ARP_5_05 Development of a Maturity Model for Oxygen Ecosystems in Developing Countries

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Applied Research Project

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Abbreviations and Definitions

CDC - Centres for Disease Control and Prevention

COVID-19 - Coronavirus Disease 2019

CPAP - Continuous Positive Airway Pressure

Executive Board, WHO - Executive Board of the World Health Organization

HR - Human Resources

ICU - Intensive Care Unit

OSPT - Oxygen System Planning Tool

PATH – Program for Appropriate Technology in Health

PPE - Personal Protective Equipment

QA - Quality Assurance

QC - Quality Control

UNICEF – United Nations Children's Fund

WHO - World Health Organization

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Introduction

Oxygen is known to be critical for all aerobic organisms to sustain life. This lesson is taught from the very basics of elementary science and built upon in every further tutelage in biomedical science involving living creatures. When it comes to human beings, a reliable and sustainable oxygen supply is of crucial importance and can have mortal consequences if compromised. Attributing to this, the World Health Organization (WHO) listed oxygen as an essential medicine to treat all cases of hypoxia in 2017 ("New WHO Designation for Oxygen Could Save Thousands of Lives Globally" n.d.). Before this, however, medicinal oxygen had been used in hospital settings as early as 1798 in Bristol, England, to treat respiratory and pneumonic diseases and was later first stored in oxygen cylinders in 1868 (Heffner 2013). Since this medical breakthrough, nearly all medical facilities in developed countries today have some degree of infrastructure to supply medical oxygen to patients in need of it. However, many of these oxygen ecosystems were poorly developed to meet the typical needs of day-to-day medical oxygen demands by their host facilities ("BRING O2 To Fill Oxygen Gap in Five Countries" n.d.). This project, therefore, aims to develop a maturity model for oxygen ecosystems in developing countries. This project will examine the different critical components of an oxygen ecosystem and then use this information to create a maturity model. Developing countries/ healthcare facilities can then use this maturity model to assess their existing oxygen ecosystems and then take the necessary steps to evolve into the next advanced level of the maturity model. For the purposes of this deadline, this paper will only focus on the introduction and literature review aspects of the project.

The WHO describes an oxygen ecosystem as "The oxygen ecosystem refers to holistic efforts, initiatives and resources across health systems, that are required for an optimal and sustainable implementation of oxygen systems" (World Health Organization 2023). During a South East Asia Regional meeting, it was further described as "all (parts) needed to incorporate, adopt, operationalize, and sustain investments into health systems at the country and facility level (i.e. Appropriate infrastructure, policies and health systems frameworks, health financing, multidisciplinary guidelines, qualified and appropriately robust multidisciplinary teams)" (World Health Organization South-East Asia Region - WHO SEARO 2022). In essence, a medical oxygen ecosystem is the overall oxygen supply chain from production to patient delivery. Comparatively, 'oxygen systems' for medical use include but are not limited to, oxygen production, storage, distribution and delivery supplies, as well as various items for flow regulation, conditioning, quality assurance (QA), quality control (QC) and safety, that are embedded into the dynamics of the oxygen ecosystem (World Health Organization 2023)

A maturity model is defined as “a tool that helps people assess the current effectiveness of a person or group and supports figuring out what capabilities they need to acquire next to improve their performance… Maturity models are structured as a series of levels of effectiveness. It is assumed that anyone in the field will pass through the levels in sequence as they become more capable” (“Bliki: MaturityModel” n.d.) Applying the concept to oxygen ecosystems. Through examining the existing literature around the components needed to create and operationalize an oxygen ecosystem in addition to conducting interviews with technical experts in oxygen ecosystems, this project seeks to draft an oxygen model that can guide health systems managers and oxygen administrators on how to transition their oxygen (eco)systems from its current maturity model level to a level 5 maturity model which ensures a highly efficient system that can meet all levels of oxygen demand by a healthcare facility/ facilities.

Context

Before the COVID-19 pandemic, many developing states had very primordial oxygen ecosystems and this vulnerability was manifested many times over during the COVID-19 pandemic. Learning from the consequences of their oversight many persons belonging to the medical-provider community including policymakers, public health experts and researchers began to seek greater access to secure oxygen supply to meet both regular demands in addition to a surge in demand as experienced during the COVID-19 pandemic (“BRING O2 To Fill Oxygen Gap in Five Countries” n.d.). The phenomenon of a steep increase in research and analysis of oxygen ecosystems began during the COVID-19 pandemic. This saw many initiatives by the global health community and researchers alike investing in identifying the knowledge gaps in the existing literature and seeking to fill those gaps with appropriate evidence-based information and provide further recommendations to states and health facilities which seek to secure their oxygen ecosystems (Haque and Mamun 2022).

