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Enhancing sustainability of medical devices procurement in Low- and Middle-Income Countries

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ABSTRACT

this research originates from the observation that a significant proportion of Medical Devices (MDs) in Low- and Middle-Income Countries (LMICs) remain unused. Unused MDs in the public health sector are the result of an unsustainable procurement that does not consider the existence or creation of the conditions for a safe, effective and sustainable use of the MD. Focusing on the causal factors behind unused MDs, this study aims to explore how procurement processes can be improved to avoid this unsustainable waste of resources. A systems thinking approach was applied to investigate the root causes of the failure of the processes involved in MD procurement. Beginning with the development of a diagram based on a literature analysis and expert panel judgements, this research resulted in the recommendation of three key leverage points to be implemented during the procurement of MDs: conducting robust, evidence-based assessments of local needs, conditions, capabilities and constraints; involving a multidisciplinary team of experts in the procurement process; and strengthening local clinical engineering capabilities. The results show how sustainable procurement shall primarily focus on effective, long-term use of MDs, strengthening procurement governance and resources appropriate use, and assess their environmental, social, and financial impacts as second steps.

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Medical devices procurement; sustainable procurement; Low- and Middle-Income Countries; health care governance

1. Introduction

Low investments in Medical Devices (MDs) maintenance as well as a lack of MDs management systems are critical factors that condition the life expectancy of MDs. It affects their sustainability and requires additional investments for their premature replacement (2023; World Health Organization 2010). Since the 2007 60th World Health Assembly, it has been recognised that Low- and Middle-Income Countries (LMICs) face economic and technical challenges with MDs. In particular, LMICs are '*concerned about the waste of resources resulting from inappropriate investments in health technologies in particular medical devices that do not meet high-priority needs, are incompatible with existing infrastructures, are irrationally or incorrectly used, or do not function efficiently*' (World Health Organization 2007).

According to WHO '*Up to three quarters of these devices do not function in their new settings – developing countries – and remain unused*' due to '*lack of needs assessment, appropriate design, robust infrastructure, spare parts when devices break down, consumables, and a lack of information for procurement and maintenance, as well as trained health-care staff. These issues are part of a broader problem in many countries: the lack of a medical device management system*' (World Health Organization 2010). According to a survey published in 2024 by Medical Aid International and carried out in 23 facilities in Africa, a weighted average of 26% of equipment laid unused with a peak of 85% (Medical Aid International 2024). Based on interviews with local biomedical engineers, this report likely underestimates the total number of unused MDs, as hospitals without biomedical engineers were not included in the study.

Other studies suggest that between 40% and 70% of medical devices in these regions fall into this category, reflecting a severe misallocation of resources (Diaconu et al. 2017; Medical Aid International 2024;

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Perry and Malkin 2011). These unused MDs not only pose a safety risk and represent sunk costs for the healthcare system, but also point out the systematic failure of acquisition and management processes. Data from United Nations Global Marketplace (UNGM) show that, in 10 years, from 2014 to 2023, UN agencies have procured 11,3 billion USD of medical equipment and supplies for LMICs Countries (United Nations Global Marketplace, 2024). Applying the estimated range of 26% to 75% of unused MDs identified in the literature analysis from the introduction to the $11,3 Billion USD spent on MDs reveals a tremendous amount of wasted investments. This underscores the urgent need to enhance the governance and management of MDs procurement processes for more sustainable results.

The concept of sustainable development (SD), as defined by the World Commission on Environment and Development, is particularly relevant in this context. Sustainable development is defined as a '*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*' (Brundtland 1987). Therefore, an unused medical device in the public health services of an LMIC exemplifies an unsustainable procurement process, emphasising the misallocation of public investment (V. Di Virgilio, A. Bouchard Saindon, and F. C. G. Becerra Posada 2023). A procurement process resulting in an unsustainable technological solution represents a failed process with a negative impact on the financial, environmental and social conditions of the target population (V. Di Virgilio, A. Bouchard Saindon, and F. C. G. Becerra Posada 2023). An unused medical device has no positive impact on the health services and can even have negative effects due to associated safety risks, disposal challenges and administrative costs.

1.1. Public health investment and development

Investment projects in the health sector of LMICs are based on a virtuous cycle: investments or loans financed with existing or future taxes are converted into infrastructure and technologies to improve population health as shown in Figure 1.

Compared to high-income countries, LMICs often lack the organisational structure, funding, and human resources necessary for proactive medical equipment management. Procurement projects that overlook this weakness, focusing solely on equipment quality rather than long-term management and sustainable use, are

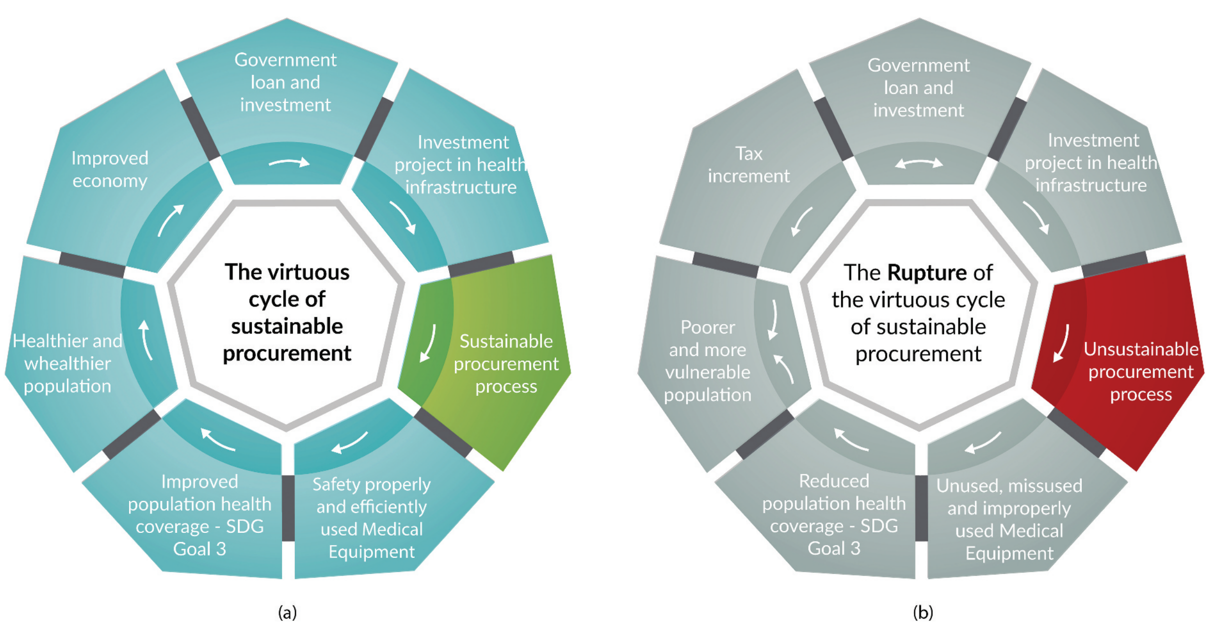

Figure 1. Panel (a): The cycle of investments in health technology. Sustainability of the procurement process is crucial to achieve the intended impact of a healthier population. Through continuous improvement of the population's economic and health conditions, sustainable development of the targeted LMIC can be achieved. Figure 1 panel (b): Disruption of the virtuous cycle of investments: it occurs when quality assurance and sustainability of the procurement project are lacking. Consequently, the purchased equipment remains unused, which leads to an unjustified tax increase for the population. This expenditure makes the population more vulnerable and health care services less accessible.

