an Income tax rate of 30%. This leads to an annual cash generation of USD 80,083. As such, the capital invested will be totally recovered after one year.

Furthermore, it was possible to measure the economic advantage that the company obtained with the implementation of CP. The economic and financial gains allowed to make up for the lack of resources for the investment in environmental actions, given the need for training and the acquisition of clean equipment.

The training offered to the employees contributed also for the reductions in the consumption of energy, raw materials, oils and chemicals, in addition to minimizing the generation of solid waste. A wastewater treatment station was also implemented, leading to the reduction in the consumption of water.

Against this background, by overcoming the economic, technical and technological barriers, several contributions were achieved for the attainment of the SDGs. These included: (i) for SDG 6, the impacts for the use of water and basic sanitation by allowing for reductions in the consumption of water due to the implementation of the wastewater treatment station; (ii) for SDG 9 that relates to the innovation and infrastructure, with the implementation of CP and the development of the wastewater treatment station; (iii) for SDG 12, concerning the sustainable production and consumption, through the reductions in the consumption of energy, water, oils and chemicals, and the minimization of the generation of solid waste.

3.3. Environmental Evaluation

In the third stage of the study the environmental gains associated with the implementation of CP were evaluated. In Table 5 we offer a view of the material intensity for each compartment (MIC) and the total material intensity (MIT). The results show that the enterprise reduced the consumption 97,696 kg for the abiotic compartment, 3,165,071 kg for water and 9279 kg for air, resulting in a total environmental gain (GA) 3,272,048 kg. A key issue concerns the water reuse that was made possible by the implementation of the

wastewater treatment station that led to a reduction in consumption of natural resources of 2,517,120 kg.

Table 5. Environmental evaluation.

Component	Sector	Compartments				Total by Component
		Abiotic	Biotic	Water	Air	
Aluminium		0.00319		0.1151	0.0036	0.12189
Aluminium chloride		0.0323		110.63	0.4142	111.0765
Lead		1.885				1.885
Copper		0.505		18.141	0.28	18.926
Nickel		19.396		32.033	5.605	57.034
Tin	Wastewater	3812.59		4923.21	66.943	8802.743
Water	Treatment Plant	19,200		2,496,000	1920	2517,120
Lime		2419.20		9340.80	50.4	11,810.4
Electrical power		480.6		6825.60	115.2	74,214
Chlorine		0.024		0.63	0.0068	0.6608
Oil		326.4		2328	4.8	2659.2
Steel		68,376		534,828.00	3696	606,900
Aluminium		3060		110,664.80	3420	117,144.8
Mass Intensity per compartment (MIC)		97,696.64		3,165,071.96	9279.65	3,272,048.25
Mass Intensity Total (MIT)						

The last stage of the study concerned the comparison between the economic and environmental gains. Data suggests that the total saved materials (MTE), considering the solids and liquids that were minimized of 1,934,101 kg, that corresponds to 3,272,048 kg when considering the total material intensity in the ecosystem. This data allows for determining the Eco efficiency levels.

For SEs the economic gains are the most relevant for overcoming most of the barriers. However, this study shows that the minimization of environmental impacts also contributes to overcoming cultural barriers. The study documents that the awareness activities about the environmental gains, that were conducted with the employees, had positive impacts. As such there is evidence of contributing for the SGD 15 concerning the ecosystems and the biodiversity associated with the environmental impacts from the abiotic, biotic, water and air compartments.

4. Discussion and Contributions

The results of the study suggest that the economic and financial barriers are among those that most hinder the implementation of CP in a SE. This is largely explained by the lack of resources for the investments in new technologies, as well as by the difficulties in accessing financing and the lack of qualification of employees in the specific domain of environmental issues. The economic factor emerges as the key obstacle for the SEs in the metal and mechanics sector when called for decision making and implementation of environmental practices. Former studies highlight the economic determinants as key obstacles that are hard to overcome [27,44]. The study supports that the achievement of an economic gain is a key requirement for the survival of SEs and that its investments are targeted to increase the production capabilities often disregarding the environmental factors. To invest in environmental actions, SEs need to have evidence of economic returns. Otherwise, such investments will very likely not occur, even if there is a growing understating about the environmental issues, its importance to the strategy of the company and for the achievement competitive differentiation. Several authors have also highlighted the importance of CP for sustainability [29].

