

Model for environmental management accounting and sustainable decision-making in manufacturing micro and small enterprises in Chimbote, Ancash

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Abstract

This exploratory, pilot-type study examines how the environmental management accounting model, referred to throughout this paper as EMA, can influence sustainable decision-making of micro and small manufacturing enterprises (MSEs) in Chimbote. A mixed-method, quasi-experimental one-group pretest-posttest design (without a control group) was used, incorporating Likert-type questionnaires, semi-structured interviews and document review. Twenty MSEs voluntarily participated in the pilot implementation of the model. Participants showed changes associated with the intervention: environmental accounting knowledge scores increased by 15.71% and sustainable decision-making scores by 29.80%, both statistically significant according to the Wilcoxon signed-rank test ($p < .05$). Thematic qualitative analysis showed a positive attitude toward the model, highlighting its usefulness for identifying hidden costs, optimizing resources, and supporting a sustainable organizational culture. Limited technical training and resources were the main barriers identified, while access to green markets and improved corporate image emerged as opportunities. Given the small, non-probabilistic sample and the absence of a control group, these findings should be interpreted as preliminary, exploratory evidence rather than proof of a direct causal effect. Overall, the EMA model offers a practical, flexible, and scalable tool for business sustainability, provided it receives institutional, academic, and regulatory support.

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1. Introduction

It is a challenge that in the world, most small and medium-sized businesses struggle to integrate formal environmental management systems in their accounting and financial activities [1], [2]. Comparable difficulties have been reported in other economic contexts [3]. The effectiveness of adoption of ISO 14001:2015 in the management of environmental impacts is still constrained by the gap between its traditional accounting and the

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global sustainability standards as firms cannot internalize the actual environmental costs in their economic choices [4], [5]. Similar gaps have been documented elsewhere [6]. Although the ISO 14001:2015 gives rise to an internationally accepted standard of managing the environmental impacts, its adoption has been limited, particularly by firms lacking technical capacities or financial resources [7], [8]. This limitation has also been confirmed in other manufacturing sectors [9].

Lack of integration of ISO 14001 principles in accounting management has been cited as one of the factors that have led to low ecological efficiency in manufacturing industries in the developing countries where environmental regulations are less stringent or poorly enforced [10], [11]. Against this backdrop, there is an urgent need for adapted models that enable micro and small enterprises to meet international standards and improve their economic and environmental performance [12], [13]. Recent literature further underscores this necessity [14], [15].

Even though sustainability was seen as extremely important by 49.8% of companies in the region and 59% in Peru prior to the pandemic, the situation changed radically in 2021: 71% of companies in the region and 76% in Peru recognized the strategic importance of sustainability for their business future [16]. This trend is consistent with the Ministry of the Environment [17] and General Environment Law No. 28611, which encourages sound and healthy ecosystems. Companies have begun to position themselves as significant players in environmental conservation and the appropriate use of natural resources, contributing to the sustainable growth of the country [18].

Micro and small enterprises (MSEs) within the manufacturing sector of the Ancash region are the backbone of the local economy, which, however, faces major constraints regarding sustainability. Most of these businesses fail to record environmental costs including energy usage, waste production, and pollution in their financial accounting, thereby distorting their financial statements and creating a barrier to making informed, sustainable decisions [6], [19]. Furthermore, the absence of accounting models tailored to this reality makes it difficult to identify hidden costs, comply with environmental regulations, and fulfill the requirements of a more conscious market [20] - [22].

The lack of environmental accounting proposals specifically for Peruvian MSEs restricts organizational sustainability, as financial decisions continue to ignore ecological costs. To address this, environmental accounting enables firms to identify, capture, and value environmental impacts in accounting terms [23] - [25]. Nevertheless, its effective implementation is hindered by a lack of specific training and contextual adaptation. Thus, there is a strong need for an environmental management accounting model that unifies ecological and financial accounting while fitting the reality of local manufacturing MSEs. Furthermore, this proposal directly supports the Sustainable Development Goals (SDGs), particularly those related to responsible production, climate action, and sustainable innovation [26], [27].

