MULTIDISCIPLINARY JOURNAL EPISTEMOLOGY OF THE SCIENCES

Volume 3, Issue 1
January–March 2026

Quarterly publication

CROSSREF PREFIX DOI: 10.71112

ISSN: 3061-7812, www.omniscens.com

Multidisciplinary Journal Epistemology of the Sciences

Volume 3, Issue 1
January–March 2026

Quarterly publication
Made in Mexico

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Multidisciplinary Journal Epistemology of the Sciences Vol. 3, Issue 1, January-March 2026, is a quarterly publication edited by Dr. Moises Ake Uc, C. 51 #221 between 16B and 16C, Mérida, Yucatán, Mexico, C.P. 97144, Tel. 9993556027, Web: https://www.omniscens.com, admin@omniscens.com. Responsible Editor: Dr. Moises Ake Uc. Rights Reservation No. 04-2024-121717181700-102, ISSN: 3061-7812, both granted by the Instituto Nacional del Derecho de Autor (INDAUTOR). Responsible for the last update of this issue: Dr. Moises Ake Uc, last modification date: January 1, 2026.

Multidisciplinary Journal Epistemology of the Sciences

Volume 3, Issue 1, 2026, January–March

DOI: https://doi.org/10.71112/gp286b38

CORIOLIS-BASED CALIBRATION BENCHE FOR 2” AND 4” FLOW METERS: EVIDENCE FROM CARTAGENA’S PETROCHEMICAL SECTOR ON DYNAMIC CAPABILITIES, RELIABILITY AND SUSTAINABILITY

BANCO DE CALIBRACIÓN BASADOS EN CORIOLIS PARA MEDIDORES DE 2” Y 4”: EVIDENCIA DEL SECTOR PETROQUÍMICO DE CARTAGENA SOBRE CAPACIDADES DINÁMICAS, CONFIABILIDAD Y SOSTENIBILIDAD

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DOI: https://doi.org/10.71112/gp286b38

Coriolis-based calibration benche for 2” and 4” flow meters: evidence from Cartagena’s petrochemical sector on dynamic capabilities, reliability and sustainability

Banco de calibración basados en Coriolis para medidores de 2” y 4”: evidencia del sector petroquímico de Cartagena sobre capacidades dinámicas, confiabilidad y sostenibilidad

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ABSTRACT

This study evaluates the acceptance of an in-house calibration bench for 2” and 4” meters based on Coriolis technology in Cartagena’s petrochemical sector. A sequential mixed-methods design combined a survey (n=135) with semi-structured interviews (n=5). Partial Least Squares–SEM tested five drivers—perceived reliability, cost reduction, calibration time

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efficiency, traceability/compliance, and environmental sustainability—on acceptance. The model showed strong explanatory and predictive power (R^2 = 83.11%; Q^2 = 0.499), good fit (GOF = 0.706; SRMR = 0.061; NFI = 0.804), and significant paths. Qualitative findings corroborated demand for accredited certificates, price transparency, volume discounts, rapid reporting, and post-service support. Results indicate that Coriolis-based benches outperform traditional volumetric/gravimetric systems on efficiency, sustainability, and legitimacy, positioning the Colombian Caribbean as a regional reference in metrological modernization. The study also contributes a novel lens to Dynamic Capabilities by framing metrological infrastructures as strategic assets that reconfigure resources, reduce uncertainty, and enhance competitiveness across regulated industrial contexts.

Keywords: dynamic capabilities; coriolis flow meters; calibration bench; PLS-SEM; petrochemical sector

RESUMEN

Este estudio evalúa la aceptación de un banco de calibración propio para medidores de 2” y 4” basado en tecnología Coriolis en el sector petroquímico de Cartagena. Se empleó un diseño mixto secuencial que combinó una encuesta (n=135) con entrevistas semiestructuradas (n=5). Mediante PLS-SEM se probaron cinco impulsores—confiabilidad percibida, reducción de costos, eficiencia en tiempos de calibración, trazabilidad/cumplimiento y sostenibilidad ambiental—sobre la aceptación. El modelo mostró alta capacidad explicativa y predictiva (R^2 = 83.11%; Q^2 = 0.499), buen ajuste (GOF = 0.706; SRMR = 0.061; NFI = 0.804) y rutas significativas. Los hallazgos cualitativos corroboraron demanda por certificados acreditados, transparencia de precios, descuentos por volumen, informes rápidos y soporte postservicio. Los resultados indican que los bancos basados en Coriolis superan a los sistemas volumétricos/gravimétricos en eficiencia, sostenibilidad y legitimidad, posicionando al Caribe

colombiano como referente regional en modernización metrológica. El estudio aporta además una perspectiva novedosa a las Capacidades Dinámicas al concebir las infraestructuras metrológicas como activos estratégicos que reconfiguran recursos, reducen la incertidumbre y fortalecen la competitividad en contextos regulados.