The study illustrates how the economic factors have a direct and indirect influence for overcoming the barriers for the adoption of CP. The strategies described in the study to

overcome the barriers to CP were derived from observing the combination of the economic benefits, the environmental impacts, and the implementation costs.

The project generated gains and savings for the company, suggesting the possibility of developing a stepwise strategy for the implementation of CP to reduce the financial burden that is usually associated with it. These results are aligned with [27] that affirm that given the specificities of SEs, some specific actions might be required to overcome the upfront barriers related with costs and with the lack of familiarity and knowledge about the implementation of CP. The economic gains achieved by the company addressed in the study allowed for investments in the improvement of technical and professional elements, contributing for the motivation of employees and raising the awareness about the actions for the implementation of CP. This result is also in accordance with the findings of [29] that observed that the CP barriers can be overcome with evidence of economic and environmental gains, and by means of investments in the qualification and training of employees, as well as in the acquisition of more efficient equipment.

In the work of [15], it is mentioned that the estimation of the volumes of waste and emissions is necessary for the effectiveness in the adoption of CP because there are many managers that are unaware of the opportunities to achieve financial gains from the adoption of CP. The studies of [10,30] contributed to this argument by referring to the opportunity of achieving economic gains from the implementation of CP. However according to [37], CP is not thoroughly known in terms of cost-benefit analysis, and that most companies does not make a viable comparison between the environmental investments focused on the end line and the investments related with CP. This study is aligned with such findings in the literature and the organizational practice by demonstrating a substantial economic gain in the SE due to the reduction that was achieved in water consumption following the adoption of CP and the implementation of the wastewater treatment station, that allowed for the reuse of water in the manufacturing process. It was also possible to observe a reduction in the losses and in the waste by means of a better use of the raw materials leading to an overall economic gain of USD 112,031.

In this context the perspective of achieving economic gains triggered the company to adopt a CP approach and to pursue the SDGs. The findings of the study are therefore aligned with theory, highlighting that economic gains can be an incentive to overcome barriers in the adoption CP, and offering a first empirically documented support to this hypothesis. The study also offers a pragmatic contribution by describing and illustrating how to perform the economic assessment of the adoption of CP, notably by addressing the estimation of the economic viability and offering an empirical basis for advancing the knowledge of the managers in this field.

The study also documented how obtaining economic gains with the adoption of CP in SEs can be associated with overcoming barriers on financial, technical and technological domains. The company invested in training for the employees and invested in new equipment leading to reduction in energy consumption, raw materials, oils and chemicals, while minimizing the generation of solid waste. The implementation of the wastewater treatment station was also determinant to reduce the water consumption.

Another relevant result offered by the study concerns the evaluation of the environmental impact at several levels including abiotic, biotic, water and air, while promoting the awareness about the damage that manufacturing can cause to the environment when there is a less cautious use of raw materials. Similar results were found in the work of [23,24] that considers that microbiology can contribute for the attainment of a more sustainable future. There is still a paucity of research work addressing the relationship between the activities of SEs and the preservation of the environment, and a lack of evidence about solutions that can be applied and that lead to both economic and environmental gains. For this reason, several authors have claimed that the environmental actions are still far from being a reality for most of the SEs [12–14,26].

The study results led to the observation that it is necessary to perform the evaluation of the reduction in the environmental impact from several perspectives, including the biotic,

abiotic, water and air, in order to fully capture the contributions for the attainment of SDGs. The assessment of the reduction in the environmental impacts was performed with the mass Intensity Factor (MIF) tool, offering, therefore, another relevant contribution to the advancing of the knowledge in this field, given the paucity of quantitative studies about the overcoming of barriers to CP.

