Measurement system contributions in industry, innovation, and quality infrastructure

Contribuciones de los sistemas de medición en la industria, la innovación y la infraestructura de calidad Contribuições dos sistemas de medição na indústria, inovação e infraestrutura de qualidade

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Abstract

Measurement systems, as a key component of metrology, play a crucial role in quality infrastructure, which is essential for promoting trade and enhancing industrial competitiveness. Without proper standardization and accreditation, metrology remains invisible, thereby limiting its impact on the broader industrial and societal frameworks. This article explores how metrology, a fundamental pillar of quality infrastructure, directly contributes to the achievement of Sustainable Development Goal 9 (SDG 9), which focuses on building resilient infrastructure, promoting inclusive and sustainable industrialization, and fostering innovation. By conducting a bibliometric analysis of scientific literature over the last two decades, this study identifies the direct contributions of metrology to SDG 9. These include improving measurement accuracy, standardizing processes, and strengthening quality control systems. The findings highlight the essential role of metrology in supporting sustainable industrial growth and innovation, making a tangible impact on the achievement of SDG 9. This research serves as a foundation for future work on the intersection of metrology, quality infrastructure, and the SDGs, emphasizing the need for a more visible and recognized role of metrology in industrial and societal development.

Keywords:. Metrology, Quality Infrastructure, Quality Engineering, Sustainable Development Goal (SDG).

Resumen

Los sistemas de medición, como componente clave de la metrología, desempeñan un papel crucial en la infraestructura de calidad, que es esencial para

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promover el comercio y mejorar la competitividad industrial. Sin una normalización y acreditación adecuadas, la metrología sigue siendo invisible, lo que limita su impacto en los marcos industriales y sociales más amplios. Este artículo explora cómo la metrología, pilar fundamental de la infraestructura de calidad, contribuye directamente al logro del Objetivo de Desarrollo Sostenible 9 (ODS 9), que se centra en construir infraestructuras resilientes, promover la industrialización inclusiva y sostenible y fomentar la innovación. Mediante un análisis bibliométrico de la literatura científica de las últimas dos décadas, este estudio identifica las contribuciones directas de la metrología al ODS 9. Entre ellas se incluyen la mejora de la precisión de las mediciones, la normalización de los procesos y el fortalecimiento de los sistemas de control de calidad. Los resultados ponen de relieve el papel esencial de la metrología en el apoyo al crecimiento industrial sostenible y la innovación, lo que tiene un impacto tangible en la consecución del ODS 9. Esta investigación sirve de base para futuros trabajos sobre la intersección entre la metrología, la infraestructura de calidad y los ODS, y hace hincapié en la necesidad de que la metrología tenga un papel más visible y reconocido en el desarrollo industrial y social.

Palabras clave:. metrología, infraestructura de calidad, ingeniería de calidad, Objetivos de Desarrollo Sostenible (ODS).

Resumo

Os sistemas de medição, como componente essencial da metrologia, desempenham um papel crucial na infraestrutura de qualidade, que é fundamental para promover o comércio e melhorar a competitividade industrial. Sem uma normalização e acreditação adequadas, a metrologia continua invisível, o que limita o seu impacto nos quadros industriais e sociais mais amplos. Este artigo explora como a metrologia, pilar fundamental da infraestrutura de qualidade, contribui diretamente para a consecução do Objetivo de Desenvolvimento Sustentável 9 (ODS 9), que se concentra na construção de infraestruturas resilientes, na promoção da industrialização inclusiva e sustentável e no fomento da inovação. Através de uma análise bibliométrica da literatura científica das últimas duas décadas, este estudo identifica as contribuições diretas da metrologia para o ODS 9. Estas incluem a melhoria da precisão das medições, a normalização dos processos e o reforço dos sistemas de controlo da qualidade. Os resultados destacam o papel essencial da metrologia no apoio ao crescimento industrial sustentável e à inovação, o que tem um impacto tangível na consecução do ODS 9. Esta investigação serve de base para trabalhos futuros sobre a interseção entre metrologia, infraestrutura de qualidade e ODS, e enfatiza a necessidade de a metrologia ter um papel mais visível e reconhecido no desenvolvimento industrial e social.