likely to result in unused medical devices. Conversely, when viewing procurement as one essential stage within the broader process of MDs management, and acknowledging the deficiencies in this process within LMICs, it becomes clear why these low-resource countries frequently rely on internationally funded projects for MDs procurement. These projects, therefore, present a unique opportunity to enhance LMICs MDs management practice.

An unused MD is inherently unsustainable. The procurement process that resulted in its acquisition should be deemed unsustainable, regardless of the MD's quality, cost and its environmental and social impact. The failure to utilise these devices effectively transforms what should be a virtuous cycle of investment and health improvement into a vicious cycle of wasted resources and unfulfilled potential, ultimately leaving future generations burdened with debt and compromised economic and health outcomes as illustrated in Figure 1b.

1.2. Objectives

This article aims to identify the causes behind the public procurement of MDs that are unfit for their intended purpose and remain unused. It also seeks to examine the relationships between these causes and provide recommendations to enhance the sustainability of public and international MD procurement processes. The central question this article addresses is as follows: why are there so many unused MDs in LMICs? This question can be broken down into the following key inquiries:

(1) What causal elements lay behind unused MDs in LMICs?
(2) What key factors explain the unsustainable procurement dynamics resulting in unused MDs in LMICs and what leverage points can be identified to improve these processes?

Indeed, an unused MD invariably indicates a failure in the procurement process, whether due to the provision of low-quality devices, the neglect of local needs, capabilities, or installation conditions, or the failure to recognise and address weaknesses in MD management at the recipient unit.

This study aims to address the critical issue of unsustainable procurement of MDs in LMICs by applying a systems thinking approach to unravel the complex dynamics at play, focusing on identifying the factors that hinder MDs sustainable use. Through this analysis, it seeks to develop a comprehensive CLD that models the relationships and feedback loops that contribute to the issue of unsustainable procurement and the prevalence of unused MDs in LMICs. By doing so, leverage points or critical areas within the system where interventions can lead to significant improvements in procurement will be identified, ultimately enhancing the sustainability of MD purchase and use.

Recognising that unsustainable procurement practices can be seen as a misuse of public funds, the study will explore the connections between identified leverage points and critical governance factors of the health system: transparency, corruption, and bureaucracy quality (Rajkumar and Swaroop 2008). Additionally, the study considers the knowledge gap between buyers and vendors – which often occurs in the procurement of health technologies characterised by high-value, low-frequency transactions (Anin, Essuman, and Owusu 2020; Hoksbergen et al. 2020; Lewis 2006; Liang, Liang, and Wei 2023), - as a significant dysfunctional mechanism in governance. Finally, this study explores how the identified leverage points can contribute to prevent and mitigate the specific factors of corruption, weak bureaucracy and knowledge gaps and thus strengthening the governance of LMICs healthcare systems as a key element to reduce poverty, mortality and morbidity and to guarantee an adequate return on health investments (Lewis 2006).

2. Materials and methods

2.1. Focusing on MD procurement in LMICs

As evidenced by the literature in the introduction, LMICs, as defined by the World Bank, face a significant challenge with unused medical devices. In the 60th World Health Assembly LMICs expressed their concerns on procuring medical devices without considering alignment with existing high-priority needs, compatibility with local existing infrastructure, capacity building for rational and correct use, and efficient functioning constitutes an inappropriate investment and, ultimately, an unsustainable procurement practice. This article investigates the causes of the prevalence of unused medical devices in LMICs, viewing it as a systemic failure of international efforts to improve healthcare. The key objective is to understand how to enhance procurement processes, thereby improving the appropriateness and impact of health technology investments.

2.2. Causal loop diagram

Systems thinking has become an invaluable approach for understanding the complex dynamics within healthcare systems. Unlike traditional methodologies that focus on individual components separately, systems thinking considers the interrelationships, feedback loops, and processes that connect different elements that are part of the system. This approach has been successfully applied to address complex health challenges such as tobacco control, obesity, and neonatal mortality (National Cancer Institute 2007, Rwashana et al. 2014; Waterlander et al. 2021). The World Health Organization (WHO) has recognised the value of systems thinking in the design and evaluation of health interventions, acknowledging its potential to enhance the effectiveness of public health programs (de Savigny and Adam 2009). Moreover, system thinking is being widely used in corruption investigations (Glynn 2022).

A Causal Loop Diagram (CLD) is a systems thinking tool that can be particularly useful in this context. CLDs help visualise the causal relationships between different variables in a system, identifying feedback loops that reinforce or counteract particular outcomes (de Pinho 2019; Kim 1999). By mapping out these relationships, policymakers and health professionals can gain a deeper understanding of the underlying causes of procurement failures and identify leverage points for intervention. This approach offers a holistic perspective, enabling the design of more sustainable procurement processes that align with the larger goals of improving health outcomes and ensuring long-term development.

Addressing the misallocation of public funds in the procurement of medical devices in LMICs requires a systems thinking approach that considers the complex interplay of factors influencing procurement outcomes. In this study, our aim is to suggest how, by adopting this methodology, it is possible to move towards a more sustainable and effective use of resources, ultimately leading to better health services and outcomes for the populations they serve.

2.3. The process of identifying the causal elements and key factors

The development and analysis of the causal elements and key factors followed a structured and iterative process described below to ensure a thorough exploration of causal dynamics, and it is summarised in Figure 2.

Step 1: Scoping the problem. The process of mapping causal elements started by focusing on two key questions mentioned in Section 1.4.