Recent empirical evidence continues to reinforce the strategic relevance of integrating environmental and governance considerations into organizational accounting and reporting practices. Performance-based budgeting has been shown to enhance sustainable performance through innovation and information-quality mechanisms [28]. In parallel, corporate social responsibility, technological capability, and green entrepreneurial orientation have been found to foster green innovation and sustainable performance [29]. Likewise, embedding ESG practices into corporate strategy has been associated with stronger brand loyalty through consumer brand identification [30], while audit quality and female audit-committee characteristics have been linked to reduced earnings management [31]. Governance structures and ownership types have also been shown to influence firm performance during periods of crisis [32]. Although conducted in different institutional and sectoral settings, these studies collectively support the premise that environmentally and socially responsible accounting and governance practices are associated with improved organizational performance, reinforcing the relevance of the EMA model proposed for manufacturing MSEs in this study. This is consistent with a broader shift in sustainable-development theory, from early awareness-raising efforts toward more integrated, performance-oriented frameworks [33], and with growing attention to how environmental information is incorporated into managerial accounting in response to climate-related pressures [34]. Addressing the concerns discussed above, the research question is as follows: How does the use of the environmental management accounting model influence sustainable decision-making in manufacturing MSEs in Chimbote in 2025?

The general aim of this study was to measure changes in the application of the environmental management accounting model and its effect on sustainable decision-making in manufacturing MSEs in Chimbote in 2025. To achieve this overall goal, the following specific objectives were set:

1. Test the level of environmental accounting knowledge among participants prior to and following the implementation of the model.
2. Test the difference in sustainable decision-making when the model has is implemented.
3. Examine participants' perceptions of the environmental accounting model used.
4. Determine the obstacles and opportunities for MSEs regarding the adoption of the suggested model.

This study is highly relevant as integrating an environmental approach into the accounting practices of manufacturing MSEs is now essential. Through this model, companies can quantify hidden environmental costs, providing crucial information for managing operations more efficiently, responsibly, and sustainably. At the institutional level, the study aligns with the university's commitment to sustainability and applied research. Scientifically, it enriches the specialized literature, particularly in Peru, where significant theoretical and practical gaps remain.

Moreover, the designed model can be replicated and transferred to other productive industries, increasing its reach and utility. This strategy supports a culture of sustainability among MSEs and helps them gain access to more demanding, responsible markets in the medium term, while also promoting quality academic output.

1.1 Theoretical framework

1.1.1. Environmental management accounting

For clarity, this paper uses a single acronym, EMA (environmental management accounting), throughout to refer to the model applied in this study; the Spanish-language literature commonly refers to the same construct as Contabilidad de Gestión Ambiental (CGA). Operationally, the EMA model implemented in this study comprises five sequential dimensions: (1) identification of environmental costs, recognizing energy, water, waste, and pollution-related costs embedded in production processes; (2) measurement and monetary valuation of those costs; (3) differentiated environmental accounting records, segregating environmental costs from conventional cost accounts; (4) cost allocation and control, assigning environmental costs to specific products, processes, or responsibility centers and monitoring them over time; and (5) perception of benefits and barriers, capturing entrepreneurs' and workers' views on the value and obstacles of the model. These five dimensions were operationalized through a structured training and technical-assistance program delivered to the participating enterprises, described in detail in the Research method section, rather than through a purely conceptual application. The remainder of this section reviews how prior literature has conceptualized EMA before Section 3 describes how it was implemented and measured in this study.

According to [35], environmental management accounting integrates financial information with the evaluation of environmental impacts to quantify, analyze, and control expenses associated with natural resources, waste, and pollution. This allows organizations to make more sustainable choices, optimize processes, and meet environmental requirements. Furthermore, it enhances transparency and corporate accountability by linking economic performance directly to environmental performance, thereby driving strategic management toward sustainable development and a competitive advantage grounded in eco-efficiency [19], [36], [37].

Ecological concerns are incorporated as a strategy in environmental management accounting within the business decision-making process, as this appreciates the interdependence among the economy, society, and the environment. It has progressed from the traditional accounting system, which merely quantified monetary values, to a system that considers the physical flows of resources and ecological effects [38], [39]. It aims at establishing the relationship between business activities, planetary limits, and sustainable aspirations, and encouraging more balanced and responsible organizational designs under the challenge of environmental degradation, balancing profitability with environmental protection [19].