Palavras-chave:. metrologia, infraestrutura de qualidade, engenharia de qualidade, Objetivos de Desenvolvimento Sustentável (ODS).

Introducción

Measurement systems are the main foundation of the quality infrastructure, which aims to enhance trade and improve industry competitiveness (Ruso et al., 2017; Li et al., 2019). Metrology, as a central pillar of quality infrastructure, plays a critical role in ensuring that measurements are reliable, reproducible, and universally recognized. However, its full impact cannot be realized in isolation. Metrology, standardization, and accreditation work synergistically, forming a holistic system that drives consistent, high-quality outcomes across industries to strengthen Quality Infrastructure (Blind, 2024).

In the context of the Sustainable Development Goals (SDGs), SDG 9 aims to "build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation" (Naciones Unidas, 2015). This goal focuses on developing infrastructure that is not only efficient and resilient but also accessible and sustainable, supporting long-term economic growth while addressing global challenges such as inequality, climate change, and resource depletion (UNIDO, 2020).

Measurement systems, as part of Quality Infrastructure, play a fundamental role in advancing SDG 9. By ensuring the reliability and accuracy of measurements, metrology supports the development of infrastructure that is both technically sound and aligned with global sustainability standards (UNIDO, 2020). Through its interaction with the other two pillars of quality infrastructure , standardization and accreditation, metrology provides the foundation for driving innovation and sustainable industrial practices (Aswal, 2020 b). These contributions are particularly evident in industries striving to meet the dual challenge of growth and sustainability, where metrology helps ensure that infrastructure projects are not only efficient but also equitable and adaptable to future challenges (Brown, 2021).

Regional Metrology Organizations (RMOs), formed by the national metrology institutes of different countries, exemplify the interdependence of these pillars. These organizations are committed to coordination and cooperation on issues related to scientific metrology, exchange of standards, measurement or calibration procedures, legal metrology, and knowledge dissemination (Velychko, 2011; Centro Español de Metrología, 2019). These regional metrology institutes aim for the fulfillment of SDGs and the strengthening of the National Quality Systems (NQS) (EURAMET, 2015; Banco Interamericano de Desarrollo, 2019). In regions like Latin America and the Caribbean (LAC), the strengthening of National Metrology Institutes (NMIs) and digital transformation are key proposals within the Inter-American Metrology System, which focuses on digitization, calibration services, and metrological cloud development to improve the reach and effectiveness of quality infrastructures (Banco Interamericano de Desarrollo, 2019).

In Europe, countries are increasingly integrating digitalization, automation, and Industry 4.0 technologies into their national metrological infrastructure. Supported by organizations like the Physikalisch-Technische Bundesanstalt (PTB), these advancements help strengthen quality infrastructures and enhance metrological systems (Durakbasa, 2018; Eichstädt, 2017). The challenges posed by the Fourth Industrial Revolution are forcing industries, metrology centers, and laboratories to adapt to new digital requirements which are essential for the future of global trade and competitiveness (Prieto, 2018). Digital transformation, alongside advancements in automation and smart measurement technologies, strengthens the capabilities of metrology and quality infrastructures, ensuring that they are not only up to date but capable of supporting sustainable development. An illustrative example of the importance of quality infrastructure in the international context can be found in Quality Infrastructure Systems (QIS) models for customer satisfaction, which have evidenced an improvement in practices for high competitiveness in international trade (Thiel, 2018; Prieto, 2017).

In sectors such as health, ensuring the reliability and traceability of medical instruments and diagnostics is paramount. Pardo (2020) emphasizes the importance of Quality Assurance in these areas to meet international standards, which is only possible through the integral strengthening of the National Quality Infrastructure. This includes adopting reliable measurement systems that improve operational efficiency and product quality, allowing industries to optimize processes and meet the established specifications and standards, ultimately gaining a competitive edge (Agencia Española de Cooperación Internacional para el Desarrollo, 2017).

Despite the growing recognition of the importance of quality infrastructures and measurement systems, the direct impact of metrology on SDG 9 remains underexplored. This article presents a comprehensive review of the literature from 2002 to 2022 to explore how metrology contributes to the strengthening of quality infrastructures and its broader impact on SDG 9, seeking to clarify the role of metrology in ensuring the development of resilient infrastructures, promoting sustainable industrialization and fostering innovation, particularly in the context of global challenges such as climate change, inequality, and resource depletion.

