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Oxygen Systems in Indonesian Hospitals: Cross-Sectional Study and Strengthening Roadmap

Abstract
Medical oxygen is a life-saving medicine essential to modern healthcare; however, ensuring its availability remains a critical policy challenge in low- and middle-income countries. Weaknesses in production, distribution, and preparedness often translate into inequities in access, while the COVID-19 pandemic demonstrated how governance and logistical failures can rapidly escalate into a national emergency. This study aimed to assess the oxygen system readiness in Indonesian hospitals and highlight priority gaps for reform. A cross-sectional survey was conducted in 2022 across 96 hospitals in 18 districts across five provinces. Using an adapted WHO Biomedical Equipment for COVID-19 Case Management Inventory, seven domains of oxygen readiness were evaluated: oxygen source, distribution, regulation, delivery, monitoring, power supply, and maintenance. Findings revealed that only 65% of hospitals had a complete oxygen system, with better readiness among hospitals on Java, public hospitals, and higher-class facilities (A and B). Significant disparities persist, particularly among referral hospitals outside Java and among lower-class hospitals. This study underscores the importance of embedding oxygen management explicitly into health system reform and governance frameworks. Strengthening oxygen supply

mechanisms offers practical and managerial opportunities to enhance resilience, equity, and preparedness for future health emergencies.

Keywords:
hospital readiness; health system; Indonesian hospitals; oxygen management; oxygen systems; public policy

Introduction

The World Health Organization (WHO) classifies medical oxygen as an essential drug with utility across a wide range of clinical disciplines, including pediatrics, neonatology, obstetrics, surgery, and trauma (World Health Organization, 2023). However, oxygen management should be recognized as a fundamental issue beyond technical or hospital-level concerns. It must be explicitly integrated as a priority for health systems and governance. Treating oxygen solely as a technical matter leads to fragmented responsibilities, unclear funding, and weak oversight and implementation in practice. Therefore, framing oxygen as a public policy imperative is essential for advancing equity, resilience, and the right to health.

Despite this recognition, medical oxygen remains insufficiently accessible in many low- and middle-income countries (LMICs), partly due to the under-regulation of medical equipment compared to pharmaceuticals (Aronson *et al*., 2020). The Lancet Global Health Commission explains that despite investments since the COVID-19 pandemic, a significant gap in oxygen coverage remains in LMICs. Pulse oximeters are available in only 54% of general hospitals and 83% of tertiary hospitals, whereas oxygen therapy is available in 58% and 86% of these facilities, respectively. The frequent scarcity and breakdown of equipment necessitate the rationing of care, which is a source of moral pressure for healthcare workers in the unit. In primary healthcare facilities, both oxygen and monitoring devices such as oximeters are almost entirely unavailable (Graham *et al*., 2025). This gap highlights the urgent need for evidence-based policy reforms informed by global experiences.

The COVID-19 pandemic demonstrated that failures in governance, particularly in regulation, financing, logistics, and monitoring, can quickly escalate into a national health emergency. Evidence shows that hypoxemia contributes to an estimated 9 million deaths annually, including 1.6 million among children under five, underscoring that access to oxygen is fundamentally linked

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Siti Nurfadilah is a public health researcher and lecturer specializing in epidemiology. She earned her bachelor's degree in Epidemiology from Universitas Halu Oleo and a master's degree in Field Epidemiology (FETP) from Universitas Gadjah Mada, both with excellent academic performance. Her research experience spans infectious diseases, non-communicable disease risk factors, immunization, health system performance, and COVID-19 response, often in collaboration with national and international partners. She currently serves as a lecturer in the Epidemiology concentration at the Faculty of Public Health, Universitas Halu Oleo, while remaining active in research, scientific presentations, and professional public health networks.

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to equity, system resilience, and the right to health (Global Oxygen Alliance 2023). The COVID-19 crisis magnified deficiencies in production capacity, distribution logistics, equipment maintenance, workforce training and financing (Bhatt *et al*., 2022; Graham *et al*., 2025). In Indonesia, the crisis exposed critical weaknesses in healthcare capacity and emergency management, especially outside Java, where oxygen shortages and a lack of ventilators became major issues. While the government has taken steps to expand critical bed capacity, broader challenges remain, including the uneven distribution and welfare of healthcare workers, reliance on imported medical supplies, inadequate management of medical waste, and disruptions to essential services. Strengthening oxygen management through decentralized production, improved distribution, and emergency reserves must be integrated into wider strategies, such as scaling up telemedicine, supporting healthcare professionals, and promoting the local production of medical technologies. However, increasing capacity is insufficient; an effective pandemic response requires coupling these efforts with evidence-based public health measures to flatten the curve, reduce transmission, and build both immediate and long-term healthcare preparedness (Mahendradhata *et al*., 2021).

The Indonesian experience during the Delta surge of 2021 illustrates these dynamics. Oxygen demand in Indonesia increased by 400% from the normal situation, overwhelming the national production capacity and contributing to more than 1,000 preventable deaths (BBC, 2021; CNN Indonesia, 2021; UNICEF, 2021). This was not simply a hospital-level problem but reflected a broader systemic failure, marked by unclear responsibilities and insufficient preparedness, which weakened the health system's ability to respond effectively. Comparable challenges have been observed across sub-Saharan Africa, where integrated and policy-driven approaches in Kenya, Rwanda, and Ethiopia have shown that coordinated strategies can sustainably enhance access (Ibrahim et al. 2025; Smith *et al*. 2022).

Developing robust and resilient oxygen ecosystems requires integration across regulation, financing, logistics, and accountability to ensure preparedness for both routine needs and future crises. Indonesia's oxygen crisis illustrates how gaps in governance can translate into preventable mortality, but it also highlights the potential for systemic reforms to strengthen the resilience of the health system. Building a sustainable oxygen ecosystem requires clear national regulations and a comprehensive governance framework involving stakeholders at the central and regional levels (Federal Ministry of Health, 2021). Strengthening the medical oxygen policy in Indonesia is currently an increasingly urgent need, especially after experiencing oxygen supply

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shortages during the COVID-19 pandemic. Countries such as Nigeria provide examples of well-structured policies that govern the production, distribution, and national use of medical oxygen **in Nigeria.** Nigeria's National Medical Oxygen Policy is the first policy to provide a legal and strategic framework to ensure fair, safe, and affordable access to medical oxygen in health facilities in Nigeria. The five-year national strategy includes the development of clinical guidelines, updating the list of essential drugs and equipment, and strengthening the governance systems. The policy's implementation involves the central government, states, health facilities, the private sector, professional organizations, and international partners (Federal Ministry of Health, 2021).