Step 2: Bibliography search. Relevant articles from bibliographic databases from 1999 to 2024, written in English, discussing the procurement of medical equipment in LMICs were analysed. The searches on Scopus and Pubmed were conducted using, respectively, the following strings:

> TITLE-ABS-KEY ((‘MEDICAL DEVICES’ OR ‘MEDICAL EQUIPMENT’) + (‘PROCUREMENT’ OR ‘PURCHASE’ OR ‘ACQUISITION’ OR ‘SUPPLY CHAIN’) + ((‘DEVELOPMENT’ OR ‘LOW INCOME’ OR ‘MID INCOME’ OR ‘MIDDLE INCOME’))) AND PUBYEAR > 1998 AND PUBYEAR < 2025 AND (LIMIT-TO (LANGUAGE, ‘English’))

> (‘MEDICAL DEVICES’ OR ‘MEDICAL EQUIPMENT’) AND (‘PROCUREMENT’ OR ‘PURCHASE’ OR ‘ACQUISITION’ OR ‘SUPPLY CHAIN’) AND (‘DEVELOPMENT’ OR ‘LOW INCOME’ OR ‘MID INCOME’ OR ‘MIDDLE INCOME’)

> **Step 3: Widening the search**. Additional searches in the WHO publications and using Google Scholar as well as by snowballing techniques complemented the process.

> **Step 4: Bibliography analysis**. Articles unrelated to the procurement of MDs in LMICs were excluded. Documents that did not refer to the procurement of MDs in LMICs were excluded. Documents that referred

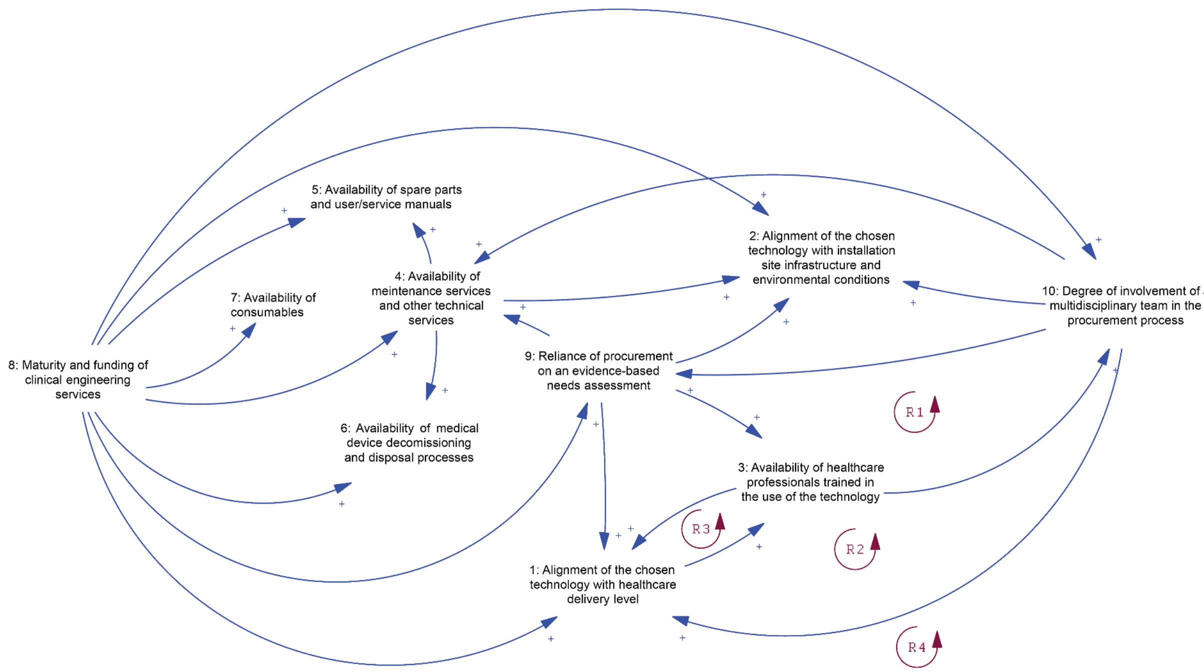

Figure 2. Flowchart of the research methodology, as process for mapping causal dynamics, starting from the observation of unused MDs in LMICs as the result of a procurement process that does not guarantee effective and efficient use of the MDs; and implementing seven steps to analyse the causal dynamics that lay behind the observed unsustainable procurement results.

to consumables or disposables were excluded because they are usually single use products and its nature does not associate with the concept of sustainability that the article focuses on: sustainable use in time.

Step 5: Application of CLD method to identify key factors. The causal elements influencing the sustainability of MD procurement, mentioned in the selected literature extracted, are listed in Appendix A. The extracted causal element have successively been grouped, according to the main concept each element refers to, into a reduced numbers of key factors. The resulting key factors serve as the input variables for the CLD.

To ensure that the names of the key factors aligned with the properties of system dynamics maps, the following criteria were applied: names had to be neutral (e.g., 'infrastructure' rather than 'poor infrastructure'), measurable or observable (e.g., 'availability of personnel') and had to represent quantities that can change over time. (e.g. 'level of involvement')

Step 6: Creation of the Causal Loop Diagram. An interrelationship diagram was created by mapping the connections between the key factors to identify the system's drivers and outcomes. The process was carried out in collaboration with a senior group of five biomedical engineers, each possessing over 20 years of experience in the procurement of MDs in LMICs. Each expert was asked separately to propose the causal relations between the ten key factors extracted from the literature. Only the causal relations proposed by at least three out of the five experts have been included in the diagram. The final scheme has been proposed to an open discussion of the panel that jointly confirmed its validity. This diagram was then converted into a CLD using Vensim v10.2.1 software.

Step 7: Identification of Leverage points. The resulting diagram enabled the identification of feedback loops, leverage points and their implications in the sustainability of MDs public-funded procurement projects. The identified leverage points were correlated with the causes of public fund misallocation. Based on this analysis, hypotheses were formulated to demonstrate how these causes influence sustainability and how certain actions can be recommended to mitigate adverse effects.

3. Results

3.1. Identifying causal elements and key factors

The search on Scopus database carried out on 4 December 2024 yielded 595 results, while the search on PubMed database carried out on 4 December 2024 yielded 168 results. Using the methodology described above to filter by relevance, 14 articles were selected. The results are shown in Table 1. It is interesting to note that including the terms 'SUSTAINABLE' or 'SUSTAINABILITY' significantly reduces the number of articles and orients the results towards environmentally sustainable medical devices.