This article is organized as follows: the methodology used for the study is detailed below, where the search, inclusion, and exclusion criteria are stated, as well as the research question and the selection of studies. Then, a bibliometric analysis of the information found is made in order to subsequently apply the inclusion and exclusion criteria to make the selection and classification of the study. Furthermore, the results are discussed considering the current trends in digital transformation and Industry 4.0, emphasizing the evolution of the role of metrology in modern industries. Finally, we present our conclusions and future research directions.

Figure 1. *Methodology stages*
Source: own elaboration.

Research question

The investigative work was carried out based on the formulation of the following research question (RQ):

RQ: How does metrology have a direct impact on the strength of Quality Infrastructure and SDG 9?

This question allows identification of alignment, trends, and knowledge on the impact of metrology as one of the pillars of Quality Infrastructure and its impact on the achievement of SDG 9. The classification and selection of information were developed considering the two-way relationship between the concepts previously mentioned (See Figure 2).

Figure 2. *Conceptual Framework*
Source: own elaboration.

The search in the scientific databases Science Direct, IEEE, Emerald, Google Scholar, and Scopus was carried out between 2002 and 2022, using the initial search equations: "Economic AND Development AND Metrology", "Industry AND Innovation Metrology", "Industrial growth AND Metrology", "Industrial Infrastructure AND Metrology", "Technological advances AND Metrology", "Sustainable Development AND Metrology", and "Sustainable Industry AND Metrology". Then, for the selection of the articles relevant to the research, the following inclusion criteria were determined: (1) Documents related to metrology and the quality of industrial processes, (2) documents related to SDG 9, metrology, and quality infrastructures, and (3) documents that present contributions to the strengthening of the quality infrastructure. Similarly, those that met at least one of the following exclusion criteria were discarded: (1) the documents are not related to metrology and Quality Infrastructure, and (2) the documents are only related to metrology or Quality Infrastructure.

Results

The first general search with each of the seven search equations mentioned above yielded a total of 1958 articles with possible studies of interest for the research topic. Then, applying the criterion of the period of interest between the years 2002 and 2022, a total of 197 articles were obtained. Then, applying the inclusion and exclusion criteria to provide greater precision for the study, 28 documents were selected, whose distribution by year of publication is shown in Figure 3. There is evidence of a growing trend since 2014 in research and industry contributions, innovation, and Quality Infrastructure, with a greater growth between 2020 and 2022.

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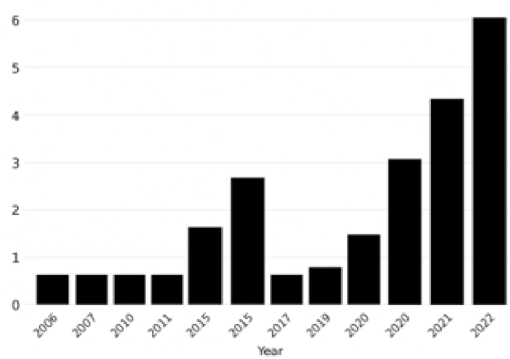

Figure 3. *Number of studies published per year*
Source: own elaboration.