Palabras clave: capacidades dinámicas; medidores Coriolis; banco de calibración; PLS-SEM; sector petroquímico

Received: November 25, 2025 | Accepted: January 1, 2026 | Published: January 2, 2026

INTRODUCTION

The measurement of water flow has long been recognized as a cornerstone in the effective management of water resources, as it ensures both the reliability of measurements and the sustainability of service provision. In developing regions, particularly Latin America, limitations in infrastructure and technological adoption have constrained the modernization of water supply and sewerage systems. These gaps not only undermine tariff transparency but also hinder operational efficiency, emphasizing the urgent need for innovative metrological solutions (Costa et al., 2020).

Recent advances in flow metrology have highlighted the relevance of Coriolis technology as a disruptive alternative to traditional volumetric and gravimetric calibration methods. Unlike conventional systems, Coriolis-based solutions provide higher levels of accuracy, reduced sensitivity to flow disturbances, and robust performance under dynamic conditions (Kenbar et al., 2021; Mills, 2020). In this sense, the adoption of calibration benches employing Coriolis meters represents a strategic response to the technical and institutional challenges faced by emerging economies.

Within the Colombian Caribbean, the design and construction of an in-house calibration bench for 2” and 4” large water meters constitutes a pioneering achievement. This

infrastructure, developed by the Metrology Laboratory of Aguas de Cartagena S.A. E.S.P., not only incorporates advanced instrumentation for pressure and temperature monitoring but also leverages Coriolis meters as master standards. Its implementation marks a shift away from the dependence on large volumetric tanks, enabling continuous operation, substantial reductions in water consumption, and improved safety for personnel.

The novelty of this initiative lies not only in its technical configuration but also in its organizational implications. By aligning with international standards such as ISO 4064-1:2014, ISO/IEC 17025, and ISO/IEC 17020, the bench integrates rigorous metrological practices with broader strategic imperatives of sustainability and competitiveness. As documented in international studies (Furuichi et al., 2022; Wright & Mickan, 2016), the validation of Coriolis technology as a transfer standard underscores its suitability for cross-sectoral adoption, extending beyond the water industry to applications in petroleum, natural gas, and hydrogen (American Petroleum Institute, 2020; Kang et al., 2022).

From a research standpoint, the evaluation of this calibration bench addresses a critical knowledge gap. Despite international evidence of Coriolis meters' reliability, no systematic studies had previously examined their adoption in Colombia's petrochemical sector, a domain where measurement accuracy directly impacts operational efficiency, safety, and sustainability. This study therefore provides both theoretical and empirical insights into how metrological innovation is perceived and valued within a strategically important industry.

Accordingly, this article pursues a dual objective: first, to analyze the perceptions and acceptance levels of professionals in Cartagena's petrochemical sector regarding the adoption of the Coriolis-based calibration bench; and second, to assess its technical, economic, and environmental pertinence. By integrating a sequential mixed-methods design, combining structural equation modeling with qualitative interviews, the research offers a comprehensive perspective on the interplay between measurement reliability, regulatory compliance, sustainability, and organizational innovation. In doing so, it not only validates the novelty of the

proposed calibration infrastructure but also positions it as a replicable model for other emerging economies seeking to modernize their metrological systems. Finally, it also adds a novel perspective to the Theory of Dynamic Capabilities.

Theoretical framework

Flow metrology constitutes an essential pillar in the modern management of water resources. Its role is not only to guarantee the reliability of measurements but also to ensure tariff transparency and the sustainability of public services. In the case of Latin America, where potable water and sewerage infrastructure face technological limitations, the adoption of innovative calibration benche is a strategic necessity (Costa et al., 2020).

The in-house design of a calibration bench based on Coriolis technology and the Master Meter contrast method in the Colombian Caribbean region marks a milestone, as it breaks with the dependence on traditional volumetric or gravimetric comparison methods. Moreover, it aligns with international standards of metrological quality and global trends in digitalization and sustainability (Furuichi et al., 2022).

Principles of operation of Coriolis flow meters

The operating principle of Coriolis flow meters is based on the detection of inertial forces produced when a moving fluid passes through a vibrating tube. This interaction generates a deflection proportional to the mass flow, allowing flow measurement with an accuracy greater than 0.1% (Mills, 2020).