Environmental management accounting is a tool that combines accounting information with ecological variables to quantify the effects of business activities on the natural environment, where its role is to guide decision-

making towards sustainable management, balancing profitability with environmental responsibility [40], [24]. Through this accounting approach, environmental costs can be analyzed, resource utilization efficiency is promoted, waste is minimized, and more sustainable processes are facilitated. Furthermore, it enhances a responsible corporate image, improves community relations, and helps ensure compliance with environmental laws, thereby consolidating a business model founded on sustainability and environmental respect [41].

Environmental management accounting is a system that enables the identification, measurement, and communication of the ecological impacts posed by business activities, incorporating environmental information into the accounting process to aid in responsible and sustainable decision-making. The method combines physical and financial information regarding resource use, emissions, and waste, allowing for the analysis of the ecological efficiency of business activities [42], [43].

It also encourages the development of environmental indicators that reveal risks, costs, and benefits based on environmental performance. Through this accounting approach, organizations enhance their transparency, improve their reputation, and advance sustainability by aligning economic administration with the conservation of the natural world [44], [45].

1.2. Sustainable decision-making

The development of sustainable decision-making has experienced various phases representing the shift in environmental consciousness and socioeconomic principles. Between 1970 and 1990, it underwent an emergence and awareness stage aimed at creating awareness of environmental problems and the need to adopt environmentally friendly practices [46]. During the following stage from 2000 to 2010, known as integration and mainstreaming, sustainability evolved from a buzzword into a core principle in business strategies, where organizations began incorporating environmental, social, and economic policies into their decisions to strike a balance between profitability, responsibility, and sustainable development [47].

From 2010 to date, there has been a paradigm shift in the concept of sustainable decision-making. The current age of innovation and transformation has placed the emphasis on utilizing innovative technologies, which advance the models of the circular economy and renewable energies that create substantial shifts in global sustainability practices [48]. These technologies bring about a more sustainable future, and they have raised extensive discussions on responsible business models and the formulation of smart cities that are social, environmental, and economic in nature [49]. As literature develops, scientists and practitioners are searching for new options to solve the increasing problem of sustainability within the dynamic world environment.

One of the tools of sustainable decision-making is environmental cost accounting, according to which the assessment of the economic and ecological effects of business activities is carried out by using the specified approach, and in accordance with which the costs associated with the environment are supposed to be reflected in corporate management and bring both financial and environmental benefits [50], [51].

2. Research method

The study is practical in nature. In reference, an applied study is a type of research that aims at finding solutions to practical problems by utilizing theoretical knowledge [52]. Its primary goal is to create practical and tangible solutions that can translate into real-life situations, thereby engaging in shaping and advancing practices in different areas. A quasi-experimental mixed (quantitative-qualitative) design was used. A quasi-experimental mixed-methods research study is a combination of qualitative and quantitative approaches without randomized assignment in the study of phenomena to develop a practical solution in the real world [53], [54]. Specifically, a one-group pretest-posttest design was used, in which the same 20 participating enterprises were measured before and after the intervention; no comparison or control group was included. Due to the absence of random assignment and a control group, the design allows changes associated with the EMA intervention to be documented, but it does not permit the isolation of the intervention as the sole cause of the observed changes, since other concurrent factors cannot be ruled out.

The population was composed of micro and small enterprises (MSEs) in the manufacturing industry in the

Ancash region. A convenience sample of 20 MSEs, which consented to take part in the pilot implementation of the model, was chosen. The population is the entire collection of elements sharing similarities; the sample is a representative proportion that gives the opportunity to obtain data about the whole proportionally and correctly [55]. Enterprises were selected under a non-probabilistic, convenience-sampling procedure, with the inclusion criteria that each enterprise (a) was formally or informally engaged in manufacturing activity in the Ancash region, (b) had between 1 and 10 workers, consistent with the Peruvian legal definition of a micro enterprise, and (c) had an owner or manager willing to participate in the full training and measurement cycle. The respondent in each enterprise was the owner or general manager, who was directly responsible for accounting and operational decisions. Given that only 20 enterprises met these criteria and agreed to participate, the sample size is a limitation of this study; consequently, the findings are presented as exploratory, pilot-level evidence rather than as generalizable conclusions for the broader population of manufacturing MSEs, and replication with larger and probabilistic samples is recommended.