While international evidence has highlighted the urgency of systemic reforms, empirical research on oxygen system readiness in Indonesia remains limited. Previous studies have primarily focused on pandemic response or general health service constraints, with little systematic evidence on how referral hospitals perform across regions, ownership, and classification. This gap restricts policymakers from designing targeted strategies to ensure nationwide equitable access to oxygen.

In this context, our study specifically focused on COVID-19 referral hospitals but considered oxygen availability as a systemic aspect involving primary, secondary, and tertiary levels of care. Referral hospitals play a strategic role in the national referral network because they receive severe cases and use advanced medical equipment, making them the ideal focal point for identifying the strengths and weaknesses of the oxygen system in Indonesia. By documenting readiness and disparities at this level, our analysis provides a conservative picture of oxygen security while revealing governance gaps that are likely to be greater in non-referral hospitals and primary-care facilities.

This study addresses the problem of fragmented and inequitable oxygen system preparedness in Indonesia. Its objective is to systematically assess the completeness of oxygen systems across referral hospitals in five provinces, focusing on disparities by geographic region, hospital class, and ownership type. The unit of analysis was the referral hospital, with readiness assessed across seven domains adapted from the WHO–UNICEF oxygen system framework: oxygen source, distribution, regulation and conditioning, delivery, patient monitoring, power supply, and maintenance.

The insights from this assessment offer a clear path for improving oxygen governance and service delivery in Indonesia. Thoroughly examining readiness across different hospital types and regions will help clarify roles, direct smarter investments, and establish measurable standards to track progress. Integrating oxygen system improvements into a data-driven governance framework is vital for transforming the current momentum into enduring enhancements in healthcare quality and readiness for future health crises, ultimately ensuring better care for all Indonesians.

Methods

Study Design

This hospital-based cross-sectional survey aimed to systematically assess the oxygen system readiness in Indonesian referral hospitals. The overall design was guided by the WHO–UNICEF oxygen system framework (Fig.1), which has been widely recognized as a comprehensive standard for assessing medical oxygen infrastructure. This framework outlines seven critical subsystems—oxygen source, distribution, regulation and conditioning, delivery, patient monitoring, power supply, and maintenance—that together define whether a hospital can provide safe, reliable, and continuous oxygen therapy. For this study, the framework was adapted to the Indonesian context, considering the specific biomedical equipment and infrastructure typically used in Indonesian hospitals. For example, central piping systems were contextualized as wall pipe networks, and monitoring systems were categorized based on the availability of multiparameter devices with or without an ECG. Such adaptations were necessary to ensure that the framework's global standards could be meaningfully applied within Indonesia's varied hospital environments.

Study Setting and Sampling

Fieldwork was conducted in June 2022 across five provinces, each representing one of Indonesia's major geographic regions: Java, Sumatera, Kalimantan, Nusa Tenggara/Bali, and Sulawesi/Maluku/Papua. This broad coverage was chosen to reflect both the concentration of hospitals in Java and the more constrained infrastructure typical of hospitals on the outer islands.

The sample size was set at 107 hospitals based on an assumed precision of ±10% and a 95% confidence level, with a 20% allowance for potential non-response. Ultimately, data were successfully collected from 96 hospitals that met the minimum requirements. A stratified three-stage cluster sampling design was employed. In the first stage, one province was randomly selected from each region. In the second stage, 18 districts within these provinces were chosen,

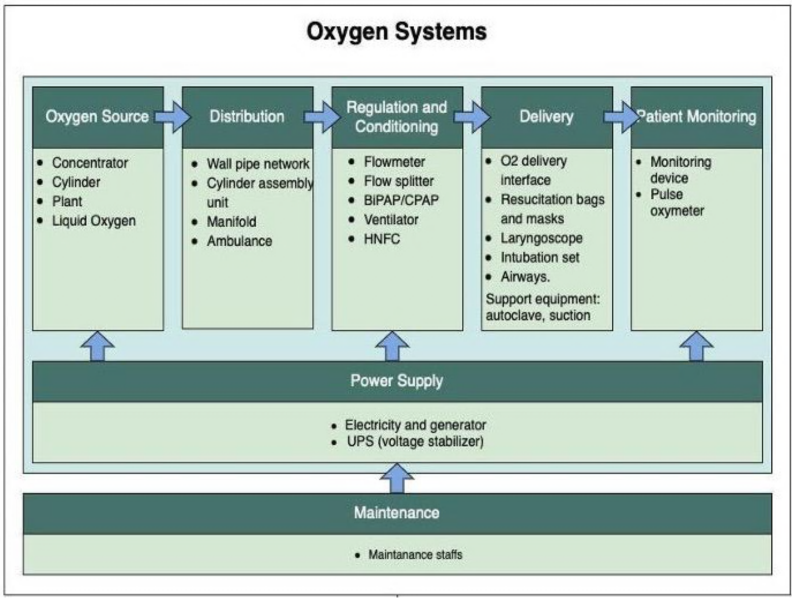

Figure 1. WHO-UNICEF oxygen system framework (2023)

Source: Author

with allocations proportional to the number of hospitals in each region. In the third stage, hospitals were selected through random sampling using probability proportional to their size. Because hospitals were sampled proportionally to their distribution across regions, the sample is considered to be judgmentally representative of referral hospitals nationally.

Eligibility Criteria

Eligibility was limited to hospitals officially designated as COVID-19 referral hospitals by the Ministry of Health. These hospitals were considered most likely to have invested in oxygen-related infrastructure and were thus appropriate for a readiness assessment. Hospitals were excluded if they were located outside the selected provinces or districts, were not referral facilities, declined participation, or were unavailable during the data-collection period. Several hospitals cited ongoing accreditation activities as a reason for non-participation, a limitation that is further addressed in the discussion of the study limitations.

Data Collection

Data collection combined primary survey and secondary contextual data. Primary data were obtained directly from hospitals using the WHO tool *Biomedical Equipment for COVID-19 Case Management: Inventory Tool for Facility Readiness and Equipment Reallocation* (WHO, 2020). The instrument was organized around the seven domains of oxygen system readiness. Thirteen trained data collectors were deployed to the 96 hospitals, where they facilitated the completion of an assisted self-reported questionnaire. The designated hospital informants were typically facilities and maintenance officers, support service staff members, or medical service officers. These individuals were chosen because of their institutional responsibility for equipment and service readiness. The enumerators guided hospital staff in completing the survey, but did not alter or interpret responses. We performed data quality control through the main researchers who visited at least 20% of the hospitals and checked the oxygen equipment of the hospitals after they returned the instruments.