Compared to volumetric, ultrasonic, or electromagnetic meters, Coriolis meters offer notable advantages: lower sensitivity to asymmetric flow profiles, immunity to changes in viscosity, and greater stability under dynamic conditions (Kenbar et al., 2021). These features make them ideal for compact calibration benches in industrial or urban environments.

Metrological traceability and uncertainty estimation

The relevance of a calibration bench depends on the traceability of its results. Standards such as the Guide to the Expression of Uncertainty in Measurement (JCGM, 2008) and Icontec (2017) establish rigorous methodologies for estimating calibration uncertainties. These guidelines are complemented by ISO 4064-1 International Organization for Standardization (2014), which defines metrological requirements for water meters, and by ISO/IEC 17025 and 17020, which regulate the technical competence and impartiality of laboratories and inspection bodies.

International studies, such as those by Wright and Mickan (2016) at PTB and by the National Institute of Standards and Technology (2016), have consolidated the use of Coriolis as transfer standards, achieving combined uncertainties below 0.15%. These validations have been fundamental for expanding their adoption across different sectors.

International experiences with benches using Coriolis meters

The adoption of Coriolis meters in calibration benches is not exclusive to the water sector. In the oil industry, the API Manual of Petroleum Measurement Standards recommends their use due to their direct traceability and immunity to adverse flow conditions (American Petroleum Institute, 2020). Likewise, the International Organization for Standardization (2020) supports their application in the measurement of natural gas in closed conduits.

Furuichi et al. (2022) documented the validity of Coriolis meters in large-scale water flow key comparisons, confirming their usefulness up to diameters of DN100 or 2”. Kang et al. (2022), in turn, demonstrated their relevance in hydrogen stations, where they operate under high pressures and temperaturas.

Calibration bench for 2” and 4” large water meters

The calibration bench for 2” and 4” large water meters was designed and built by the staff of the Metrology Laboratory of Aguas de Cartagena S.A. E.S.P., with the support of a metal-mechanical supplier. This system includes a set of hydraulic components and advanced instrumentation for pressure and temperature measurement, as well as the incorporation of two

Coriolis meters as reference standards. Its operation is carried out under a dynamic scheme, in which the comparison of the meters under test is performed using the Master Meter method, in accordance with the *Guía para la Expresión de la Incertidumbre de Medida (GUM, JCGM 100-2008)*, *GTC 214-2017 and* CENAM (2008), which establish the criteria for a rigorous estimation of uncertainty in calibration processes. Likewise, the design and operation of the bench are based on the guidelines of *ISO 4064-1-2014*, which specifies the metrological requirements for water meters, including tests with continuous flow standards.

The main novelty and innovation of this development is that it is the first bench of its kind in the Colombian Caribbean region, the second implemented by a public utility company for water supply and sewerage in Colombia, and the fourth in Latin America.

Technical and Operational Innovations

The in-house designed bench based on Coriolis comparison introduces disruptive innovations compared to traditional systems. Among these are:

• Reduction of more than 90% in water consumption.

• Elimination of large metallic volumetric tanks.

• Continuous operation with multiple flow points.

• Greater safety for personnel.

Druzhkov et al. (2025) validated its stability in CO_2 measurement, highlighting the ability of Coriolis meters to adapt to complex fluids. Frahm et al. (2025) confirmed their accuracy in international comparisons, with uncertainties as low as 0.01%. These advances consolidate their role as a metrological reference in modern benches.

Comparisons with traditional methods

Gravimetric or volumetric benches, although they have been the standard for decades, present limitations: high water consumption, large physical space requirements, vulnerability to errors due to evaporation, and high investment costs (≈ USD $750,000). In contrast, the bench

based on the comparison method using Coriolis meters represents a more economical (≈ USD $50,000), efficient, and sustainable alternative consistent with (Mills, 2021).

Moreover, studies such as those by Sawada et al. (2019) on turbulence in flow lines and Nguyen et al. (2021) on cryogenic measurement demonstrate that Coriolis technology maintains consistency even under extreme conditions, where other methods fail.

Relevance in the water supply and sewerage sector

In the Latin American context, where technological innovation often arrives belatedly, the in-house design of this bench in Colombia represents a pioneering advancement. The specialized literature (Li et al., 2022; Zhang et al., 2020) agrees that the modernization of water metrology is key for urban sustainability and tariff transparency.

This project not only strengthens the company's competitiveness but also positions the Caribbean region as a benchmark in innovation applied to public services, aligned with digitalization and global best practices.