The environmental management accounting model is an independent variable. It consists of five basic dimensions that include the identification of environmental costs, measurement and monetary valuation, differentiated environmental accounting records, cost allocation and control, as well as the perception of benefits and barriers. Sustainable decision-making is a dependent variable. This consists of five dimensions which include environmental information, green investment, perceived value, future vision, and ecological culture.

2.1. Intervention period and implementation procedure

The EMA model was implemented over a defined intervention period comprising three sequential stages. In the diagnostic stage (week 1), the pre-test Likert-type questionnaires on environmental accounting knowledge and sustainable decision-making were administered, together with the documentary analysis sheet, to establish a baseline for each enterprise. In the intervention stage (weeks 2 to 9, approximately eight weeks), participating owners/managers received structured training and technical assistance, delivered through weekly sessions of approximately two hours plus on-site technical assistance, on the five EMA dimensions described above, applied to their own accounting records and production processes. In the evaluation stage (weeks 10 and 11), the post-test questionnaires and the semi-structured interviews were administered to assess changes and to explore perceptions, barriers, and opportunities. The full intervention period thus spanned approximately eleven weeks.

Techniques and instruments:

1. Likert scale survey (before and after application)
Measure: Likert scale pre- and post-training questionnaire.
2. Semi-structured interviews
Instrument: 20 open-ended interview guides (based on the dimensions of the model)
3. Documentary analysis
Instrument: Documentary analysis sheet (to peruse accounting records, reports, or any other documents prior to and following the model implementation).

2.2. Measurement instruments

The environmental accounting knowledge questionnaire and the sustainable decision-making questionnaire were both structured as five-point Likert-type scales, with items distributed across the five EMA dimensions and the five sustainable decision-making dimensions described above, respectively. Items were adapted from prior environmental management accounting and sustainability decision-making instruments used in the literature cited in this paper and were reviewed for content validity by expert judges prior to administration. Internal consistency reliability was estimated using Cronbach's alpha, calculated on an independent pilot sample used to validate the instruments prior to their application in the present study. Cronbach's alpha was .823 for the environmental accounting knowledge questionnaire (V1, 25 items across five dimensions) and .814 for the sustainable decision-making questionnaire (V2, 15 items across five dimensions), both indicating good internal consistency. The semi-structured interview guide comprised 20 open-ended questions distributed across the model's dimensions, ten addressing perceptions of the EMA model, corresponding to specific objective 3, and ten addressing barriers and opportunities, corresponding to specific objective 4.

2.3. Data analysis

For the quantitative analysis, SPSS software was used to test the results before and after the intervention using a non-parametric test, specifically the Wilcoxon signed-rank test for related samples. The method produced a high level of enhancement in the variables analyzed following the implementation of the EMA model. For the qualitative analysis, a thematic categorization analysis was conducted using ATLAS.ti software, in which the responses of the experts were coded in an inductive manner. This method enabled us to discover trends in perceptions, barriers, and opportunities regarding the implemented environmental management accounting model.

3. Results and discussion

Regarding specific objective 1, evaluating changes in the level of accounting-environmental knowledge, the results of the Wilcoxon signed-rank test (V1) are presented in Table 1.

Table 1. Results of the Wilcoxon signed-rank test (V1)

Category	Frequency (N)	Percentage (%)	Interpretation
Positive ranks (improved)	14	70.0%	Participants who improved after the intervention
Negative ranks (worsened)	3	15%	Participants who worsened after the intervention
Ties (no change)	3	15%	Participants who showed no change

Note. SPSS V. 27

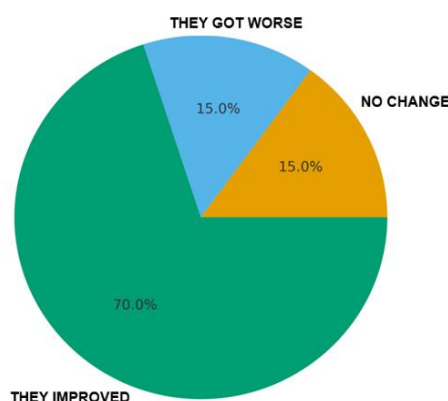


Figure 1. Percentage distribution of changes (V1POST - V1PRE)

Table 2. Descriptive results and Wilcoxon test (V1)