In addition to primary data, secondary data were incorporated to support the analysis and contextualization. These include official Ministry of Health datasets on hospital classifications (A–D, based on service capacity and infrastructure) and ownership categories (public vs. private). These classifications were essential for stratifying the results and identifying disparities.

Data verification was performed in several stages. After the hospital staff submitted the paper-based questionnaires, the data collectors reviewed each submission for completeness. Enumerators then entered the data into *the Kobo Toolbox*, after which the research team performed secondary validation checks within the application. In cases of discrepancies or missing information, the researchers contacted enumerators, who in turn rechecked with hospital officers for further clarification. Upon completion of data entry and cleaning, preliminary findings were presented to all participating hospitals to confirm their accuracy and ensure that the results resonated with their institutional realities.

At this data collection stage, the questionnaires were completed independently and in a structured manner by the designated hospital. At this stage, no direct verification of equipment functionality was conducted on-site. In future studies, the survey could be supplemented with direct observational checks, such as close inspection of equipment, photographic evidence, and spot checks on critical equipment, to obtain more accurate data and ensure that oxygen equipment is truly usable in service.

Data Analysis

The analysis focused on determining the "completeness" of the hospital oxygen systems.

A hospital was categorized as having a complete oxygen system if it possessed all the required elements across the seven framework domains: oxygen source, distribution, regulation and conditioning, delivery, patient monitoring, power supply, and maintenance. Descriptive statistics were used to summarize the data, and cross-tabulations were generated to examine patterns by geographic region (Java versus outside Java), hospital classification (A, B, C, and D), and ownership (public versus private).

Hospital oxygen equipment completeness indicators were developed based on the WHO standards and expert consensus on key oxygen system elements. Hospitals are categorized as complete if they provide all essential components on site, such as a reliable oxygen source (concentrator or cylinder), a safe distribution system, flow controllers and regulators, suction devices, basic delivery interfaces (nasal cannula, simple mask, or non-rebreather), advanced respiratory devices (BiPAP/CPAP, or HFNC), and airway management devices (intubation set with laryngoscope).

The descriptive approach provided valuable insights into the disparities and patterns across the sampled hospitals. Although the modest sample size and the primary aim of mapping readiness limited the study, it included inferential analysis through chi-square tests and logistic regression to identify significant disparities in the ownership of critical equipment between regions. Logistic regression provides a deeper understanding of the determinants of oxygen equipment ownership, including the influence of regional factors, hospital class, and ownership type.

All analyses were conducted using STATA for Windows version 14.2. Because the sampling was proportional to the distribution of hospitals by region, the dataset was treated as self-weighting, and no additional sampling weights were applied to it.

Ethical Issues/Statement

This study was approved by the Ethics Committee of the Faculty of Medicine, Universitas Gadjah Mada (Ref. No. KE/FK/0290/EC/2022). Written informed consent was obtained from all hospital representatives before data collection. All procedures adhered to the principles of research ethics and were conducted in accordance with relevant institutional and national regulations.

Results and Discussion

Oxygen supply in Indonesian hospitals is delivered through a range of systems, including high-pressure oxygen cylinders, liquid oxygen (LOX) tanks, large oxygen concentrators, and pressure swing adsorption (PSA) plants (Table 1). Among these, oxygen cylinders were the only universal source available in all hospitals surveyed, reflecting their centrality in hospital operations and emergency preparedness. Cylinders are widely used as both primary and backup oxygen sources, particularly in lower-tier hospitals and regions with unstable power or limited technical capacity. Oxygen concentrators were available in approximately 80% of hospitals overall, with slightly higher availability outside Java (84%) than within Java (79%). Coverage was nearly universal in larger hospitals—100% in Type A and B—and remained relatively high in Type C facilities (86%) but fell to 60% in Type D hospitals. Public hospitals reported full coverage of concentrators (100%), whereas 70% of private hospitals had them, suggesting that public investment and donor-supported programs have contributed to broader access in government-managed facilities.

However, more advanced and sustainable systems, such as bulk liquid oxygen (LOX) and PSA plants, were far less common, revealing the uneven modernization of hospital oxygen infrastructure. Only 43.8% of hospitals were equipped with LOX tanks, with strong regional and class-based disparities: 54% of hospitals in Java compared to only 23% outside Java. All Type

A and B hospitals had LOX tanks, but only half of Type C and 7% of Type D hospitals possessed such systems, reflecting the infrastructural and logistical constraints at lower levels of care. The availability of on-site PSA oxygen generation plants was even more limited, found in only 7% of hospitals nationwide. This minimal uptake indicates that decentralized oxygen production, although crucial for resilience during supply chain disruptions, has not yet been scaled across Indonesia. Overall, these findings highlight an oxygen ecosystem that is still dependent on traditional and transport-based systems, with modernization concentrated in high-tier and urban hospitals, while smaller and peripheral facilities remain vulnerable to oxygen shortages.

Overall, 65% of the hospitals included in the study had complete oxygen supply systems. Of the hospitals, 66% are on Java Island and 61% are outside Java (Table 3). In terms of hospital Class A Class A hospitals had complete oxygen systems, but this declined steadily to 36.7% in Class D hospitals. Public hospitals were substantially more likely to have complete oxygen systems (81.3%) than private hospitals (56 %). Given that 44% of Indonesia's population resides on outer islands, Class C and D hospitals far outnumber Class A and B hospitals, and the private sector delivers approximately 60% of outpatient and 50% of inpatient services, the data indicate inequities in access to oxygen for a significant share of the Indonesian population.