ID	Authors - Year	Contribution
1	(Wipplinger *et al.*, 2006)	Methodology for the promotion of quality infrastructures of small enterprises.
2	(Weckenmann *et al.*, 2007)	Review of current manufacturing as seen from metrology and industrial trends and demands.
3	(Frota *et al.*, 2010)	Discussion on the importance of metrology and policy development to support the regulatory environment and strengthen the quality infrastructure.
4	(Velychko & Gordiyenko, 2010)	Basic principles for the development of regional metrological documents with a European international normative basis.
5	(Peuckert & Goncalves, 2011)	Studies for the promotion of the creation of necessary interface units fostering STI and DUI modes of learning.
6	(Bakhtiar, 2014)	Qualitative methods evaluation to ensure business efficiency and effectiveness of legislative projects.
7	(Okrepilov *et al.*, 2014)	Projects based on metrological services and manufacturing of measuring equipment for the modernization of the Russian machine-building industry.
8	(Bauer *et al.*, 2015)	Trend studies between metrology and automation as challenges of the future, with solutions from collaborative work.
9	(Gonçalves *et al.*, 2015)	Identification of challenges and constraints to conducting impact studies for quality infrastructure.
10	(Rodrigues Filho & Gonçalves, 2015)	Legal metrological control study and its impact on society and the economy as a tool for organizational management.
11	(Savio *et al.* 2016)	Metrological application in industrial production for the improvement of process chains and process control.
12	(Thiel *et al.*, 2017)	Digital quality development infrastructure to support conformity assessment processes and services based on new technologies and data.
13	(Yoo, 2019)	Axes analysis for standardization, conformity assessment, and metrology in National Quality.
14	(Aswal, 2020a)	Impact of contributing metrological study models on national economy and quality of life, affordable healthcare, high-quality science and technology, and sustainable energy, among others.
15	(Aswal, 2020b)	Study on strengthening quality infrastructure through the implementation of regulation sconsidring industrial growth, affordable healthcare, and investment attraction.
16	(Harmes-Liedtke, 2020)	Methodological proposal for quality infrastructure measurement through metrology, standardization, certification, and accreditation application.
17	(Shen *et al.*, 2020)	Improved coupling model to recognize contributed and weakened indicators.
18	(Brown, 2021)	Metrology as "measurement of measurement" to re-examine post-COVID-19 effects .
19	(Eichstädt *et al.*, 2021)	Key challenges analysis for metrology in the digital area, addressing metrological principles for trust in data and algorithms.
20	(Garg *et al.*, 2021)	Report outlining the paradigms of the metrological cloud in Indian perspectives for the establishment of a national digital quality infrastructure.
21	(Isharyadi & Kristiningrum, 2021)	Systems and product certification analysis using comprehensive tools to assess the quality of a country's infrastructure.
22	(Nzumile & Taifa, 2021)	Exploratory study of the functions of standardization and quality infrastructure systems.
23	(Bhatnagar *et al.*, 2022)	Quality Infrastructure analyses and measurement standards for technology and personnel. Indian study case.
24	(Demissie *et al.*, 2022)	Service evaluation and its impact on the development of the national quality infrastructure of supply chains.
25	(Juraboyevich *et al.*, 2022)	Methodology for impacting product quality indicators as seen from the metrological supply side.
26	(Kumar & Albashrawi, 2022)	Study reflecting a need for upgrading improving capabilities by implementing new primary and secondary standards.
27	(Tsimidou, 2022)	Study for strategic priorities definition and identification of transversal areasbetween metrology and the food sector.
28	(Zhang & Liu, 2022)	Hybrid methodological application to reduce carbon emissions in China.

Table 1. *Contribution of selected studies*
Source: own elaboration.

Figure 4 shows the number of studies published by country. Although countries such as Germany, France, Spain, and Mexico are considered as references in the metrological field, this study shows that countries such as Brazil, the United States and China stand out for their contributions with a greater number of research papers that relate metrology to the SDG9.

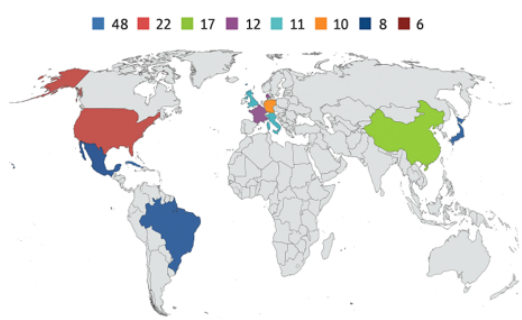

Figure 4. *Number of studies published by country*
Source: own elaboration.

Table 1 describes the contributions identified in the selected studies, identifying the tools, models, or methodologies related to the integration of measurements and quality infrastructure. In general, the contributions focus on the impact of SDG on the growth of communities with infrastructure issues and how metrology has contributed.

Bibliometric analysis results

Selected studies are submitted to a bibliometric analysis to identify the keywords most used by the authors, their groupings, and their interrelations. Figure 5 shows the bibliometric map obtained using the VosViewer Software, identifying the interrelationships through clusters of different colors which correspond to those words with the highest affinity through interaction links.