Objective

1) The objective of this project is to create a maturity model for oxygen ecosystems in developing countries.

Research Questions

In achieving this objective, this project will answer the following questions:

1) What are the key elements/attributes of oxygen ecosystems through reviews of existing literature on oxygen ecosystems?
2) What are the gaps in the oxygen ecosystems of developing countries?
3) How can these gaps be addressed/minimized?
4) How can a maturity model be utilized to improve existing oxygen ecosystems?

Research Design

To answer the research questions, this research took the form of a qualitative research design.

Sources of Data

This research project utilizes both primary and secondary sources of data.

Data Collection Tools

Semi-structured interviews with selected scientific experts in the field of medical oxygen systems were chosen as the means of collecting primary data. These interviews were conducted with consent from the interviewees to disclose their identity and their job titles in recognizing that they were selected for the interviews based on their expertise concerning the research topic.

Online websites and journal articles about the research questions were used as secondary sources of data.

Data Analysis

Secondary data across academic journals and technical websites belonging to international organizations concerning oxygen systems and components were sourced and the findings related to the research questions were documented in the literature review.

Semi-structured interviews were then conducted and were then transcribed using NVIVO 14 software. Codes/Themes were then extracted from these scripts and then these themes were analysed with excerpts from the transcripts used to emphasize qualitative data findings when necessary.

Presentation of Results

The findings of the data analysis will be used to construct a Maturity Model for Oxygen Ecosystems in which health systems managers can take the appropriate steps listed to transform their current health (eco)systems into a Level 5 Oxygen Ecosystem.

Literature Review

1) Key Elements/Attributes of Oxygen Ecosystems:

Oxygen ecosystems within healthcare facilities encompass a comprehensive framework that involves various interconnected elements working harmoniously to ensure the consistent availability, efficient utilization, and safe administration of medical-grade oxygen. A systematic review conducted by Haque and Mamun (2022) provides valuable insights into the intricate attributes that constitute the fundamental components of these ecosystems. These attributes can be broadly categorized into five central themes: Planning, Production, Storage, Dispensation, and Monitoring (Haque and Mamun 2022).

Planning: The planning phase of an oxygen ecosystem is characterized by a meticulous consideration of both structural and financial factors, which collectively lay the foundation for an effective and resilient oxygen supply system. This involves the strategic design of an optimized supply chain, encompassing a comprehensive evaluation of logistical requirements, distribution networks, and transportation modes. Effective planning also entails hazard analysis and protection strategies to mitigate potential risks associated with oxygen storage, handling, and distribution.

Production: The production element of oxygen ecosystems encompasses a pivotal role in generating medical-grade oxygen using various technological processes. Cryogenic distillation, adsorption techniques, electrochemical reactions, and chemical processes are among the methodologies employed to produce oxygen with the requisite purity levels. The production phase necessitates a high degree of technical expertise, specialized equipment, and stringent adherence to quality control measures to ensure the consistent delivery of oxygen that meets established standards.

Storage: Storage mechanisms serve as a critical link in maintaining a continuous and reliable oxygen supply within healthcare facilities. Oxygen ecosystems encompass a range of storage solutions, each tailored to the specific healthcare context. These include oxygen concentrators suited for low-resource settings, cryogenic liquid storage facilitated by specialized vessels like dewars, cylinders, and tanks, as well as compressed gas storage utilizing oxygen cylinders. The selection of a suitable storage method hinges on factors such as resource availability, existing infrastructure, and patient demand.

Delivery: Delivery strategies represent a diverse array of methods through which medical oxygen is effectively administered to patients. These strategies encompass a spectrum of interventions, ranging from passive delivery methods like nasal cannulas and oxygen masks to more dynamic approaches such as continuous positive airway pressure (CPAP) and ventilator support. The choice of delivery method is guided by the patient's condition, the severity of hypoxemia, and the technological capabilities of the healthcare facility. The effective implementation of delivery techniques necessitates proper training and adherence to established clinical guidelines.

Monitoring: The monitoring facet of an oxygen ecosystem is centred on real-time tracking and assessment of oxygen supply levels to ensure timely interventions that prevent potential shortages. Monitoring mechanisms encompass the deployment of alerts and notifications that promptly notify stakeholders when oxygen sources approach depletion thresholds. Additionally, the ongoing evaluation of patient well-being is paramount, often achieved through the measurement of arterial oxygen saturation using pulse oximeters. Effective monitoring mechanisms safeguard the continuous availability of oxygen and contribute to the overall safety and well-being of patients.