Table 1.
Oxygen Production and Distribution Equipment in Hospitals Across Java and Outside Java, 2022

Oxygen Production Equipment	Region		Hospital Class				Ownership		Total
	Java	**Outside Java**	**A**	**B**	**C**	**D**	**Public**	**Private**	
	(n=65)	**(n=31)**	**(n=6)**	**(n=9)**	**(n=51)**	**(n=30)**	**(n=32)**	**(n=64)**	**(n=96)**
	%	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
Facility has oxygen cylinder (n=96)									
Yes (n=96)	100	100	100	100	100	100	100	100	100
No (n=0)	0	0	0	0	0	0	0	0	0
Facility has oxygen concentrator (n=96)									
Yes (n=77)	78.5	83.9	100	100	86.3	60	100	70.3	80.2
No (n=19)	21.5	16.1	0	0	13.7	40	0	29.7	19.8
Facility has Bulk liquid oxygen tank (n=96)									
Yes (n=42)	53.8	22.6	100	100	49	6.7	62.5	34.4	43.8
No (n=54)	46.2	77.4	0	0	51	93.3	37.5	65.6	56.3
Facility has a pressure swing adsorption-based oxygen generating machine (PSA) (n=96)									
Yes (n=7)	9.2	3.2	16.7	11.1	7.8	3.3	12.5	4.7	7.3
No (n=89)	90.8	96.8	83.3	88.9	92.2	96.7	87.5	95.3	92.7
Type of Wall Pipe Network (n=92)									
Oxygen, Air and Vacuum (n=43)	46	48.3	83.3	66.7	55.1	17.9	62.5	38.3	46.7
Oxygen and Air (n=6)	6.3	6.9	0	11.1	6.1	7.1	6.3	6.7	6.5
Oxygen (n=41)	46	41.4	16.7	22.2	34.7	75	31.3	51.7	44.6
Other (n=2)	1.6	3.4	0	0	4.1	0	0	3.3	2.2
Cylinder Assembly Unit									
Yes (n=86)	89.2	90.3	100	100	88.2	86.7	100	84.4	89.6
No (n=10)	10.8	9.7	0	0	11.8	13.3	0	15.6	10.4
Oxygen cylinder manifold									
Yes (n=82)	86.2	83.9	100	100	86.3	76.7	93.7	81.3	85.4
No (n=14)	13.8	16.1	0	0	13.7	23.3	6.3	18.7	14.6
The Ownership of Ambulance (n=96)									
With Oxygen (n=96)	100	100	100	100	100	100	96.9	90.6	100
Without Oxygen (n=19)	23.1	12.9	50	33.3	17.6	13.3	75	78.1	19.8

Source: obtained from primary data

Table 2.
Regulation, Conditioning, and Oxygen Delivery Equipment in Public and Private Hospitals, 2022

Oxygen Delivery Equipment	Region		Hospital Class				Ownership		Total
	Java	**Outside Java**	**A**	**B**	**C**	**D**	**Public**	**Private**	
	(n=65)	**(n=31)**	**(n=6)**	**(n=9)**	**(n=51)**	**(n=30)**	**(n=32)**	**(n=64)**	**(n=96)**
	%	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
Flowmeter (n=96)									
Yes (n=95)	100	96.8	100	100	98	100	100	98.4	99
No (n=1)	0	3.2	0	0	2	0	0	1.6	1
Flow-splitter (n=96)									
Yes (n=26)	38.5	3.2	50	66.7	25.5	13.3	31.3	25	27.1
No (n=70)	61.5	96.8	50	33.3	74.5	86.7	68.8	75	72.9
BiPAP/CPAP machines (n=96)									
Yes (n=68)	76.9	58.1	83.3	66.7	86.3	43.3	87.5	62.5	70.8
No (n=28)	23.1	41.9	16.7	33.3	13.7	56.7	12.5	37.5	29.2
High-Flow Nasal Cannula (HFNC) (n=96)									
Yes (n=63)	66.2	64.5	100	100	76.5	30	90.6	53.1	65.6
No (n=33)	33.8	35.5	0	0	23.5	70	9.4	46.9	34.4
Patient ventilator (n=96)									
Yes (n=84)	89.2	83.9	100	100	96.1	66.7	100	81.3	87.5
No (n=12)	10.8	16.1	0	0	3.9	33.3	0	18.8	12.5
Oxygen delivery interface (n=96)									
Yes (n=96)	100	100	100	100	100	100	100	100	100
No (n=0)	0	0	0	0	0	0	0	0	0
Type of oxygen delivery interface (n=96)									
Nasal cannula (n=96)	100	100	100	100	100	100	100	100	100
Nasal catheters (n=30)	35.4	22.6	16.7	11.1	29.4	43.3	25	34.4	31.3
Oxygen mask (n=87)	95.4	80.6	100	88.9	90.2	90	93.8	89.1	90.6
Venturi mask (n=40)	46.2	32.3	16.7	55.6	39.2	46.7	37.5	43.8	41.7
Resuscitation bags and masks (n=96)									
Yes (n=95)	98.5	100	100	100	98	100	100	98.4	99
No (n=1)	1.5	0	0	0	2	0	0	1.6	1
Laryngoscope (n=96)									
Yes (n=94)	98.5	96.8	100	100	98	96.7	96.9	98.4	97.9
No (n=2)	1.5	3.2	0	0	2	3.3	3.1	1.6	2.1
Intubation set (n=96)									
Yes (n=91)	98.5	87.1	100	88.9	96.1	93.3	93.8	95.3	94.8
No (n=5)	1.5	12.9	0	11.1	3.9	6.7	6.3	4.7	5.2
Airways (n=96)									
Yes (n=91)	96.9	90.3	100	100	98	86.7	96.9	93.8	94.8
No (n=5)	3.1	9.7	0	0	2	13.3	3.1	6.3	5.2
Type of airways (n=91)	(n=63)	(n=28)	(n=6)	(n=9)	(n=50)	(n=26)	(n=31)	(n=60)	
Oropharyngeal Airway (n=88)	96.8	96.4	83.3	100	96	100	96.8	96.7	96.7
Nasopharyngeal Airway (n=26)	25.4	35.7	50	22.2	30	23.1	32.3	26.7	28.6
Intubation-trained staff (n=96)									
Yes (n=75)	76.9	80.6	100	88.9	78.4	70	78.1	78.1	78.1
No (n=21)	23.1	19.4	0	11.1	21.6	30	21.9	21.9	21.9
Suction devices (n=96)									
Yes (n=96)	100	100	100	100	100	100	100	100	100
No (n=0)	0	0	0	0	0	0	0	0	0
Autoclave/sterilizer (n=96)									
Yes (n=91)	96.9	90.3	100	88.9	92.2	100	87.5	98.4	95.8
No (n=5)	3.1	9.7	0	11.1	7.8	0	12.5	1.6	4.2

Source: obtained from primary data

This disparity indicates a lack of facilities capable of meeting oxygen needs, particularly in basic-level hospitals, which are far more numerous than high-level ones. A notable difference was also observed in hospital ownership, where public hospitals had much better oxygen systems (81.3%) than private hospitals (56%), despite the private sector dominating outpatient and inpatient services in Indonesia.