Based on the visualization of the term co-occurrence map, five thematic clusters can be identified, each reflecting interrelated domains across metrology, quality infrastructure, and economic development. The blue cluster (I) is centered around the term "metrology," which appears with the highest frequency in this group, and is closely linked to concepts such as sustainable development, standardization, nanotechnology, commerce, measurement, and traceability. This cluster highlights the central role of metrology in supporting sustainability, facilitating trade, and fostering innovation. The red cluster (II) is led by the term "economic development," and includes related terms such as "finance," "China," "research and development," "investment," "economic analysis," and "economic growth".

This reflects a strong focus on empirical economic research, development strategies, and the role of financial and policy instruments, with a particular geographic emphasis. The green cluster (III) is dominated by economic and social effects, alongside terms such as "measurements," "standards," "calibration," "optimization," "automation," and "international trade". This cluster emphasizes the broader socio-economic implications of measurement systems, efficiency improvements, and trade facilitation. The yellow cluster (IV) is structured around the term "economics," incorporating concepts like Industry 4.0, technology transfer, digital transformation, competition, industrial economics, and digital storage, thereby reflecting current trends in economic digitalization and industrial modernization.

Lastly, the purple cluster (V) is anchored by quality assurance, with terms including "reliability," "quality control," "conformity assessment," "accreditation," and "quality infrastructure" underscoring the importance of technical competence and standardized practices in ensuring reliable systems and international compliance. Collectively, these clusters illustrate the complex and integrated relationships among metrology, quality, technological advancement, and sustainable economic growth.

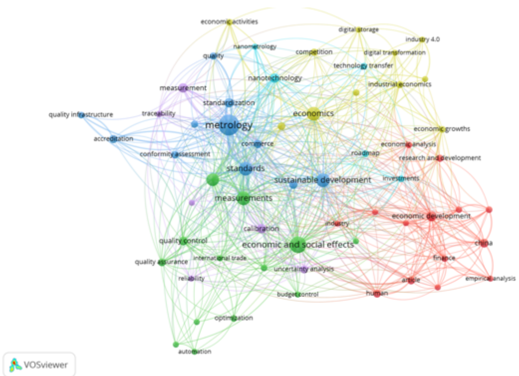

Figure 5. *Results of the bibliometric map of the Economic AND Development AND Metrology equation*
Source: own elaboration.

Studies evaluation and analysis

Table 2 presents a summary of how measurement systems have been employed to strengthen quality infrastructure, with a particular focus on their contribution to industry, innovation, and infrastructure. Additionally, it presents the different SDGs to identify the relationship they may have with metrology and quality infrastructure. This allowed us to evidence from the data presented for SDGs 3, 4, 6, 7, 9, 12, and 13, that there is a relationship. Additionally, we discuss how each of those present a direct relationship. Even though there is a relationship with different SDGs, the focus of this paper is SDG 9.

SDG	Metrology	Quality infrastructure	How to respond
1	N/A	N/A	N/A
2	N/A	x	Invest in rural and urban areas and social protection
3	x	x	Growth of health infrastructure.
4	x	x	Through the strengthening of educational entities in metrology.
5	N/A	N/A	N/A
6	x	x	Invest in the research and development of water resources for the population.
7	x	x	Accelerate the transition to an affordable, reliable, and sustainable energy system by investing in renewable energy resources, prioritizing energy-efficient practices, and adopting clean energy technologies and infrastructure.
8	N/A	x	N/A
9	x	x	Establish rules and regulations to ensure the sustainable management of business projects and initiatives.
10	N/A	x	Enhance and promote inclusive economic and social growth.
11	N/A	N/A	N/A
12	x	x	Promote the use of sustainability in production processes.
13	x	x	Decarbonize business operations and supply chains.
14	N/A	N/A	N/A
15	N/A	N/A	N/A
16	N/A	N/A	N/A
17	N/A	N/A	N/A

Table 2. *Relationship, application, and SDG response*
Source: own elaboration.