The 78 causal elements, reported in Annex A, were extracted from the publications listed in Table 1 and grouped into the following 10 *key factors* as detailed described in Appendix A:

(1) Alignment of the chosen technology with healthcare delivery level (6);
(2) Alignment of the chosen technology with installation site infrastructure and environmental conditions (9);
(3) Availability of healthcare professionals trained in the use of the technology (9);
(4) Availability of maintenance services and other technical services (20);
(5) Availability of spare parts and user/service manuals (7);
(6) Availability of medical device decommissioning and disposal processes (2);
(7) Availability of consumables (7);
(8) Maturity and funding of clinical engineering services (15);
(9) Reliance of procurement on an evidence-based needs assessment (8);
(10) Degree of involvement of a multidisciplinary team in the procurement process (5).

The numbers in parentheses at the end of each *key factor* measure its occurrences in the analysed literature as a relative weight (RW), indicating how relevant the topic is perceived for the sustainable use of medical devices.

3.2. Causal loop diagram and reinforcing loops

The 10 *key factors* identified in the literature serve as inputs to create the CLD showed in Figure 3, illustrating the dynamics between the factors that influence the sustainability of MDs procurement.

Table 1. List of 14 relevant articles and publications about unsustainable MDs in LMICs.

Publication	Year of Publication	Source
Methods for medical device and equipment procurement and prioritisation within low- and middle-income countries: findings of a systematic literature review Diaconu et al. (2017).	2017	PubMed and Scopus
Sustainable procurement of medical devices in an international context: background and definitions V. Di Virgilio, A. Bouchard Saindon, and F. C. G. Becerra Posada (2023).	2023	Scopus
Sustainable procurement of medical devices in an international context: needs assessment V. Di Virgilio, Bouchard Saindon, and Becerra Posada (2023).	2023	Scopus
Developing Strategies for Sustainable Medical Equipment Maintenance in Under-Resourced Settings Webber et al. (2020).	2020	Scopus
Barriers for medical devices for the developing world Malkin (2007).	2007	Snowballing
Medical device procurement in low- and middle-income settings: protocol for a systematic review Diaconu et al. (2014).	2014	PubMed
Procurement process resource guide World Health Organization (2011).	2024	WHO Database
Medical devices: managing the mismatch: an outcome of the priority medical devices project World Health Organization (2010).	2010	WHO Database
Avoid equipment graveyards: rigorous process to improve identification and procurement of effective, affordable, and usable newborn devices in low-resource hospital settings (Asma et al. 2023).	2023	PubMed
Medical Equipment Management in General Hospitals: Experience of Tulu Bolo General Hospital Kabeta, Chala, and Tafese (2023).	2023	PubMed
Devices and furniture for small and sick newborn care: systematic development of a planning and costing tool Tarus et al. (2023).	2023	PubMed
Medical equipment in government health facilities: missed opportunities Pardeshi (2005).	2005	PubMed
Sustainable procurement of medical devices in an international context: Assessment of local and lifelong use conditions (Di Virgilio, Becerra Posada, and Bouchard Saindon (2024).	2024	Scopus
Problems with systems of medical equipment provision: an evaluation in Honduras, Rwanda and Cambodia identifies opportunities to strengthen healthcare systems Emmerling, Dahinten, and Malkin (2018).	2018	PubMed

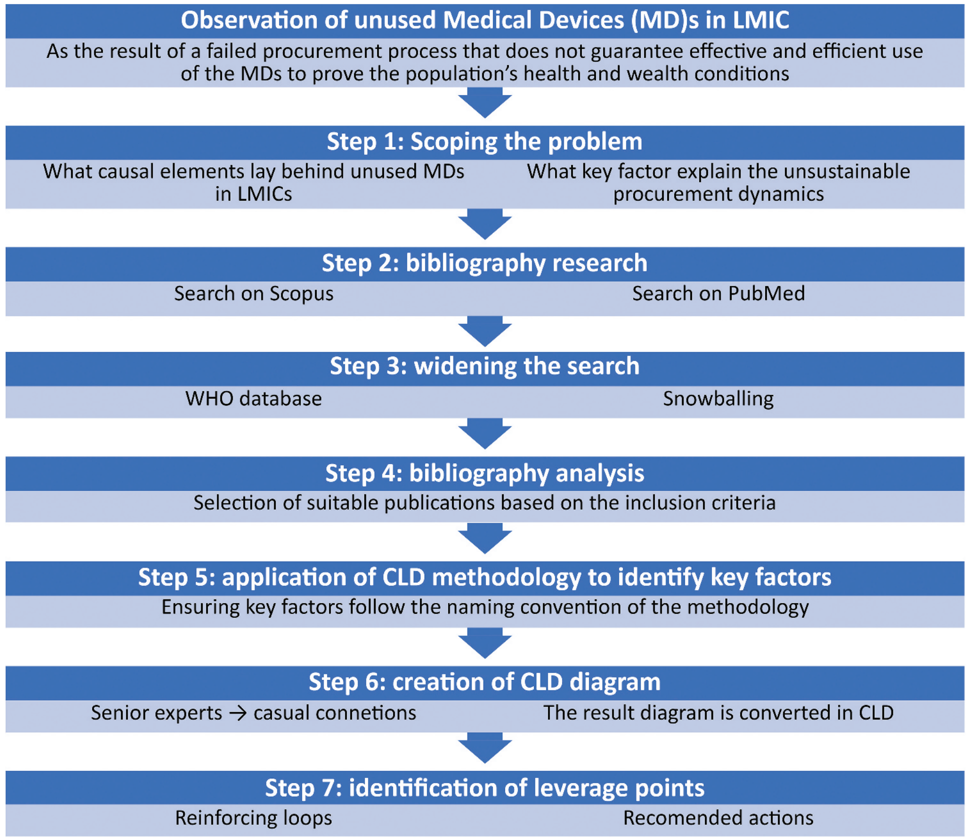

Figure 3. Causal loop diagram (CLD) representing the ten key factors involved in the sustainable procurement of MDs and their causal dynamics. The key factors have been extracted by grouping the causal elements identified in the literature as shown in appendix A. The causal connections between them were identified by senior group of five biomedical engineers, each possessing over 20 years of experience in the procurement of MDs in LMICs.

Figure 4 reveals four reinforcing loops (R1-R4) identified by the software used to create the CLD. The first reinforcing loop (Figure 4 Panel a) shows that the availability of healthcare professionals trained in the use of the technology encourages the degree of involvement of a multidisciplinary team in the procurement process, leading to a process with a higher probability of being founded on an evidence-based needs assessment.

The second reinforcing loop (Figure 4 Panel b) builds upon the previous one, illustrating that a procurement process based on a needs assessment is more likely to ensure that the procured MDs align with the local healthcare context and delivery level. When this occurs, the likelihood of the device being used effectively and efficiently increases, thereby enhancing the sustainability of the purchase.