This disparity has serious implications for equitable access to medical oxygen, as approximately 44% of Indonesia's population resides outside Java, and these areas are dominated by Class C and D hospitals and private services. This indicates that a large number of people are at risk of experiencing limitations in optimal oxygen services, which can directly increase vulnerability to preventable deaths due to hypoxemia, especially during crises such as the COVID-19 pandemic, which has exposed the weaknesses of the national oxygen supply system. These data illustrate that despite significant progress in the provision of equipment and facilities, the focus on strengthening the oxygen system should not be limited to central regions and high-referral facilities but must be evenly distributed to remote areas and basic health facilities through comprehensive and equitable policies.

Based on the table above, almost all hospitals met the basic standards for essential oxygen equipment for medical services. The distribution of equipment, such as flowmeters, suction devices, and oxygen delivery interfaces, has reached almost 100% in various classes of hospitals and regions, demonstrating a commitment to meeting basic oxygen therapy needs. However, there are significant disparities in advanced equipment, such as BiPAP/CPAP, high-flow nasal cannula (HFNC), and ventilators, which are only available in some hospitals, especially in regions outside Java and in non-referral hospitals. This indicates that there is still a gap in equitable access to critical medical technology, which has the potential to hamper effective treatment of severe respiratory cases. In addition, the availability and training of staff in the use of intubation devices also show deficiencies that can affect clinical responses in emergencies. Although laryngoscopes and airways are widely available, intensive training has only been achieved in a limited number of facilities. This lack of training, combined with the heterogeneity of airway device types, has the potential to reduce the readiness of medical personnel and the quality of medical oxygen service. This phenomenon confirms the challenges in oxygen management, which are not only about equipment availability but also human resources and access to distribution in the field.

Overall, these results support the need to strengthen medical oxygen policies that not only set minimum standards for equipment but also require the equitable distribution of advanced oxygen technology and strengthening of healthcare capacity. The disparities between regions and hospital classes reflect the need for more stringent national regulations and integrated governance strategies to ensure fair and optimal access to oxygen, in line with the objectives of strengthening the national health system and reducing mortality related to hypoxemia, especially during health crises such as the COVID-19 pandemic.

The results of an analysis of the adequacy of oxygen equipment in Indonesian hospitals in 2022 show that only approximately 64.6% of hospitals have complete oxygen equipment, while the remaining 35.4% still lack adequate oxygen equipment. This disparity is particularly evident between hospitals on the island of Java and those outside Java, with hospitals in Java performing better (66.1%) than those outside Java (61.3%) in terms of equipment. Based on hospital class, primary referral facilities (class A) met the full completeness standard (100%), while classes B and C showed moderate levels of completeness

Table 3.
Completeness of Oxygen Equipment in Indonesian Hospitals by Region, Classification, and Ownership, 2022

Completeness of Equipment	Region		Hospital Class				Ownership		Total
	Java	**Outside Java**	**A**	**B**	**C**	**D**	**Public**	**Private**	
	(n=65)	**(n=31)**	**(n=6)**	**(n=9)**	**(n=51)**	**(n=30)**	**(n=32)**	**(n=64)**	**(n=96)**
	%	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
Completeness of equipment (n=96)									
Complete (n=62)	66.1	61.3	100	77.8	74.5	36.7	81.3	56.3	64.6
Not complete (n=34)	33.8	38.7	0	22.2	25.5	63.3	18.7	43.7	35.4

Source: obtained from primary data

Table 4.
Distribution of Oxygen Equipment Ownership by Region, Indonesia, 2022

Equipment	**Java**	**Outside Java**	**Total**	**Person Chi2(1)**	**P-Value (Pr)**
Concentrator				0.3869	0.534
Yes	51	26	77		
No	14	5	19		
Oxygen Tank				8.3375	0.004
Yes	35	7	42		
No	30	24	54		
BiPAP Machine				3.6132	0.057
Yes	50	18	68		
No	15	13	28		
HNFC				0.0250	0.874
Yes	43	20	63		
No	22	11	33		
Intubation Set				5.4911	0.019
Yes	64	27	91		
No	1	4	5		
Ventilator				0.5513	0.458
Yes	58	26	84		
No	7	5	12		
Medical Gas Pipe				0.5986	0.439
Yes	63	29	92		
No	2	2	4		

Source: obtained from primary data

(77.8% and 74.5%, respectively), and class D lagged far behind, with only 36.7% of hospitals having complete equipment.

Ownership factors also contribute to this disparity, with 81.3% of public hospitals having complete oxygen equipment, significantly higher than that of private hospitals (56.3 %). These findings confirm that the issue of equipment completeness is related not only to supply but also to distribution and equitable access between regions, service classes, and ownership status. This table highlights the need for strengthened public policies that emphasize the equitable distribution of medical resources and improvement of oxygen service standards from large hospitals to basic health facilities. These efforts are crucial for reducing access disparities and ensuring equitable healthcare services that are prepared to address national emergencies.

These results show that most oxygen equipment is distributed relatively evenly between hospitals in and outside Java. However, for certain types of equipment, there are significant disparities between Java and Outside Java, particularly for oxygen cylinders and intubation sets. Oxygen cylinder ownership was significantly higher in Java than in areas outside Java, with a p-value of 0.004, indicating a distribution gap that could impact the readiness of respiratory emergency services outside Java. Additionally, there was a disparity in the ownership of intubation sets (p = 0.019), which is crucial considering that this equipment is fundamental in the treatment of critical patients and resuscitation procedures. For concentrators, HFNC, ventilators, and medical gas pipes, the p-value was > 0.05. This means that, statistically, there is no evidence of a difference in the ownership of these devices based on the region. In other words, it can be assumed that hospitals in both regions appear to have comparable levels of availability for these types of equipment.