Relevance of calibration benches using Coriolis meters

The literature review confirms that calibration benches based on Coriolis technology constitute a disruptive innovation in flow metrology. Their technical, economic, and social relevance is clear: they reduce costs, optimize space, and guarantee reliable results with international traceability. In this way, the company is consolidated as a pioneer in the modernization of water management in Colombia and Latin America.

Knowledge gap

Although international literature has documented the relevance of using Coriolis meters in calibration benches for applications in sectors such as petroleum, natural gas, or hydrogen (American Petroleum Institute, 2020; Furuichi et al., 2022; Kang et al., 2022), in Colombia —and particularly in the Caribbean region— there are no systematic studies evaluating the adoption of calibration benches based on Coriolis technology by the petrochemical sector.

The lack of local evidence generates uncertainty regarding the acceptance, applicability, and economic benefits that this type of metrological infrastructure could offer in strategic industrial processes, where measurement reliability is critical for operational efficiency, safety, and sustainability.

Research hypothesis

H1: The petrochemical sector in Cartagena perceives the calibration bench with Coriolis meters as a more reliable alternative compared to traditional volumetric or gravimetric methods.

H2: The adoption of the calibration bench would reduce operating costs associated with meter calibration in the petrochemical sector.

H3: The calibration bench increases efficiency in calibration times compared to traditional methods.

H4: The petrochemical sector positively values the international traceability and regulatory compliance derived from the use of Coriolis as transfer standards.

H5: Environmental sustainability (reduction in water consumption and lower carbon footprint) is a determining factor in the acceptance of the calibration bench.

Research objective

General: To evaluate the perception and level of acceptance of the petrochemical sector in Cartagena regarding the use of the 2” and 4” calibration bench based on Coriolis meters as an alternative to traditional methods, identifying its technical, economic, and environmental relevance in flow measurement processes.

Specific:

1. Analyze the sector’s perception regarding the reliability and accuracy of the calibration bench.
2. Determine the potential economic benefits of its adoption.
3. Measure the sector’s assessment of efficiency in calibration times.

4. Explore the importance assigned to metrological traceability and international regulatory compliance.
5. Evaluate the relevance of environmental factors in the decision of technological adoption.

METHODOLOGY

Research Design

The study adopts a non-experimental design and applies a sequential mixed-methods approach (Quant → Qual) with both exploratory and explanatory–descriptive orientations. The research was carried out over a three-month period (August–November 2025) within a cross-sectional framework, scheduled for implementation during the fourth quarter of 2025.

From the quantitative perspective, the study examines the relationship between the dependent variables—Perceived reliability, Reduction of operational costs, Calibration time efficiency, Valuation of traceability and regulatory compliance, and Environmental sustainability impact—and the independent variable, defined as the Availability of a calibration bench for 2” and 4” macrometers based on Coriolis meters. For this purpose, a structured instrument was administered to a representative sample of employees working in the areas of quality, process engineering, and reliability management within petrochemical companies located in Cartagena de Indias, Colombia.

The subsequent qualitative phase was designed to provide an in-depth understanding of how industry professionals themselves interpret and contextualize the quantitative findings, thus offering a more holistic and comprehensive perspective of the phenomenon under study.

Population and Sample

- Target population: Professionals from the petrochemical sector of Cartagena de Indias working in quality assurance, process management, and reliability engineering.
- Quantitative sample: A total of 135 professionals were selected through purposive non-probability sampling, based on three main criteria: (a) at least four years of professional experience, (b) holding a formal leadership role within their organization, and (c) voluntary willingness to participate in the study.
- Qualitative sample: Five (5) participants were intentionally selected from the quantitative pool, meeting the same criteria, in order to provide more nuanced insights into the results.

Data Collection Techniques and Instruments

Quantitative Component

An ad hoc structured questionnaire consisting of 30 Likert-scale items (1–5) was developed to evaluate the six dimensions corresponding to the dependent and independent variables. The instrument's design was informed by the contributions of prior research in metrology, flow measurement, and organizational innovation (Costa et al., 2020; Mendoza Betin, 2019a; Mills, 2020; Kenbar et al., 2021; Wright & Mickan, 2016).

The construction process followed four sequential phases:

1. **Initial design**
    - Review of relevant literature and adaptation of validated scales from previous studies.
    - Formulation of items consistent with the study's objectives and hypotheses.
2. **Content validity**
    - Expert evaluation by three specialists (one with PhDs in Metrology and two with a Master's in Coriolis-based methods), following the guidelines of Hernández-Nieto (2011) and Lynn (1986).