The third reinforcing loop (Figure 4 Panel c) shows a virtuous cycle in which having professionals trained in the use of the technology helps to align the procurement process of the chosen technology with the delivery level, and vice versa. If the procured technology is aligned with the level of care of the health centre, it is more likely that there will be users with knowledge on how to safely and efficiently use the technology.

The fourth loop (Figure 4 Panel d) shows that the involvement of a multidisciplinary team in the procurement process strengthens the alignment of the purchased technology with the local healthcare context, capability, and level of care, contributing to the local availability of trained professionals in the use of the technology.

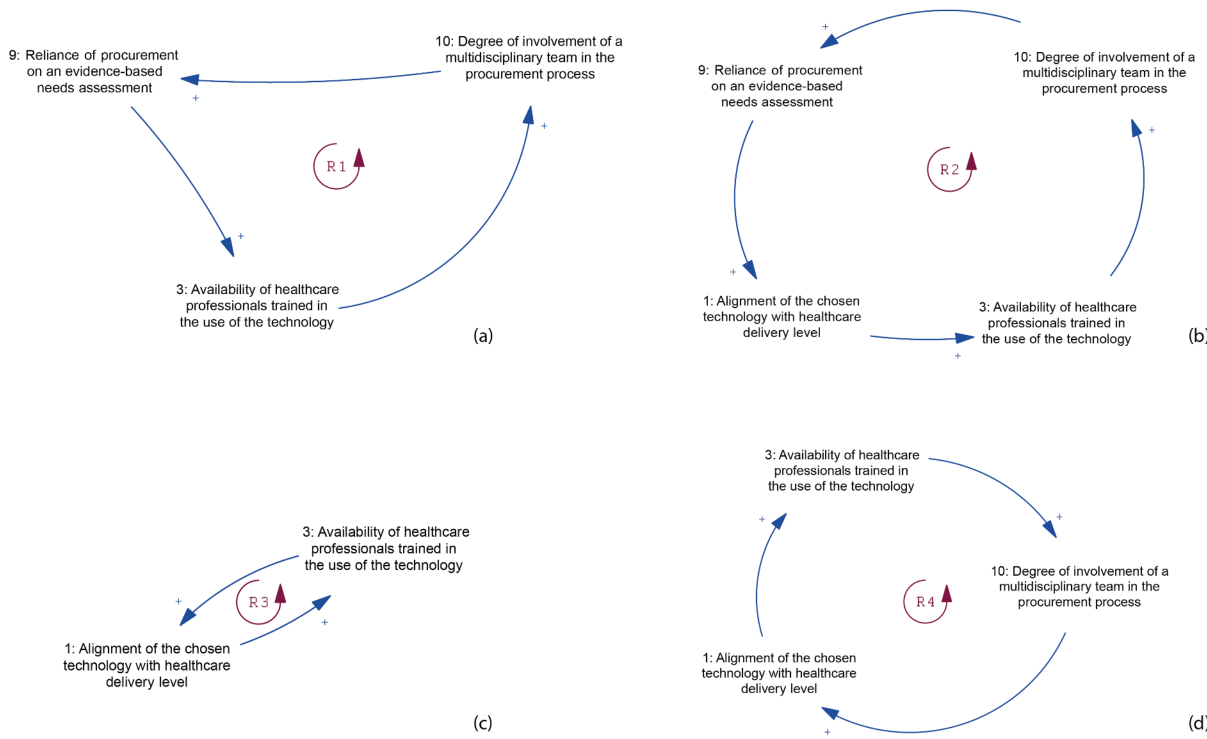

Figure 4. **Panel (a)**: reinforcing loop 1 - an evidence-based needs assessment is more likely to influence the procurement process if a multidisciplinary team is involved and health professionals trained in the use of MDs are present. **panel (b) and (c)**: reinforcing loops 2 and 3 - in addition to the reinforcing loop 1, aligning the chosen technology with the healthcare local context and delivery level by conducting a sound needs assessment during the procurement process, contributes to the availability of trained healthcare professionals. In fact, if the needs assessment identifies a requirement to reinforce the capabilities of local users, the procurement process of MDs can be tailored to the local context by including adequate training to address this specific need. Once trained users are available, they will actively contribute in aligning future procured technologies with their specific needs during subsequent evidence-based needs assessment processes. **panel (d)**: reinforcing loop 4 - it shows that involvement of a multidisciplinary team in the procurement process strengthens the alignment of the purchased technology with the local healthcare context, capability and level of care, contributing to the local availability of trained professionals in the use of the technology.

3.3. Leverage points

Three leverage points can be identified in the system presented in Figure 3. The first leverage point, 'Reliance of procurement on an evidence-based needs assessment', plays a crucial role in ensuring that the selected medical technology is appropriately aligned with the healthcare delivery level, the installation site infrastructure, and the environmental conditions. This factor has a direct connection with the concern expressed by the member states in the SIXTIETH WORLD HEALTH ASSEMBLY chapter WHA60.29 Health technologies (World Health Organization 2007).

The second leverage point, 'Degree of involvement of a multidisciplinary team during procurement' is crucial to correctly implement the needs assessment included in the previous point. Involving a multidisciplinary team ensures that various perspectives are considered during the procurement process, including clinical, technical, and managerial insights. This holistic approach reduces the risk of neglecting critical factors that could affect the long-term sustainability and effectiveness of MDs.

The last leverage point, 'Maturity and funding of clinical engineering services', is the most impactful variable in the system, influencing eight out of 10 key factors. Clinical engineering services are typically provided by clinical or biomedical engineers to ensure that medical devices are not only purchased based on rigorous technical and clinical needs evaluations, but are also maintained and managed effectively and safely throughout their useful life. This leverage point underscores the indispensable role of mature clinical engineering services in the entire lifecycle of medical devices, from procurement to disposal. This last result aligns with a wide body of literature, including WHO publications, indicating that biomedical and clinical engineers play an indispensable role in the procurement and management of medical technology (World Health Organization 2017).

4. Discussion

4.1. Leverage points

The systems approach analysis of the MD procurement process in LMICs yields three key recommendations to enhance the utilisation and sustainability of MDs within their public health services:

4.1.1. Base the procurement process on a robust, evidence-based needs assessment

Successful implementation of investment projects in LMICs requires a thorough evidence-driven analysis of healthcare needs, clear objectives, and a detailed list of MDs the required technical specifications. As illustrated by the causal diagram in Figure 3, an evidence-based needs assessment is crucial for ensuring that the selected equipment aligns with local epidemiology, installation conditions and capabilities. This alignment is indispensable to prevent the underutilisation of devices. However, unused MDs are alarmingly prevalent and reflect critical failures in procurement processes that neglect the clinical objectives, the target population's health needs, and the contextual constraints. Conducting a thorough needs assessment requires substantial resources, including time, appropriate expertise and funding; while abbreviating it jeopardises the sustainability of project outcomes.