Variable	N	Minimum	Maximum	Mean	Standard deviation	Median	p*
Pre-test	20	59	103	79.60	12.791	78.00	.003
Post-test	20	72	107	92.10	11.285	91.50	

Note. Wilcoxon test, $p < 0,05$

The results of the Wilcoxon test for specific objective 1 show significant improvements in the level of accounting-environmental knowledge after applying the model (see Tables 1 and 2, and Figure 1). Seventy percent of participants showed an increase in their scores, while only 15% worsened and another 15% showed no change. The mean increased from 79.60 (pre-test) to 92.10 (post-test), with an improvement of 15.71% (Wilcoxon signed-rank test, $Z = -2.964$, $p = .003$, matched-pairs rank-biserial effect size $r = .66$, a large effect), indicating a statistically significant difference with a large practical effect size, consistent with the effectiveness of the model applied in the enterprises evaluated.

Table 3 presents the results of the Wilcoxon signed-rank test for the second variable (V2), evaluating changes in sustainable decision-making following the intervention.

Table 3. Results of the Wilcoxon signed-rank test (V2)

Category	Frequency (N)	Percentage (%)	Interpretation
Positive ranks (improved)	15	75.0%	Participants who improved after the intervention
Negative ranks (worsened)	1	5%	Participants who worsened after the intervention
Ties (no change)	4	20%	Participants who showed no change

Note. SPSS V. 27

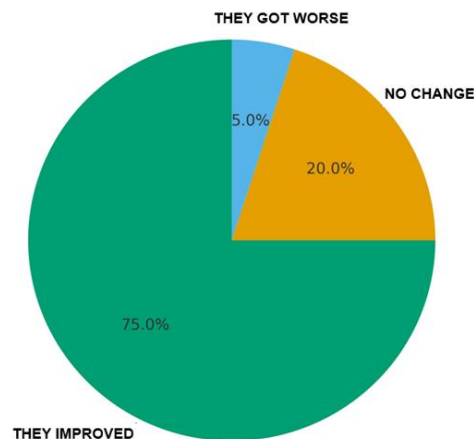


Figure 2. Percentage distribution of changes (V2POST – V2PRE)

Table 4. Descriptive results and Wilcoxon test (V2)

Variable	N	Minimum	Maximum	Mean	Standard deviation	Median	p*
Pre-test	20	36	50	42.10	4.327	41.00	.001
Post-test	20	39	66	54.65	8.093	56.50	

Note. Wilcoxon test, $p < 0,05$

The outcome to particular objective 2 demonstrates that the model has a positive association with sustainable decision-making (see Tables 3 and 4, and Figure 2). Three-quarters of the participants scored higher post-intervention and only 5% worsened and 20% showed no change. The mean was raised by 29.80 percent, which was 42.10 (pre-test) to 54.65 (post-test). This difference was statistically significant (Wilcoxon signed-rank test, $Z = -3.469$, $p = .001$, matched-pairs rank-biserial effect size $r = .78$, a large effect), consistent with the EMA model being effective in strengthening sustainable decisions in the enterprises evaluated, though this association should not be read as definitive proof of causality given the absence of a control group. Regarding specific objective 3, a thematic analysis of the responses to the first ten questions of the semi-structured interview guide was conducted to compare participants' perceptions of the applied environmental management accounting model. The resulting six recurring themes are summarized in the word cloud in Figure 3 and described below.

Perceived value for decision-making. Participants consistently described the EMA model as valuable because it made previously invisible costs, such as waste and energy use, measurable, and because it reframed accounting as an environmental management tool rather than a purely financial record, giving what one participant called “a more realistic picture of the costs” that supports more strategic and sustainable choices.

Applicability of specific tools. Environmental activity-based costing, life-cycle analysis, and the monetary valuation of waste were the tools most frequently cited as practically useful, helping participants identify where their production processes generated the greatest environmental impact and how to allocate the associated costs. Most participants also considered the model transferable to other types of MSEs, provided specific tools are adapted to each sector's input and waste profile.

Organizational culture change. Participants reported tangible cultural shifts, including reduced paper use, internal recycling initiatives, and the repair rather than disposal of materials previously treated as waste, alongside greater employee awareness once environmental information began to be recorded and reported.