Afterwards, a taxonomic analysis of the 28 selected studies was performed, establishing two main categories (see Table 3). The development of this taxonomy provides a foundation for identifying how the issues surrounding SDG9 have been addressed in terms of industry, innovation, and infrastructure. This will allow future researchers to identify development trends in this area. The first category is contribution type, which has three subcategories (theoretical, practical, and mixed). 32.1% of the studies correspond to theoretical contributions, 28.6% are practical, and 39.3% are mixed, that is, contributions that combine theoretical and practical contributions to study. The second category is the methodology type, which includes the quantitative, qualitative, and mixed subcategories. 21.4% of the studies are quantitative, 25% are qualitative and, finally, 53.6% combine both qualitative and quantitative aspects.

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ID	Contribution type			Methodology type		
	1.1. Theoretical	1.2. Practical	1.3. Mixed	2.1. Quantitative	2.2. Qualitative	2.3. Mixed
1	X			X		
2	X			X		
3	X					X
4			X			X
5		X				X
6			X		X	
7		X				X
8			X			X
9	X					X
10	X				X	
11		X		X		
12		X				X
13	X				X	
14			X			X
15	X				X	
16		X		X		
17			X			X
18			X			X
19	X					X
20			X			X
21			X			X
22		X			X	
23			X		X	
24			X			X
25	X			X		
26		X		X		
27			X		X	
28		X				X
Total (%)	32.1	28.6	39.3	21.4	25	53.6

Table 3. *Taxonomic classification of selected studies.*

Discussion of the results

Technological innovation generates numerous changes in the industrial context as measurement systems incorporate trends and cloud data storage . From the perspective of organizations, innovative companies agree that to grow, they must adopt new technology and consider clean processes to support sustainability (AECID, 2017). In addition, digital transformation enables quality infrastructure. Metrology, accreditation, and standardization have been essential for digital expansion, harmonizing the interconnection between industry, society, and economy (PTB, 2017).

Quality infrastructure and measurement systems in goods and services organizations contribute to improving product quality and process efficiency, and effectiveness. The use of calibrated instruments and measuring equipment guarantees the quality and reliability of the results obtained, for which European countries presented an industrialization plan supported by an Industry 4.0 model aligned with the SDGs (Casalet, 2018).

The SDGs consider challenges in the international context, among which we find the reduction of hunger and poverty, access to drinking water and health services, reducing inequality, promoting sustainability and innovation in organizations, having sustainable cities, participation in actions that contribute to climate change, among others. The SDGs seek to achieve a future of prosperity and development for companies with an infrastructure to support sustainability, which allows the increase of the productivity of the private and public sector (DNP, 2018) by strengthening the capabilities of the individual, supported by the triad of the SDGs, Quality Infrastructure, and metrology, which are fundamental elements for achieving a future with technological innovation, evaluate their progress, and prioritize their efforts to generate a positive impact on society and the environment.

As shown in Table 2, the SDG impact on metrology and its object of study is indisputable; providing measurement methods, adequate instruments, and competent personnel to take reliable measurements is part of the Quality Infrastructure system. According to the World Institute for Development Economics Research of the United Nations University, between 1990 and 2015, there was a percentage decrease in poverty between 36% and 10% (UN, 2019a). In the last years, events such as pandemics have opened the possibility of not decreasing this percentage. That is where the Quality Infrastructure system plays a vital role in keeping the poverty factor from increasing.

The agricultural sector and the application of metering systems enable the growth of infrastructure in the rural sector. However, the impact of measurement science is not perceptible in the first two SDGs proposed by the UN. For this reason, measurement systems are essential for the quality and protection of ecosystems, where water quality management and pollution control are relevant factors. Therefore, measurements give confidence to provide reliable quality. Diseases caused by impurities in water affect 1.5 billion people worldwide. In countries like Indonesia, the Ministry of Health and measurement and regulatory agencies in quality specifications implement their standards to guarantee water purification. Proposals then appear for measurement and control systems for the detection, recording, and storage of drinking water in residential tanks, where it is necessary to ensure the optimal management of measurements through the implementation of quality infrastructures (Luvita et al., 2019).