Needs assessment is recognised by WHO as a critical part of the procurement of MDs and funded on three main questions (World Health Organization 2025):

- What do we want/need in terms of health services?
- What do we have? (local conditions/limitations/capabilities)
- Which standards/recommended best practices exist that could be applied or adapted?

Currently, there is no consensus on the process for implementing needs assessments for MDs. Most of the focus tends to be on prioritising the needs instead of assessing their suitability in relation to the country, region, and local epidemiological context, as well as the conditions at the installation site and the capabilities of the beneficiary (World Health Organization 2007; Quintana and Cruz, 2022).

4.1.2. Increase the degree of involvement of a multidisciplinary team during the procurement process of MDs

A multidisciplinary team, including health planners and economists, financial managers, clinical users, biomedical, structural, electromechanical and IT engineers is critical for ensuring that all aspects of the procurement process are thoroughly analysed. Diverse perspectives are essential for assessing existing needs and local conditions, guaranteeing that the selected or designed technologies are optimally suited to the specific challenges of the healthcare environment in LMICs. Beyond improving procurement processes outcomes, this multidisciplinary approach enhances the fluid integration of MDs into healthcare systems, maximising their public health impact. The multidisciplinary team, led by a Biomedical/Clinical Engineer, must be included in all of the project's phases from scope definition and needs assessment to the design and implementation to ensure the procurement's success. According to the WHO, only a multidisciplinary team is able to answer the questions that arise a during the procurement associated decision-making process (World Health Organization 2010):

- What clinical need will the device address?
- Is the cost of the MD justified by the need?
- Will this expense compromise funding for other higher-priority acquisitions?
- Is it a priority in this particular setting?

4.1.3. Strengthen and financing clinical engineering services.

Sustainable use of MDs relies on the local capacity of clinical engineering services to provide maintenance, secure spare parts and consumables, and ensure operational safety. Embedding the development or enhancement of national and local clinical engineering services into the procurement project is not optional since it is a fundamental requirement for capacity building. A robust clinical engineering service is indispensable for maintaining the long-term functionality and safety of MDs, thus ensuring their contribution to public health goals over time. Enhanced funding and strategic development of these services will support the long-term sustainability of MD procurement, enabling LMICs to optimise the benefits of their investments in medical technology (Kehinde et al., 2024; Saks,2021).

In the 1980s the cost-effectiveness of newborn clinical engineering departments in the US was studied and confirmed, and more recently the improvement of patient outcome was also proven (An, Sc, and Arthhur 1989; Betts 1987; David and Judd 2020).

As the core activity of a clinical engineering department is the management of the MDs their strengthening is aligned with the recommendations of WHO that states: *The biomedical/clinical engineer can play a crucial role in supporting the best and most appropriate use of medical technologies to help in achieving universal health coverage and the targets of the SDGs*" (World Health Organization 2010, 2017).

4.2. Leverage points implementation to strenghtening procurement governance

The authors argue that any impactful procurement process in LMICs should focus on the use of the purchased devices while also addressing the conditions for their management. This mature governance approach helps to compensate the lack of resources that prevents the establishment of effective MD management processes. It is crucial that procurement processes take responsibility for building the capacities needed to manage MDs after their procurement. Otherwise, the life expectancy of the procured goods will be dramatically reduced, necessitating new repeated procurement efforts within a few years resulting in a considerable waste of resources.

This investigation highlights the essential components of an effective procurement process that ensures sustainable benefits of purchased MDs in beneficiary countries. Beyond products quality, the process must include the ability to:

(1) Translate clinical needs into precise technical requirements.
(2) Address local conditions and capacities and translate them into post sales services requirements.
(3) Ensure the long-term operational lifespan of the MDs through strategic requirements.

These abilities can only be found in multidisciplinary teams involving clinical and technical specialists that shall work together to assess the needs and build up the bases of the procurement process. The shortage of health professionals and clinical engineers remains a determinant of poor procurement outcomes leading to the widespread issue of unused equipment. As highlighted in paragraph 1.3, the international procurement framework can effectively support LIMICs MD procurement towards long term sustainable results. However, its success is highly dependent on the presence of experienced clinical and technical professionals able to understand and address the local needs and conditions (V. Di Virgilio, A. Bouchard Saindon, and F. C. G. Becerra Posada 2023).

The quality of MD procurement projects in LMICs must be focused on guaranteeing that the purchased equipment is utilised effectively. Key performance indicators (KPIs), aligned with tangible enhancements in clinical productivity, are critical to measure the effectiveness of the MDs procurement. Any occurrence of unused equipment should be treated as a nonconformity requiring a thorough investigation. Lessons learned from these cases must serve as a basis for continuous quality improvement (Hussein et al. 2021; McCaskill 2022).

4.3. Leverage points and misuse of public funds

Local procurement can be heavily affected by limited technical capabilities and a knowledge gap between the buyer and the vendor, by corruption and – unnecessary and rigid – bureaucracy (Anin, Essuman, and

Owusu 2020; Hoksbergen et al. 2020; Liang, Liang, and Wei 2023; Mo 2001; Rajkumar and Swaroop 2008). This often leads internationally funded projects to rely on implementing agencies with the aim to seek highly qualified technical expertise, mature processes, and transparency. However, the results in terms of sustainable used MDs are not the expected.

Corruption distortion of procurement processes due to political pressures on weak bureaucracy is a well-known issue in LMICs. It has been often experienced by the authors that, in the presence of a weak bureaucracy, there is a tendency to prioritise quick, visible results over a thorough and methodical procurement process. This results in a reduced or absent needs and local conditions assessment, due to political pressure for immediate, albeit unsustainable, results (Lehne, Shapiro, and Vanden Eynde 2018). In LMICs, conventional transparency and accountability measures fail, as they rely on the assumption that corruption is driven by individuals and that once corruption is rendered visible by said measure it can be acted upon. However, corruption and rule breaking are widespread issues that must be understood and addressed as a systemic problem (Hutchinson 2020). The damage caused by corruption in this context extends beyond bribery; it also includes the manipulation of procurement decisions to favour specific products or brands, often at the expense of actual healthcare needs. Decisions made by a multidisciplinary team, where each professional respects the role and specificity of the others, increase the transparency of the procurement process from needs assessment and requirement preparation to the evaluation of the received offers and strengthen its results.