- Based on their feedback, four items per dimension were refined, and one item from each variable was removed.

3. **Pilot testing and adjustments**
   - Piloting with 15 professionals from the petrochemical sector (outside the final sample), consistent with the recommendations of Hair et al. (2010).
   - Revisions were made to improve clarity, reduce technical jargon, and adjust item length and format. Three items were rewritten.
4. **Final administration**
   - The survey was distributed online between August and November 2025 to the 135 participants, including the 15 members of the pilot test.
   - The effective response rate was 98%, yielding 118 valid questionnaires.

Internal consistency was assessed with Cronbach's alpha, yielding an overall coefficient of 0.94, with sub-dimensions ranging from 0.86 to 0.93, demonstrating high reliability.

For data analysis, Structural Equation Modeling (SEM) was applied, following the methodological recommendations of Lloret-Segura et al. (2014), MacCallum et al. (1999), and Preacher & MacCallum (2003).

Qualitative Component

- To complement the quantitative results, five semi-structured interviews were conducted with selected participants.
- Each interview lasted between 60 and 90 minutes, was audio-recorded, and later transcribed verbatim.
- Thematic coding and analysis enabled the researchers to identify the participants' perceptions, contextual interpretations, and critical reflections on the adoption of Coriolis-based calibration benches in the petrochemical sector.
- This qualitative phase allowed the construction of a more nuanced and integrated understanding of the phenomenon.

DOI: https://doi.org/10.71112/gp286b38

RESULTS

The findings of this research, viewed from a positive perspective, are derived from a rigorous analysis of the data collected in accordance with the methodology previously established. Through the use of structural equation modeling, the proposed hypotheses were examined, revealing meaningful patterns, interconnections, and effects among the studied variables. This section presents a comprehensive overview of the results, including the development of predictive models, the evaluation of model fit indicators, and the estimation of key parameters. Collectively, these aspects offer a precise and well-rounded understanding of the factors analyzed and their significance within the studied context.

The contrast analysis, designed to assess the influence of the dependent variables — perceived reliability, operational cost reduction, calibration time efficiency, valuation of traceability and regulatory compliance, and environmental sustainability impact— on the independent variable (availability of a calibration bench for 2” and 4” macrometers based on Coriolis meters), was carried out using SPSS and PLS software, both widely recognized as appropriate tools for exploratory research. In line with Cohen (1998), the f^2 index for the five variables showed a strong relationship with the coefficient of determination (R^2), which reached 83.11%. This result underlines a high level of dependence and significance among the variables considered.

Table 1

The Effects of Dependent Variables on the Independent Variable

Variables	Effects $f2$	Total Effect
Perceived reliability	0.341	Adequate or Relevant
Reduction of operational costs	0.335	Adequate or Relevant
Calibration time efficiency	0.331	Adequate or Relevant

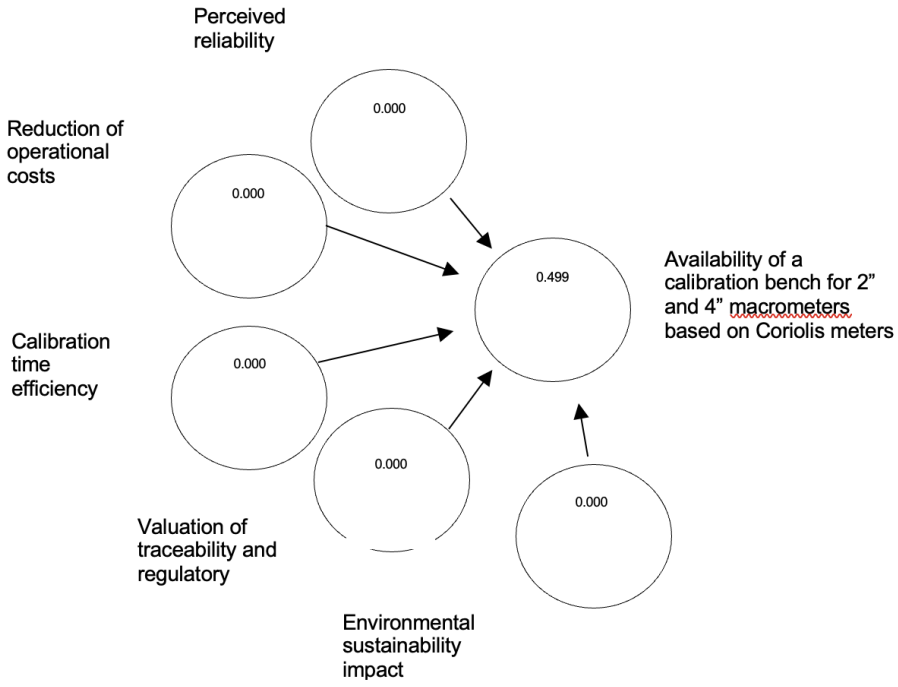
Valuation of traceability and regulatory compliance	0.338	Adequate or Relevant
Environmental sustainability impact	0.317	Adequate or Relevant
Availability of a calibration bench for 2” and 4” macrometers	0.322	Adequate or Relevant