On the other hand, energy is central to the challenges and opportunities facing the world today, whether regarding employment, security, climate change, food production, or raising incomes through universal access to essential energy. To find affordable and non-polluting energy sources in recent years, the European Commission and the European Organization of Metrology have conducted several investigations on energy. Such research focused on projects with intelligent grids and generation with wind sources that have provided advances in strategies for the continuous improvement in medium and long-term quality of life through resource efficiency (Rietveld et al., 2010; Melcher et al., 2010)

Wipplinger et al. (2006) and Weckenmann et al. (2007) emphasize the coordinated role of metrology and standardization in emerging industrial contexts. Similarly, Frota et al. (2010) and Peuckert & Goncalves (2011) highlight how national quality systems, incorporating both legal and industrial metrology, reinforce productive infrastructure. Contributions by Bauer et al. (2015), Gonçalves et al. (2015), and Rodrigues Filho & Gonçalves (2015) illustrate how metrological traceability, when linked to accreditation and certification processes, enhances industrial competitiveness. Moreover, studies such as Thiel et al. (2017), Aswal (2020a, 2020b), and Eichstädt et al. (2021) underline the need for a infrastructure of robust quality to support innovation, production efficiency, and international trade trust. Furthermore, Harmes-Liedtke (2020) and Shen et al. (2020) present governance models where metrology functions as part of an institutional network aligned with sustainable industrial development.

In addition, SDG 9 explicitly calls for building resilient infrastructure, promoting inclusive and sustainable industrialization, and fostering innovation. In this context, metrology and the broader quality infrastructure system play a critical enabling role by ensuring the reliability of measurements, facilitating compliance with international standards, and supporting technological advancement. Several studies highlight how national metrology systems contribute to industrial development, particularly in areas such as manufacturing, smart production, and clean technologies (Weckenmann et al., 2007; Frota et al., 2010; Savio et al., 2016).

Moreover, metrological traceability and standardization provide the technical foundation necessary for innovation and productivity gains, especially in developing countries aiming to integrate into global value chains (Harmes-Liedtke, 2020; Aswal, 2020a). These contributions position metrology not as a separate discipline, but as an essential component of the infrastructure that supports the achievement of SDG 9.

In addition, the influence of metrology inequality and social equity is reflected in the estimation and its application in a quantitative process, which relates to measuring the quantity and determining the progress in equity for each person within society . Therefore, Measurement System implementation for SDG contributions in an organization requires competent personnel and, therefore, the support of the agencies that are part of the quality infrastructure, such as the Institute of Standardization, accreditation bodies, the National Institute of Metrology, and conformity assessment bodies, which are part of the Quality Infrastructure. That contributes to the reduction of errors, improves the quality of products and services, and helps companies to comply with national and international standards, increasing reliability and credibility with stakeholders (Savio et al., 2016).

The present systematic review of literature identified how metrology has been approached as a strategic component within Quality Infrastructure, with special emphasis on its contribution to the fulfillment of SDG 9, which promotes the construction of resilient infrastructure, inclusive and sustainable industrialization, and the promotion of innovation. The studies analyzed show that metrology not only plays a vital role in the traceability of measurements but also acts as a key enabler to improve productivity, strengthen confidence in international trade, and boost industrial competitiveness.

It was also shown that quality infrastructure based on national metrology systems has a direct impact on the development of strategic sectors such as smart manufacturing, clean technologies, and digital innovation processes. In this context, governments have a leading role in designing and implementing public policies that encourage the adoption of emerging technologies by organizations, thus aligning their operations with the principles of sustainability and responsible industrial development. This requires effective articulation between public, private, and academic actors, as well as the integration of measurement capabilities in digital systems that allow validating processes through tools such as calibration, testing, and verification.

From a methodological point of view, the studies reviewed are characterized by mixed approaches that combine theoretical and applied perspectives. Nevertheless, relevant opportunities for future research are identified, especially those that quantitatively measure the impact of metrology on specific SDG 9 indicators in emerging economies. It is also important to promote projects that articulate Quality Infrastructure with digital transformation processes, including automation and the development of new measurement tools aimed at continuous improvement and industrial optimization.

Finally, it should be emphasized that accurate and reliable measurement systems not only improve operational efficiency and product quality but also offer substantive competitive advantages to the organizations that adopt them. Therefore, it is essential to structure integrated strategies that strengthen the relationship between industry, innovation, and metrology, thus generating long-term value in the achievement of the Sustainable Development Goals, with a systemic view towards sustainability and industrial resilience.

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