The greatest disparity in oxygen equipment ownership was in terms of region, not class or hospital ownership. Hospitals in the Java region had a significantly higher adjusted odds ratio for intubation set ownership (OR= 13.89; P= 0.03), BiPAP (OR= 10.79; p= 0.002), and oxygen cylinders (OR= 30.58; p=0) than those outside Java. This indicates a significant disparity in access to critical respiratory support equipment between regions, with hospitals in Java more likely to have complete equipment than those outside. Other variables, such as hospital class and ownership type (private vs. public), did not contribute significantly to the ownership of oxygen equipment. This is evidenced by the relatively high p-values and low or non-significant odds ratios. Even for the hospital class, the very wide confidence intervals and p-values above 0.05 indicate that the facility stratum has not yet become a primary determinant of equipment ownership. Regarding BiPAP and oxygen tank

Table 5.
Logistic Regression Models of Oxygen Equipment Ownership, Indonesia, 2022

Equipment	Variable	Category	Adjusted Odds Ratio (95% CI)	P-Value
Intubation Set	Region	Outside Java		
Intubation Set	Region	Java	13.88877 (1.282455 – 150.413)	0.03
Intubation Set	Hospital Class	Type A Hospital	Empty	
Intubation Set	Hospital Class	Type B Hospital	1.535759 (0.053074 – 44.43865)	0.803
Intubation Set	Hospital Class	Type C Hospital	5.639979 (0.3784054 – 84.06162)	0.209
Intubation Set	Hospital Class	Type D Hospital	Omitted	
Intubation Set	Ownership	Public	Reference	
Intubation Set	Ownership	Private	1.954096 (0.149065 – 25.61635)	0.61
BiPAP Machine	Region	Outside Java		
BiPAP Machine	Region	Java	10.7939 (2.428743 – 47.97065)	0.002
BiPAP Machine	Hospital Class	Type B Hospital	0.517406 (0.026598 – 10.06503)	0.663
BiPAP Machine	Hospital Class	Type C Hospital	4.087747 (0.237707 – 70.29535)	0.332
BiPAP Machine	Hospital Class	Type D Hospital	0.251859 (0.011572 – 5.481821)	0.38
BiPAP Machine	Ownership	Public	Reference	
BiPAP Machine	Ownership	Private	0.236617 (0.041338 – 1.354397)	0.105
Oxygen Tank	Region	Outside Java		
Oxygen Tank	Region	Java	30.5775 (5.676842 – 164.7014)	0
Oxygen Tank	Hospital Class	Type A Hospital	Empty	
Oxygen Tank	Hospital Class	Type B Hospital	Empty	
Oxygen Tank	Hospital Class	Type C Hospital	43.5449 (7.44764 – 254.5986)	0
Oxygen Tank	Hospital Class	Type D Hospital	Omitted	
Oxygen Tank	Ownership	Public	Reference	
Oxygen Tank	Ownership	Private	1.448342 (0.319608 – 6.563336)	0.631

Source: obtained from primary data

ownership, several hospital classes had high odds ratios, but these results were predominantly influenced by regional effects. These findings indicate that interventions to equalize the distribution of oxygen support equipment must target regional gaps, with hospitals outside Java receiving priority for assistance. Neglecting this disparity could lead to a decline in the quality and preparedness of services, especially during public health crises, such as pandemics or surges in respiratory diseases. Therefore, this disparity must be addressed immediately through appropriate public policies. Furthermore, efforts to strengthen hospitals outside Java should not only focus on upgrading their class or ownership type but also emphasize distribution and regional equity to ensure equitable access is truly achieved.

Because the region remains a strong predictor of oxygen equipment ownership, even after controlling for hospital class and ownership type variables, policy strategies that rely solely on improving individual facility quality or changing incentives for private and public hospitals will not effectively address this inequality. Health governance reforms focused on equitable access must be specifically directed toward shifting financial resources, regulatory mechanisms, and more intensive technical support to provinces outside Java, which have shown significant deficiencies in the ownership of critical equipment such as intubation sets, BiPAPs, and Oxygen Tanks. This approach is necessary to create a more equitable distribution and strengthen hospital capacity in the region, enabling them to provide adequate oxygen-based services that are responsive to clinical needs, especially during public health crises. Thus, national policy must adopt an explicit regional equity perspective, involving collaboration between the central and regional governments in designing and implementing regulations and financing that targets improving oxygen availability outside Java. Only with such targeted and systematic reforms can Indonesia reduce the oxygen access gap, which has been a major obstacle to the provision of equitable and quality health services.

These empirical results show that the main disparities in oxygen equipment readiness occur at the regional level rather than based on hospital class or ownership. Therefore, policy recommendations should focus on strengthening national and subnational governance related to the equitable distribution, funding, and regulation of the oxygen system across all regions, especially outside Java, which experiences significant limitations. Policies should target improving oxygen access in medium and basic hospitals, which dominate outside Java, as well as in the private health sector that serves most patients. In addition, increasing human resource capacity through intensive training in the use of critical respiratory equipment must also be part of the strategy so that the availability of such equipment can be optimized. Thus, policies should not only focus on the provision of equipment but also address geographical distribution issues and improve human resource competencies to ensure fair and quality access to oxygen throughout Indonesia.

Discussion

Our findings empirically confirm this pattern in Indonesia: oxygen system completeness was significantly lower outside Java and in lower-level facilities, and regression analyses identified the region as the primary predictor of critical equipment ownership. These territorial inequities indicate that oxygen security is not only a technical issue but also a governance failure in how responsibilities, resources, and regulatory oversight are distributed across the health system.

The COVID-19 pandemic laid bare the structural vulnerabilities in Indonesia's health system, most visibly in terms of surge capacity and supply chain fragility. As cases spiked, hospitals faced rapid depletion of critical consumables and equipment (e.g., ventilators) and uneven distribution of specialized staff and infrastructure, amplifying pre-existing geographic inequities in access to care (Mahendradhata et al. 2021). Consistent with the patterns observed in sub-Saharan Africa, urban hospitals are typically better equipped for oxygen delivery than rural facilities. The data show that Java-based facilities own more oxygen sources, distribution equipment, and regulators than off-Java facilities (Institute for Transformative Technologies & Oxygen Hub, 2021).

We also found that Class A/B hospitals more often possess concentrators and ventilators than Class C/D hospitals, despite national technical standards specifying ICU infrastructure and medical gas requirements across facilities (Kementerian Kesehatan 2022). The differences between the public and private sectors were substantial. This study contributes to the broader literature by providing the first systematic hospital-level evidence of disparities in the availability of oxygen systems in Indonesia. While prior studies from Africa and South Asia have identified broad barriers to access, few have quantified inequities by region, ownership, and hospital class within a decentralized LMIC. Therefore, this evidence fills an important gap in the Southeast Asian context.

Because our study sample was limited to referral hospitals, which generally have better resources than first-level hospitals and primary care facilities, the disparities we documented are almost certainly a smaller picture of the national gap in oxygen readiness in the Philippines. In many districts, patients with hypoxemia often first arrive at non-referral facilities that lack oxygen generators, advanced oxygen delivery devices, or trained staff; therefore, weaknesses at the referral hospital level contribute to the overall vulnerability of the health system.