Sectoral and regulatory context, and conditions for scalability. Participants agreed that tools must be adapted to sector-specific realities, for example life-cycle costing for input-intensive industries versus input-output analysis for any waste-generating operation, and considered existing Peruvian environmental regulation only partially sufficient, calling for stronger enforcement, tax incentives, and the inclusion of environmental costs in mandatory financial reporting (e.g., by SUNAT). They linked regional or national scalability to the dissemination of success stories, continuous complementary training, collaboration among business associations, government, and universities, and financial or reputational recognition for enterprises that manage their environmental impact effectively.



Figure 4. Word cloud about barriers and opportunities

4. Discussion

The results obtained suggest meaningful improvements in environmental accounting knowledge and sustainable decision-making among the participating manufacturing MSEs after the EMA model implementation (Tables 1–4; Figures 1–2). Seventy percent of participants improved in environmental accounting knowledge, and seventy-five percent improved in sustainable decision-making. These changes are statistically significant and, given the exploratory design of this study, are best interpreted as evidence associated with the intervention rather than as proof of a direct causal effect, though they are strategically relevant for business management in the context of growing ecological demands.

The fact that average scores increased indicates that the model was successful in incorporating environmental variables into the accounting dynamics of participating firms. Beyond this, qualitative testimonials also indicate a change in organizational culture, which supports the model as a useful tool for creating awareness, planning, and making informed decisions. In this regard, accounting is transformed into a tool for operational sustainability. The results of this research are in line with those of [56], who showed that despite environmental concerns, there is limited adoption of sustainable practices due to deficiencies in technical knowledge and resources. Similar barriers were observed in the application of the model in Chimbote; however, its flexibility and feasibility enabled a notable increase in knowledge and sustainable decisions, thereby justifying its applicability.

Furthermore, this supports the conclusions of [57] regarding the positive effect of environmental accounting on financial and social performance. Local entrepreneurs noted that they gained a better grasp of their hidden costs and operational advantages, including increased process efficiency and potential access to new markets, which aligns with international empirical findings on EMA. These findings are consistent with the conclusions of [58] that environmental accounting models produce short-term financial effects alongside long-term returns. Although the model initially entailed extra effort, participants now recognize prospective savings and an improved corporate image, aligned with stakeholder theory and its emphasis on long-term sustainability.

Likewise, [59] points to the usefulness of green accounting as an instrument for impact measurement and reduction, as observed with the MSEs in Chimbote. Nevertheless, certain constraints are widely observed, including the absence of clear regulations. This confirms why legal frameworks and state programs are required to facilitate the institutionalization of the proposed model.

The proposed EMA model is also consistent with the analysis of [60], who identified a lack of technical training among accountants, a fact validated by field experience: most entrepreneurs and accountants remain unaware of how to integrate environmental variables into their books, yet they were willing to receive training.

These results are also in line with [61], who proposed an EMA model in forestry that combines natural capital and the value of ecosystem services, and [50], who showed in Ecuador that when environmental costs are taken into account, business decision-making improves, though barriers of cultural resistance and the absence of clear regulations remain.

Lastly, the findings support those of [62] and [63] on the emerging application of environmental accounting in Peru. Despite the significant gains accomplished by the proposed model, there is a need to enhance professional training, establish standard technical guidelines, and develop tax incentives to promote its widespread adoption.

These findings are also consistent with a broader body of recent empirical evidence linking accounting, governance, and disclosure practices to sustainable organizational performance. Performance-based budgeting has similarly been shown to enhance sustainable performance through innovation and information quality [28], while corporate social responsibility and green entrepreneurial orientation have been associated with green innovation and sustainable performance in other sectors [29]. The relevance of embedding sustainability into corporate strategy is further supported by evidence that ESG practices strengthen brand loyalty through consumer identification [30], and by findings that governance mechanisms, such as audit quality, audit committee composition, and ownership structure, shape firm performance and reporting quality [31], [32]. Taken together with the present findings, this literature indicates that the potential benefits of the EMA model documented here for manufacturing MSEs in Chimbote parallel a wider pattern in which structured, accountability-oriented management practices are associated with improved sustainability outcomes across different firm types and institutional contexts. The specific contribution of this study is to provide field-level, mixed-methods evidence of how such a model can be operationalized step-by-step within resource-constrained manufacturing MSEs, a segment that is markedly under-represented in this broader literature.