Note: Based on proprietary measurements analyzed using SPSS and PLS (2025)

When assessing the structural equation model (SEM) using the PLS approach, Q^2 values must exceed zero in order to confirm the presence of an endogenous latent variable. As shown in Figure 1, the Q^2 value achieved was 0.499, well above the required threshold. This outcome strengthens and validates the model’s predictive ability.

Figure 1

Predictive model



Note: Prepared based on calculations in SPSS and PLS (2025)

The Goodness-of-Fit index (GOF) was employed to assess the extent to which the model accurately reflects and represents the empirical data. This indicator ranges from 0 to 1, with

conventional benchmarks indicating that 0.10 corresponds to a weak fit, 0.25 to a moderate fit, and 0.36 to a strong fit. The results of the evaluation showed that the model is parsimonious and consistent with the observed data. The GOF value was obtained by calculating the geometric mean between the average communality —also known as the Average Variance Extracted (AVE)— and the mean of the R^2 values, thereby reinforcing the evidence supporting the model's overall validity.

Table 2

Computation of the Goodness-of-Fit (GOF) Index

Constructs	**AVE**	**R2**
Perceived reliability	0.675	
Reduction of operational costs	0.663	
Calibration time efficiency	0.638	
Valuation of traceability and regulatory compliance	0.653	
Environmental sustainability impact	0.651	
Availability of a calibration bench for 2" and 4" macrometers	0.663	0.7470
Average Values	3.815	0.7470
AVE * R2	0.4980	
GOF = √AVE * R2	0.7060	

Note: Based on proprietary measurements analyzed using SPSS and PLS (2025)

The Standardized Root Mean Square Residual (SRMR), calculated from the difference between the observed correlations and the estimated covariance matrices, produced a value of 0.061. As this is within the acceptable limit (SRMR ≤ 0.09), the model can be considered to exhibit a satisfactory fit. In addition, the Chi-square statistic was 1914.079, and the Normed Fit Index (NFI) reached 0.804, both of which indicate that the measurement model is appropriate.

Table 3

Model estimators

	Model estimators
SRMR	0.061
d_ULS	1.640
d_G1	0.932
d_G2	0.783
Chi-Square	1.914.079
NFI	0.804

Note: Based on proprietary measurements analyzed using SPSS and PLS (2025)

Finally, Table 4 displays the correlation coefficients of the latent variables, allowing the inference of a strong relationship between the exogenous latent constructs and the endogenous observed variables.

Table 4

Correlation of latent and observable variables

Variables	PR	ROC	CTE	VTC	ESI	ACB
Perceived reliability	**1.000**					
Reduction of operational costs	0.269	**1.000**				
Calibration time efficiency	0.283	0.275	**1.000**			
Valuation of traceability and regulatory compliance	0.279	0.273	0.291	**1.000**		
Environmental sustainability impact	0.281	0.310	0.292	0.290	**1.000**	

Availability of a calibration bench for 2” and 4” macrometers	0.282	0.295	0.286	0.270	0.272	**1.000**

Note: Based on proprietary measurements analyzed using SPSS and PLS (2025)

The assessment of the measurement model confirmed its adequacy as a confirmatory framework, indicating that all proposed hypotheses achieved statistical significance and were therefore supported. The findings of this research show that the examined factors had a positive influence on shaping the notion of broad acceptance by the petrochemical sector in Cartagena (Colombia) regarding the implementation of the 2” and 4” calibration bench based on Coriolis meters as an alternative to traditional methods. This highlights its technical, economic, and environmental relevance in flow measurement processes and strengthens its theoretical foundation. However, the degree to which these results can be generalized will depend on future studies employing comparable methodological approaches.

Qualitative Component

Interviews were conducted with five employees from five different companies in the petrochemical sector of Cartagena. For reasons of data protection and corporate confidentiality, the participants requested that their names and specific positions not be disclosed in the research results.