However, availability does not guarantee use: in Nepal, rapid increases in concentrators and ventilators during the pandemic did not translate into uptake, where trained personnel, power reliability, maintenance capacity, and consumables were lacking (Bhatt et al., 2022). Our findings extend this body of work by showing that in Indonesia, decentralization and mixed public–private provision exacerbate these gaps. This highlights how the structural features of health systems condition the effectiveness of oxygen investments, adding a new dimension to the literature on oxygen readiness.

The regional disparities documented in this study also indicate where existing policy instruments fail. This study suggests that information on oxygen gaps is not systematically used to prioritize outer island facilities, regulatory standards are not yet binding in practice for private and lower-class hospitals, and financing and organizational support remain concentrated in Java, based on referral centers. From a public policy perspective, improving oxygen management benefits from a clear policy instrument map. Using Hood and Margetts' (2007) NATO framework Nodality (information), Authority (regulation), Treasure (financing), and Organization (delivery capacity) Indonesia can strengthen information flows via digital tracking of stocks/equipment functionality; tighten regulation by embedding oxygen standards into accreditation; deploy financing tools such as capital subsidies and strategic purchasing; and enhance organization by investing in biomedical engineering teams and regional maintenance hubs (PATH, 2018).

Simultaneously, policy capacity, the analytical, operational, and political competencies at the individual, organizational, and system levels, determines how well these instruments bite (Wu et al., 2015). Therefore, oxygen reforms should pair procurement with capacity building for facility managers, biomedical engineers, and provincial planners, and with governance arrangements that clarify accountability for forecasting, maintenance, and last-mile delivery (Asian Development Bank, 2022).

Crisis opened a policy window (Kingdon, 2014) to institutionalize these changes: the problem stream (oxygen shortfalls) intersected with feasible policy solutions (WHO toolkits and digital tracking) and a supportive political stream (post-pandemic reform). Embedding oxygen security into Indonesia's ongoing Health System Transformation Agenda can convert emergency fixes into durable system capabilities (Kementerian Kesehatan 2025).

Evidence-informed oxygen system design

An enhanced hospital oxygen management model can start from the WHO interim guidance on oxygen sources and distribution (World Health Organization, 2020), WHO–UNICEF technical specifications for oxygen therapy devices (World Health Organization & UNICEF, 2019), and WHO's Essential Supplies Forecasting Tool (World Health Organization, 2021). In Sri Lanka, this guidance has been adapted to procurement, storage, and carrying-capacity upgrades with measurable improvements in access (Liyanage et al., 2022). These global tools should be localized to Indonesia's geography and referral patterns and aligned with the national budgeting cycles. Studies from Sri Lanka's experience show that investing in oxygen supply demand monitoring systems, strengthening storage and logistics, and providing technical training for medical personnel can significantly improve the resilience of health facilities in the face of supply shortages. The consolidated oxygen management model operationalizes this by auditing the current supply, forecasting demand, triaging clinical use, instituting preventive maintenance, and reinforcing governance and real-time information flows. Notably, approximately 15% of COVID-19 patients required oxygen therapy, highlighting its importance beyond pandemics (World Health Organization, 2020).

This study shows that adapting international guidelines to local practices requires a cross-sectoral approach, synergy between industrial and health policies, and continuous evaluation to ensure that the national oxygen supply chain meets the needs of the entire population fairly and sustainably. Thus, strengthening oxygen governance is a strategic foundation for building a more inclusive and resilient Indonesian health system and meeting international standards for essential oxygen services in the post-pandemic era. Although our empirical data come from referral hospitals, the national oxygen management model developed based on this evidence must explicitly include primary care facilities and first-level hospitals, ensuring that forecasting tools, procurement plans, and maintenance systems cover the entire range of care. Therefore, oxygen management policies should not be limited to referral hospitals, and their scope needs to be expanded.

The Indonesian case provides new insights into global debates on oxygen equity: readiness must be understood as both a technical and governance challenge. By documenting specific disparities across hospitals, this study demonstrates that durable solutions require embedding oxygen management into financing, accreditation, and regulatory frameworks rather than relying solely on equipment procurement. A key insight from this study is that oxygen management in Indonesia cannot be understood solely as a question of technical procurement or equipment supply. Instead, it must be framed as a governance challenge that spans financing, regulations, accountability, and cross-sector collaboration. By documenting how disparities are conditioned by decentralization and ownership structures, this study advances the literature by showing that systemic governance reforms are indispensable for achieving equitable oxygen access in LMICs.

Upstream enablers: regulation, market-shaping, and industrial policy

Integrating oxygen into the global health governance framework provides important context for the policy implications of our study. Significant regional disparities in Indonesia, particularly between Java and Outside Java, reflect that the global commitment to equitable access to oxygen has not been fully realized in terms of regulation, financing, and accountability mechanisms at the national and subnational levels. Therefore, it is important for Indonesia to align its oxygen policies with global standards, including setting equity targets that specifically accommodate the needs of outlying islands and the dominant role of private service providers in oxygen supply. This approach will not only close the oxygen access gap that we have documented but also strengthen Indonesia's position as a regional leader in effective and equitable governance of oxygen systems.

Hospitals operate within the constraints of national and subnational policies. Therefore, ensuring oxygen security requires upstream actions: adopting WHA76's resolution on increasing access to medical oxygen as a guiding mandate (World Health Organization, 2023b); nurturing local production and diversified sourcing (PSA/LOX) through targeted incentives; and using market-shaping approaches (framework contracts, pooled procurement, vendor performance metrics) to ensure reliability and fair pricing (PATH, 2018). A promising model comes from Africa, where social enterprises established PSA plants at referral hospitals and used cylinder revenues to subsidize ongoing costs. By October 2022, four plants had delivered over 209,000 cylinders to 183 facilities, supporting oxygen access for more than 33 million people, including 5 million children < five years of age (Smith et al., 2022).