Finally, the development and adequate funding of mature local and national clinical engineering services, staffed with trained professionals possessing deep technical and market understanding, can play a vital role not only in mitigating the knowledge gap between the seller and the buyer but also in constructing the capacities for health technology long-term management. These professionals are also better equipped to enforce contractual obligations and reject low-quality goods, particularly in environments where bureaucratic rigidity and corruption are prevalent. By bridging the knowledge gap, these services increase the likelihood of successful and sustainable procurement outcomes, contributing to the long-term effectiveness and efficiency of healthcare access and delivery in LMICs.

4.4. Improving the sustainability of interational procurement of MDs

Internationally funded projects procuring medical devices must recognise the limited capacity of LMICs' healthcare systems to proactively manage medical equipment and assume the responsibility to address these limitations during the procurement process, when funds and high-level technical expertise are available and a systemic change can be initiated. Nevertheless, this focus on long-term sustainability often contrasts with the short duration of procurement projects funded by multilateral banks or international donors, which measure results by the amount of money spent during the project timeline, thereby encouraging fast and often unsustainable solutions.

The authors call for a reflection on the funding mechanisms of international procurement projects, advocating for greater flexibility with longer horizons, the procurement of ad hoc services alongside equipment, and a post-procurement phase to support recipient units in building or strengthening their MD management capabilities, meanwhile measuring the impact of the procured devices on the health services.

Several different qualitative and quantitative approaches, alternative to the chosen CLD, can be used to map causal relationships within complex systems and measure process failure, from System Dynamics Modelling and Statistical Process Control Charts to Six Sigma Methodologies and Balanced Scorecard. The chosen systems thinking approach aids in visualising interdependencies between factors and modelling the long-term impact of various governance strategies within the LMICs MD procurement research field, which largely lacks literature beyond qualitative approaches or studies focused on single countries. To strengthen this understanding and provide actionable insights, future field research in this area should investigate the impact of implementing the presented three leverage points on long-term sustainability. As a proposal for further investigation, the effectiveness of a procurement process could be quantitatively assessed by examining the percentage of unused or little/partially used medical equipment after three or 5 years.

5. Conclusion

The prevalence of unused MDs within the public health services of LMICs underscores a significant challenge in procurement processes that have far-reaching financial, environmental, and social implications. These unused devices are not merely a reflection of operational inefficiencies; they symbolise the broader issue of misallocation of public investment in the health sector: an unsustainable procurement practice that fails to deliver value proportional to the investment. In essence, when MDs lie unused, the intended benefits, whether it is to improve health outcomes, enhance service delivery, and/or develop the local economy, are unachieved, leaving only the environmental burden of disposal and the financial cost to be borne by taxpayers and future generations. This scenario epitomises a non-sustainable procurement process where the absence of utility renders any environmental, social, and financial costs indefensible.

Through a comprehensive analysis of the literature, this study identified 10 *key* factors that explain why unsustainable procurement and unused MDs are so prevalent in LMIC health services. Considering the causal dynamics between these factors, three leverage points were identified. They represent recommended governance actions for a more sustainable procurement of MDs:

- Base the procurement on a sound, transparent and evidence-based needs assessment, built both on statistical data and local context: clinical and technical capabilities, availability of proper infrastructure, maintenance services and consumables.
- Increase the level of involvement of a multidisciplinary team of experts during procurement ideally under the coordination of clinical/biomedical engineers, since procuring medical devices involves several technical disciplines.
- Enhance the clinical engineering services in the beneficiary country at national and local level to minimise the knowledge gap between buyer and seller and to ensure an adequate management of MDs.

Further research is recommended to test the recommendations described in this article and the relationship between the presence or absence of clinical engineering departments and the amount of unused medical devices in the healthcare system they support.

This study suggests a need to rethink the funding models of international procurement projects, recommending greater adaptability with longer project durations, the integration of tailored services during and after the equipment procurement stage to assist beneficiary countries in enhancing their MD management expertise.

Lastly, one significant gap in the literature is the lack of focus on the effective and long-term use of purchased MDs, despite the considerable attention given to environmental sustainability in *sustainable procurement* discussions. The environmental, social, and financial sustainability of MD procurement cannot be considered in isolation; rather, it must be evaluated within the broader, holistic context of the practical utility of the device and its contribution to the health outcomes of the population. However, current literature oriented on measuring or improving the quality of MDs procurement and supply chain, generally focuses on the procurement operation, omitting the assessment of the needs, local conditions and mid- and long-term impact for the beneficiary country (Di Virgilio, Becerra Posada, and Bouchard Saindon 2024).

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Author contributions

V.D.V. was responsible for conceptualisation; data curation; methodology; formal analysis; original draft preparation; review and editing. M.S.M. was responsible for conceptualisation; methodology; software; formal analysis; investigation; original draft preparation; review and editing; A.B.S. was responsible for conceptualisation, formal analysis and review and editing; L.A. was responsible for conceptualisation; review and editing, supervision and funding acquisition. All authors have read and agreed to the published version of the manuscript.

Abbreviations

LMIC	Low- and Middle-Income Country
MD	Medical Device
WHO	World Health Organization
SDG	Sustainable development Goal
CLD	Causal Loop Diagram
UNDP	United Nation Development Program
UNGM	United Nations Global Marketplace
UNOPS	United Nations Office for Project Services

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

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Appendix

Appendix A

List of factors identified in the literature of Table 1 and grouped into ten key factors

(1) **Alignment of the chosen technology with healthcare delivery level**
- Device not aligned with healthcare delivery level and general conditions encountered in deployment setting (Diaconu et al. 2017).
- Purchase based on an assessment of existing conditions (V. Di Virgilio, A. Bouchard Saindon, and F. C. G. Becerra Posada 2023).
- Integration of the purchased device with other equipment or technologies (V. Di Virgilio, A. Bouchard Saindon, and F. C. G. Becerra Posada 2023).
- Appropriateness of the medical device design in relation to its intended use (World Health Organization 2010).
- Usability evaluations conducted in the settings where the technology will be deployed (Asma et al. 2023).
- Context specific considerations affecting device performance (Tarus et al. 2023).

(2) **Alignment of the chosen technology with installation site infrastructure and environmental conditions**
- Ambient conditions in deployment settings prevent the use of the device (Diaconu et al. 2017).
- Purchase based on an assessment of existing conditions (V. Di Virgilio, A. Bouchard Saindon, and F. C. G. Becerra Posada 2023).
- Installation conditions (V. Di Virgilio, A. Bouchard Saindon, and F. C. G. Becerra Posada 2023).
- Lack of infrastructure (Malkin 2007).
- Lack of reliable power and water sources (Malkin 2007).
- Evaluation of the device performance in harsh environmental conditions (Asma et al. 2023).
- Context specific considerations affecting device performance (Tarus et al. 2023).
- Problems during installation (Pardeshi 2005).
- Appropriate infrastructure (Emmerling, Dahinten, and Malkin 2018).