Main Findings:

- **Acceptance of the method:** All participants agreed on calibrating the 2” and 4” meters used in their operations at the Macros Laboratory’s calibration bench, employing the *Master Meter* method with Coriolis meters, mainly due to the sustainability practices it promotes.
- **Prior knowledge:** Respondents indicated familiarity with the Coriolis method and valued its incorporation in a regional calibration bench, which generates confidence in traceability and result quality.

- **Interest in costs:** They expressed interest in knowing the calibration prices, the possibility of volume-based discounts, and the applicable billing schemes for recurring contracts.
- **Certification and compliance:** One of the main concerns was to confirm whether the tests carried out would include an ISO/IEC 17025 accredited certificate, which they consider indispensable for both internal acceptance and external audits.
- **Expected added value:** They emphasized the importance of the bench also providing detailed technical reports, agile response times, and post-service support, as these factors influence their contracting decisions.
- **Strategic factors:** Some participants highlighted that, beyond technical benefits, the bench could enhance their companies' social and environmental responsibility image before regulators and international clients, since it contributes to reducing water consumption and carbon footprint.
- **Recommendations:** They suggested exploring framework agreements for annual or semi-annual calibration, ensuring priority availability and better economic conditions.

DISCUSSION

The findings of this study confirm that calibration benches based on Coriolis technology represent not only a technical advancement but also an organizational innovation within the Latin American context. The strong explanatory power of the structural model (R^2 = 83.11%) reveals that the adoption of this infrastructure in the petrochemical sector is strongly associated with perceptions of reliability, efficiency, and sustainability. These results are consistent with previous empirical work in the Colombian Caribbean that highlighted the relevance of dynamic capabilities as enablers of resilience, innovation, and organizational learning (Mendoza Betin, 2018; Mendoza-Betin, 2021a,b). Just as dynamic capabilities have proven critical in sectors

such as water utilities and creative industries (Mendoza Betin, 2019a; Mendoza Betin, 2025b,c), the implementation of Coriolis-based calibration benche can be interpreted as a tangible manifestation of these capabilities, where technology adoption translates into competitive advantage and legitimacy in regulated environments. This perspective also connects with insights from other sectors, where dynamic capabilities have been shown to shape innovation and adaptability in highly competitive environments, such as the contemporary music industry (Mendoza Betín, 2025).

In addition, the qualitative evidence emphasizes that decision-makers in the petrochemical sector do not limit their assessment to technical performance but also consider issues of cost, accreditation, and environmental impact as decisive in shaping acceptance. This aligns with prior research that linked process innovation, knowledge transfer, and corporate entrepreneurship to long-term performance in domestic public water supply and sewerage utility companies (Mendoza-Betin, 2019b; Mendoza Betin et al., 2020; Mendoza-Betin, 2021b).

Furthermore, the emphasis placed by participants on traceability and sustainability highlights how technical innovations in metrology are increasingly evaluated through their social and environmental contributions. This perspective aligns with findings in emerging market contexts, where the integration of traditional and digital strategies has been shown to enhance legitimacy and strengthen stakeholder trust (Mendoza Betin, 2025d). In both cases, whether through marketing approaches or metrological innovations, organizations embed broader values of responsibility, transparency, and long-term resilience into their operational frameworks, thereby positioning themselves more competitively in dynamic environments.

At the same time, these results resonate with broader findings that identify organizational culture as a key driver of social innovation and market positioning in emerging economies. As demonstrated in empirical evidence from the Colombian Caribbean, organizations that cultivate cultural practices aligned with innovation and responsibility are better positioned to integrate sustainability into their strategic agenda (Mendoza Betin, 2025a). By embedding these values

within organizational routines, companies transform technical infrastructures into strategic assets that not only ensure compliance with international standards but also strengthen legitimacy and competitiveness in both local and global markets.

Taken together, the results suggest that the calibration bench does not merely fill a technical gap but also responds to institutional pressures and market demands, consolidating the role of the Caribbean region as a reference point for metrological modernization.

Theoretical contributions

This study contributes to the literature on flow metrology and organizational innovation by demonstrating that the adoption of Coriolis-based calibration benches can be understood as a concrete form of dynamic capability deployment (Mendoza Betin, 2018; 2019a). The results show how firms in regulated sectors such as petrochemicals adapt by incorporating technologies that simultaneously improve efficiency, reduce uncertainty, and enhance sustainability. This reinforces the idea that metrological infrastructure should not be examined solely from a technical perspective, but also as part of an organization's capability to reconfigure resources and processes in response to institutional and environmental pressures (Mendoza Betin, 2021a; 2025b,c).