To ensure the sustainability of medical oxygen systems, oxygen must be designated as a vital commodity in national regulations, healthcare financing, and facility-operational standards. An integrated oxygen technology system is needed to ensure that a safe and high-quality supply of medical oxygen is always available in healthcare facilities. All devices and equipment must meet medical standards and technical requirements in accordance with national, regional, or international regulations. A comprehensive approach is needed to strengthen policies at the national level, through the inclusion of oxygen in the list of essential medicines, development of regulations along with relevant guidelines and technical specifications, training for health workers, sustainable energy solutions for health facilities, special financing, and effective maintenance programs. The World Health Organization is committed to maintaining standards for the supply of medical oxygen with guaranteed quality through recommendations and tools that facilitate the production, distribution, storage, and use of medical oxygen so that it is always safe and of high quality in accordance with the latest guidelines (World Health Organization, 2023). Our analysis shows that oxygen safety depends not only on the availability of equipment but also on staff training, clinical protocols, and adequate supervision to ensure effective oxygen use. In addition, financing and procurement arrangements, including stable budgets, service contracts, and cost-reimbursement mechanisms, are essential to ensure the sustainability of medical oxygen systems. Therefore, future national assessments need to include clear indicators of equipment functionality and financing aspects, thereby providing a more comprehensive and accurate picture of oxygen system readiness.

As a continuation of strengthening national policies and regulations that designate medical oxygen as a vital commodity with clear standards and financing, these regulations need to be designed to extend beyond tertiary referral centers. This is important so that minimum standards and financing mechanisms are also applied in district hospitals, maternity hospitals, and primary care facilities, which, despite their limited data and capacity, still have significant clinical requirements.

Multi-level and polycentric governance

Indonesia's administrative complexity argues for multi-level governance that assigns complementary roles at the national, provincial, and district levels. Polycentric arrangements of multiple decision centers with coordinated oversight are well-suited to distributed oxygen ecosystems, as they reduce single-point failures (Ostrom, 2010). Equity targeting should be guided by the subnational disease burden and service-readiness gaps documented by the Global Burden of Disease Indonesian Subnational Collaborators (2022).

The effectiveness of polycentric governance is highly dependent on coordination mechanisms, data integration, and accountability among levels of government. In Indonesia, the decentralization of the health sector has opened up space for local experimentation in health service models, although there are often discrepancies between national policies and local practices due to differences in administrative capacity (McCollum et al., al, 2018). To achieve synergy between levels, it is necessary to implement joint performance agreements between ministries/central agencies and provincial and district/city governments, including medical oxygen performance indicators (e.g., availability, distribution efficiency, and response time). An integrated subnational data-based information system is also crucial so that oxygen resource allocation can be adjusted to the actual needs of the region (e.g., disease surveillance data systems, facility readiness, and oxygen consumption data).

Public–private collaboration

Given that utilization patterns show that approximately two-thirds of outpatient and two-fifths of inpatient care occur in the private sector, oxygen security cannot be achieved without systematic public–private coordination (EpiC, 2023). Options include conditional access to subsidized oxygen in exchange for minimum standards verified through accreditation, pooled procurement for JKN patients, and co-financed maintenance and training programmes.

Partnerships between the public and private sectors have been a determining factor in strengthening the medical oxygen system, especially during times of crisis when demand surges. A study by the Asian Development Bank shows that technical innovations such as the procurement of oxygen generators, donations of concentrators, and the active role of technology companies and startups in supporting oxygen distribution to vulnerable areas have played a major role in accelerating the national response and reducing the death rate due to oxygen deficiency. In addition, private sector participation alongside the government in joint initiatives, such as equipment maintenance programs, technical personnel training, and the development of monitoring platforms, contributes to the efficiency of the oxygen supply chain and ensures the sustainability of the system. This cross-sector integration and cooperation not only meets urgent needs but also strengthens the resilience of the health ecosystem in a sustainable manner to face future crises (ADB, 2022).

The findings also have practical implications for policymakers and hospital managers. At the policy level, embedding oxygen standards into hospital accreditation, national health financing mechanisms, and subnational performance indicators would help to institutionalize equity and resilience. At the facility level, strengthening preventive maintenance, biomedical engineering capacity, and real-time monitoring systems is crucial to ensure that the oxygen infrastructure translates into reliable patient care. Together, these measures would transform short-term, pandemic-driven interventions into long-term system capabilities.

Taken together, these contributions position this study within the broader literature on health system strengthening. This not only confirms the patterns observed globally but also advances knowledge by illustrating how decentralization, governance arrangements, and public–private dynamics shape oxygen equity in a middle-income country context.

Conclusion

This study demonstrates that many referral hospitals in Indonesia lack complete oxygen systems, with disparities evident across regions, hospital classes and ownership. Fragmented management further constrains the reliable delivery of oxygen therapy to critically ill patients. Strengthening hospital practices through the adoption of a composite model aligned with WHO–UNICEF guidelines can improve equipment completeness, utilization, and clinical readiness.

The fact that oxygen availability varies greatly between regions shows that the issue of oxygen security in Indonesia is related to complex governance challenges, where the role of national and subnational authorities is very important in resource allocation, enforcement of service standards, and regulation of service distribution. In other words, this issue is not merely a technical matter related to the procurement of equipment but rather reflects a fundamental need for holistic policy and management reforms to ensure equitable and sustainable access to oxygen.

From a policy perspective, Indonesia's ongoing health sector reforms provide a strategic opportunity to incorporate standardized oxygen management into national frameworks. Practical actions include incentivizing decentralized production through PSA plants and liquid oxygen facilities, embedding equity-based allocation into accreditation and financing mechanisms, and establishing provincial maintenance hubs staffed by trained biomedical engineers. At the hospital level, governance structures should ensure the cross-departmental integration of oxygen management, preventive maintenance schedules, and continuous training of clinical and technical personnel. Referral hospitals can serve as demonstration sites by adapting international guidelines to local contexts. In addition, future national assessments should integrate facility readiness surveys with routinely collected outcome data to quantify corrective interventions over time.

This study had some limitations. First, the sample was confined to COVID-19 referral hospitals; therefore, the results may not fully represent health facilities nationwide. In addition, the use of these data still depends on voluntary reporting by hospitals, which is prone to reporting bias. As a result, verification of the function, maintenance, and availability of equipment cannot be performed comprehensively. However, the strength of the analysis has been improved through the application of inferential and regression analyses, which enabled the identification of statistical relationships between oxygen equipment ownership factors and hospital and regional variables. Future research should examine patient-level outcomes related to oxygen system deficiencies, test the effectiveness and cost-efficiency of decentralized production models, and compare provincial experiences with those of other low- and middle-income countries (LMICs). Such research will go beyond documenting inequalities to identifying scalable solutions and integrating oxygen security as a sustainable component of resilient health systems in low-income countries. Finally, we were unable to link hospital-level oxygen readiness indicators to clinical outcomes, such as case fatality rates, length of stay, or use of mechanical ventilation. As a result, we can only infer the potential impact of readiness gaps on patient outcomes from the existing literature, rather than demonstrating it directly.

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