(3) **Availability of healthcare professionals trained in the use of the technology**
- Healthcare personnel not trained in the safe medical device use or maintenance (Diaconu et al. 2017).
- Availability of human resources that will use and maintain the medical device (V. Di Virgilio, A. Bouchard Saindon, and F. C. G. Becerra Posada 2023).
- Training in the use of the technology (World Health Organization 2011).
- Availability of healthcare staff trained in the use of the medical device (World Health Organization 2010).
- Usability evaluations conducted in the settings where the technology will be deployed (Asma et al. 2023).
- Sufficient training on the use (Kabeta, Chala, and Tafese 2023).
- Lack of trained staff (Pardeshi 2005).
- Assessment of existing capacities (Di Virgilio, Becerra Posada, and Bouchard Saindon 2024).
- A lack of personnel to be trained (Di Virgilio, Becerra Posada, and Bouchard Saindon 2024).

(4) **Availability of maintenance services and other technical services**
- Installation maintenance services available (Diaconu et al. 2017).
- Healthcare personnel not trained in safe medical device use or maintenance (Diaconu et al. 2017).
- Availability of warranty and post warranty services (V. Di Virgilio, A. Bouchard Saindon, and F. C. G. Becerra Posada 2023).
- Availability of funds for maintenance and consumables (V. Di Virgilio, A. Bouchard Saindon, and F. C. G. Becerra Posada 2023).
- Availability of human resources that will use and maintain the medical device (V. Di Virgilio, A. Bouchard Saindon, and F. C. G. Becerra Posada 2023).
- Training of local technicians to identify problems and repair equipment (Webber et al. 2020).
- Availability of solutions for maintenance and repair (Webber et al. 2020).
- Availability of trained technician to conduct maintenance (Malkin 2007).
- Certified local service capacity (World Health Organization 2011).
- Adequate maintenance (World Health Organization 2010).
- Availability of trained staff in the maintenance (World Health Organization 2010).
- Device's modular serviceability (World Health Organization 2010).
- Inappropriate device storage (Asma et al. 2023).
- Misplaced accessories, infrequent device cleaning and preventive maintenance (Asma et al. 2023).
- Sufficient training in maintenance (Kabeta, Chala, and Tafese 2023).
- Lack of trained staff (Pardeshi 2005).
- Lack of capacities of the local representative of the supplier for installation and/or post-sales services delivery (Di Virgilio, Becerra Posada, and Bouchard Saindon 2024).
- Design of the post sales services (Di Virgilio, Becerra Posada, and Bouchard Saindon 2024).

- Lack of biomedical engineers and technicians (Emmerling, Dahinten, and Malkin 2018).

(5) **Availability of spare parts and user/service manuals**
- Securing access to an appropriate supply chain of replacement parts (Webber et al. 2020).
- Lack of spare parts (Malkin 2007).
- Clear channels for the import of parts (World Health Organization 2011).
- Availability and cost of spare parts and consumables (World Health Organization 2010).
- Inadequate access to spare parts (Asma et al. 2023).
- Manage efficiently the purchase of spare-parts and consumables (Kabeta, Chala, and Tafese 2023).
- Limited access to spare parts, accessories (Emmerling, Dahinten, and Malkin 2018).

(6) **Availability of medical device decommissioning and disposal processes**
- Provision for safe medical device decommissioning and disposal (Diaconu et al. 2017).
- Availability of a plan for disposal (V. Di Virgilio, A. Bouchard Saindon, and F. C. G. Becerra Posada 2023).

(7) **Availability of consumables**
- Availability of funds for maintenance and consumables (V. Di Virgilio, A. Bouchard Saindon, and F. C. G. Becerra Posada 2023).
- Access to manufacturer-provided services, spare parts and technical expertise (Webber et al. 2020).
- Lack of consumables (Malkin 2007).
- Availability and cost of spare parts and consumables (World Health Organization 2010).
- Capacity to properly store consumables (World Health Organization 2010).
- Manage efficiently the purchase of spare-parts and consumables (Di Virgilio, Becerra Posada, and Bouchard Saindon 2024).
- Limited access to consumables (Emmerling, Dahinten, and Malkin 2018).

(8) **Maturity and funding of clinical engineering services**
- Availability of a delivery and installation plan (V. Di Virgilio, A. Bouchard Saindon, and F. C. G. Becerra Posada 2023).
- Lack of motivated technical staff (Malkin 2007).
- Availability of funds for medical device management (World Health Organization 2010).
- Availability of efficient medical device management system (World Health Organization 2010).
- Lack of or limited medical device management plan that ensures functionality, safety, accuracy and durability (World Health Organization 2010).
- No adequate budget for medical devices (Kabeta, Chala, and Tafese 2023).

(9) **Reliance of procurement on an evidence-based needs assessment**
- Device specifications should match the conditions in which it will be used (Diaconu et al. 2017)
- Device suitability determined by a needs assessment (V. Di Virgilio, A. Bouchard Saindon, and F. C. G. Becerra Posada 2023)
- Delays in permission/approvals as per local regulations (V. Di Virgilio, A. Bouchard Saindon, and F. C. G. Becerra Posada 2023)
- Purchase based on a needs assessment including demand, intended use and expected quality (V. Di Virgilio, A. Bouchard Saindon, and F. C. G. Becerra Posada 2023)
- Procurement based on a needs assessment (V. Di Virgilio, Bouchard Saindon, and Becerra Posada 2023), (Webber et al. 2020)
- Review of clinical and cost-effectiveness evidence (Diaconu et al. 2014)
- Purchase based on public health needs, cost, cost-effectiveness and likely health outcome (World Health Organization 2010)
- Resistance, reluctance or rejection of the new technology (World Health Organization 2010)

(10) **Degree of involvement of a multidisciplinary team in the procurement process**
- Involvement of all stakeholders (V. Di Virgilio, Bouchard Saindon, and Becerra Posada 2023).
- Include local project collaborators (Webber et al. 2020).
- Diverse range of stakeholders is involved in the purchase (Diaconu et al. 2014).
- Involvement of a multidisciplinary team in the assessment of the technology (World Health Organization 2011).
- Involvement of a multidisciplinary team in the decision making (World Health Organization 2010).