Moreover, the integration of quantitative modeling and qualitative insights aligns with previous findings on knowledge transfer, process innovation in Colombian utilities and Process Management in Water and Sewerage Companies in Panamá (Mendoza-Betin, 2021b; 2022), extending them to the petrochemical sector. The study demonstrates that the acceptance of Coriolis benches is not only driven by measurement accuracy but also by legitimacy factors, such as compliance with ISO/IEC standards and the perceived alignment with international best practices. In this sense, the research bridges metrology with management studies, supporting the argument that technical infrastructures can serve as strategic vehicles for social innovation and resilience (Mendoza Betin, 2025a; Mendoza-Betin et al., 2024).

Practical implications

From a managerial perspective, the findings highlight that the implementation of Coriolis-based calibration benches offers clear economic and operational benefits: lower costs, reduced water consumption, smaller physical space requirements, and accredited traceability. For petrochemical firms, this translates into improved decision-making capacity, reduced risks during audits, and stronger positioning in global supply chains. These insights resonate with prior evidence from corporate entrepreneurship and excellence programs in Acuacar, which showed that innovative practices foster competitive differentiation and stakeholder trust (Mendoza Betin et al., 2020).

Another important contribution is that in 2025, a total of 133 meters were replaced (from February to August) due to improper sizing, which resulted in the recovery of more than 100,000 m^3. This aligns with the project mentioned in Mendoza Betin et al. (2024).

The study also underscores the importance of adopting client-centered practices, as qualitative interviews revealed that users value not only the technical accuracy of the bench but also the provision of certificates, tailored contracts, and responsive post-service support. This supports the claim that organizational culture and hybrid leadership approaches are pivotal for embedding innovation in service delivery (Mendoza Betin, 2025e). By aligning sustainability goals with business imperatives, the calibration bench offers a replicable model for utilities and industrial firms in Latin America.

Limitations and future research

While the study offers robust empirical evidence, its scope is limited to a sample of professionals from Cartagena's petrochemical sector, which restricts the generalizability of findings. As argued in previous research on resilience and knowledge transfer (Mendoza-Betin, 2021a,b), context-specific dynamics may influence the acceptance and effectiveness of innovation. Therefore, broader studies across different regions and industries are necessary to validate and extend these results.

Future research should also explore the long-term impacts of Coriolis-based calibration benches, particularly in terms of sustainability outcomes, cost-effectiveness, and regulatory compliance over time. Comparative studies with other sectors, such as water utilities, hydrogen, or natural gas —where international literature already recognizes the role of Coriolis technology (API, 2020; Furuichi et al., 2022; Kang et al., 2022)— would provide additional insights into cross-sectoral transferability. Finally, integrating perspectives from marketing and digital strategies (Mendoza Betín, 2025d) could shed light on how firms communicate and legitimize the adoption of metrological innovations in competitive and environmentally sensitive markets.

CONCLUSIONS

This research provides compelling evidence that the design and implementation of a Coriolis-based calibration bench for 2” and 4” large water meters constitutes both a technological breakthrough and an organizational innovation in the Latin American context. Unlike traditional volumetric or gravimetric systems, the proposed bench reduces costs, optimizes resources, and delivers internationally traceable results with unprecedented efficiency and sustainability. The explanatory strength of the quantitative model (R^2 = 83.11%), reinforced by qualitative insights, confirms that reliability, accreditation, and environmental responsibility are decisive factors driving acceptance in Cartagena’s petrochemical sector.

The novelty of this study lies in its empirical validation of an in-house calibration infrastructure that not only challenges decades of dependence on conventional methods but also positions the Colombian Caribbean as a pioneer in metrological modernization. By demonstrating that Coriolis meters can serve as reliable transfer standards in industrial applications, this research bridges the gap between flow metrology and organizational management, showing how technical infrastructures evolve into strategic assets. Ultimately, the calibration bench emerges as a replicable model for emerging economies, offering a pathway where measurement excellence, sustainability, and competitiveness converge.

Declaration of conflict of interest

The researchers declare that there is no conflict of interest related to this research.

Author contribution statement

The authors: conceptualization, formal data analysis, investigation, methodology, project administration, resources, software, supervision, validation, visualization, writing – original draft, review and editing.

Statement on the use of Artificial Intelligence

The authors declare that Artificial Intelligence was used as a support tool for this article, and that this tool in no way replaced the intellectual task or process. The authors expressly state and acknowledge that this work is the result of their own intellectual effort and has not been published on any electronic artificial intelligence platform.

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