The adoption of the EMA model appears to be a pragmatic and useful instrument for facilitating sustainable practices within MSEs, adding strategic value to accounting. It makes a positive contribution to the quality of accounting information as well as eco-efficient decision-making because it allows identifying environmental costs and allocating them. The participating companies indicated that their organizational culture has changed considerably, and their perception of accounting as a sustainability tool has shifted significantly. Moreover, the model is not only about recording data; it allows MSEs to see the impact of their operations on the environment, identify ways to save money, and plan corrective measures. This experience leads to the belief that, through proper training and adapted tools, traditional accounting can be turned into a platform for sustainable development. It has strong potential for replication in other sectors, thus creating a framework to enhance corporate environmental commitment within similar settings.

The primary challenges that were found included a lack of technical training in environmental accounting, a lack of time and resources, and initial staff resistance to change. Nevertheless, as was observed during the process, these barriers can be overcome through clear, contextualized, and progressive training. The findings suggest that sustainability accounting should not be viewed as an additional expense, but as a strategic investment that enhances long-term efficiency and competitiveness. The interaction among academia, business, and government is of primary importance in consolidating this model within the Peruvian business ecosystem.

5. Conclusions

The implementation of the EMA model was associated with a significant improvement in environmental accounting knowledge among the entrepreneurs, as shown by a statistically significant positive difference of 15.71% in post-training scores. This development suggests that, with a proper methodology and adapted instruments, MSEs can be supported in detecting, evaluating, and documenting their environmental effects. Accounting has ceased to be purely financial and has become a strategic axis that enables sustainability, regulatory compliance, and an organizational culture more conscious of resource use and the environment.

Similarly, sustainable decision-making in the participating companies improved by 29.80 percent, which suggests that the EMA model can be an effective business planning tool. This finding indicates that, once environmental costs are brought into the limelight, operational decisions in participating enterprises tend to be more responsible, cost-effective, and proactive. The model appears to have increased efficiency within the participating companies and provided opportunities for accessing sustainable markets, although these interpretations remain exploratory given the study's design and small sample. Environmental accounting thus emerges as a potentially important tool for gaining competitive advantages in a scenario where demand for corporate social responsibility is increasing. The qualitative analysis showed that the model was perceived positively, as entrepreneurs recognized its practical utility, the clarity of the training provided, and its responsiveness to market demands. The introduction of tools such as environmental costing and life-cycle analysis was considered especially useful. Although there were significant obstacles, such as a lack of technical training and resistance to change, MSEs managed to progressively integrate environmental management into their operations, bringing about tangible changes in organizational culture, consumption patterns, and waste management.

Lastly, the paper demonstrates that the EMA model can be replicated, adapted, and applied to enhance sustainable development in the manufacturing industry. Nonetheless, its broader implementation demands the participation of government, universities, and business associations, as well as the establishment of tax incentives and official recognition of environmental expenditures. This experience reaffirms that environmental management accounting is not only relevant to business sustainability, but also essential for advancing the circular economy, enhancing corporate image, and empowering MSEs to contribute to the Sustainable Development Goals (SDGs).

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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Author contribution

The contribution to the paper is as follows: Juana Maribel Manrique Placido, Ronald Floriano Rodríguez, Luis Alberto Torres García: conceptualization, investigation, and review and editing of draft; Juana Maribel Manrique Placido, Ronald Floriano Rodríguez: methodology, software and visualization; Luis Alberto Torres García, Juan Roger Rodríguez Ruiz, María Isabel Palacios Palacios: data validation; Ronald Floriano Rodríguez: formal analysis; Juana Maribel Manrique Placido, Juan Roger Rodríguez Ruiz, María Isabel Palacios Palacios: resources, data curation, and supervision; Juana Maribel Manrique Placido: original draft preparation; Juana Maribel Manrique Placido, Luis Alberto Torres García: project administration. All authors approved the final version of the manuscript.

Ethical approval statement

This research was evaluated and approved within the framework of the institutionalization set up by the research projects supported by Competitive Research Funds Program of Universidad Católica Los Ángeles de

Chimbote (ULADECH Católica). All human studies were performed in accordance with the standards of care and institutional/national ethical requirements. Documentation from the approval process may be made available to the journal upon request.

Informed consent

Informed consent was obtained from all subjects involved in the study.

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