The actions implemented by the SE contributed for attainment of several SDGs, as shown in Figure 1: SDG 6, concerning water and sanitation, by reducing the water consumption following the implementation of the wastewater station; SDG 9, associated with innovation and infrastructure by means of the minimization of the consumption of energy, raw materials, oils, chemicals and the minimization of solid waste. The reduction of environmental impacts, also contributed to overcome the cultural barriers, supported by the awareness actions that were implemented, therefore contributing to the SDG 15 that is related with ecosystems and biodiversity, with the reduction of environmental impact for biotic, abiotic, water and air compartments. This is the first study to address how economic and environmental gains contribute to overcome barriers to the implementation of CP, for SEs, while evidencing the contributions for the SDGs.

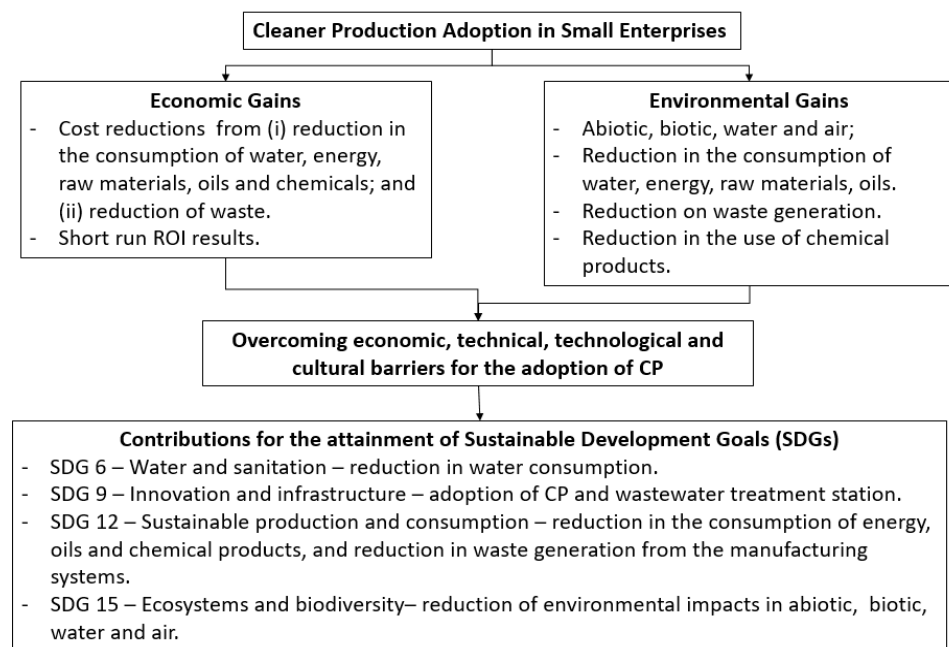


Figure 1. Contributions for the attainment of Sustainable Development Goals.

5. Conclusions

Besides the economic and environmental gains already reported herein, this research contributes for sustainability and for several of the SDG defined by the United Nations Development Program. Specific contributions were found for SDG 6 (water and sanitation), 9 (industry, innovation, and infrastructure), 12 (sustainable production and consumption) and 15 (ecosystems and biodiversity), as illustrated in Figure 1 above.

The results suggested by the study are relevant for the advancement in addressing the main barriers identified for the implementation of CP, notably lack of resources for investments in CP and the lack of technical knowledge for the implementation of CP.

Accordingly, the study puts forward that the SE from the metal and mechanics sector can work on developing plans and studies to assess the economic feasibility of implementation CP and obtain a financial return from it in the short run.

The study also offers a contribution for the academic literature and public policies about the adoption of CP, its barriers, and its contribution for sustainability by offering a description of how to develop a project for implementing CP, building on the economic

and environmental evaluation. The study documents how such analysis contributed to overcoming the barriers for the implementation of CP usually pointed out for SEs, motivated by the potential economic gains and the reduction in environmental impacts. Likewise, the study also offers a contribution for managerial practice, notably in the domain of sustainability, by offering managers evidence about how environmental concerns can be addressed with the implementation of CP actions, by promoting the improvement of environmental conditions while generating economic gains with very attractive returns on investment.

The study is not free from limitations, notably because it offers an exploratory approach that builds on the analysis of a single case study. However, the study offers a timely and relevant contribution by illustrating the application of the methodology advanced for evaluating the economic and environmental impacts that are associated with the implementation of CP, in an important industrial sector. Future replications and extensions of the study should address other industries and allow for cross-case comparison and generalizations.

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