Incorporating these critical elements into a meticulously structured oxygen ecosystem is essential for delivering high-quality healthcare services, particularly within resource-constrained settings. The intricate interplay of planning, production, storage, dispensation, and monitoring functions collectively guarantees the availability of medical-grade oxygen, enabling healthcare systems to effectively meet patient demands, optimize resource allocation, and ultimately enhance patient outcomes (Haque and Mamun 2022).

In the Lancet article "Creating an Oxygen Ecosystem for Africa" the authors describe the existing oxygen ecosystem in various states on the continent as well as provide statements by various government authorities on the knowledge, attitudes and practices of decision-makers on the continent. Here, it was revealed that the common strategy among African states is to develop oxygen strategies and fill the gaps in their sustainable oxygen requirements. The objective of this ideology and efforts is to ensure that African states have a continuous supply of oxygen at all levels of healthcare. To fulfil this key themes like infrastructure, governance, human resources, advocacy and funding have been identified (Nakkazi 2023). These themes were taken into consideration and an oxygen roadmap was created that reflected these necessities. Also, the involvement and education of not only technical staff but also of regional and facility health care managers need to occur as these persons would be responsible for procuring oxygen for their respective areas. The issue of lack of equipment maintenance of equipment is also discussed in the article. Lastly, the article talks about the importance of multistakeholder investment and involvement in creating oxygen ecosystems. These include the roles of advocates and the private sector in calling for action and financial donations/investments respectively (Nakkazi, 2023).

In a February 2023 WHO publication entitled, "Foundations of medical oxygen systems", chapter 1 focuses on the history of oxygen ecosystems and related systems. The chapter also defines an oxygen ecosystem as "the holistic efforts, initiatives and resources across health systems that are required for an optimal and sustainable implementation of oxygen ecosystems" (World Health Organization 2023). It goes on to expand that this will only be possible by "providing policies and frameworks, health financing, multidisciplinary guidelines, country roadmaps, qualified and appropriately robust multidisciplinary teams, physician engagement initiatives, patient safety and quality of care programmes, biomedical engineering strengthening and other structural and non-structural actions." It then goes on to describe how oxygen systems are affected by both internal and external factors. Internal factors include human and material resources required for the needs assessment, decision-making logistics and implementation, staff training and maintenance, and finally financial allocation for setting up and running the oxygen ecosystem. External factors include geographical locations, product and service providers, technical and clinical capacity and availability, the presence of partners to collaborate and multistakeholder partnerships such as the involvement of donor-recipient dynamics, policy-makers, health systems planners and technological upgrades (World Health

Organization 2023). Lastly, the articles list broad areas that constitute an oxygen ecosystem and its life cycle (see images below).

Figure 1 shows components of an oxygen ecosystem (WHO, 2023)

Figure 2 shows the life cycle of oxygen ecosystems (WHO, 2023)

2) Gaps in Oxygen Ecosystems of Developing Countries:

The oxygen ecosystem in developing countries is marred by multifaceted and critical gaps that hinder the seamless delivery of life-saving oxygen therapy to patients, particularly those in dire need. The issue of insufficient oxygen access takes centre stage in the healthcare narrative of these nations. A UNICEF bulletin draws attention to the gravity of these gaps, emphasizing the glaring deficiency in the provision of oxygen itself. This stems from the scarcity of both oxygen sources and providers, resulting in a stark contrast to the relatively abundant access found in more privileged private healthcare facilities. Furthermore, this scarcity extends beyond oxygen supply to encompass a dearth of cost-effective diagnostic and monitoring tools, such as pulse oximeters, which play a pivotal role in accurately assessing patient oxygen saturation levels ("Oxygen Therapy | UNICEF Office of Innovation" n.d.).

The consequences of these gaps are far-reaching, exerting a substantial toll on healthcare systems and patient outcomes in developing countries. The inability to provide timely and adequate oxygen therapy significantly compromises the management of a spectrum of medical conditions, including severe respiratory ailments like pneumonia and the respiratory distress caused by diseases such as COVID-19. This results in exacerbated health disparities, preventable morbidity, and increased mortality rates among vulnerable populations.

To effectively address these gaps and bolster oxygen ecosystems, a comprehensive and multi-pronged approach is imperative. Such an approach entails strategic planning, infrastructure development, capacity building, and the integration of appropriate technologies. By strategically bridging these gaps, healthcare systems in developing countries can enhance their resilience and responsiveness to healthcare crises, saving countless lives and advancing progress towards achieving equitable healthcare access for all. The urgency of addressing these gaps cannot be overstated, as they represent a critical challenge that requires collaborative efforts and innovative solutions on a global scale.

Another article published by Partners in Health entitled “Bring O2 to Fill Oxygen Gap in Five Countries” highlighted that even before the COVID-19 pandemic 9 out of 10 low and middle-income countries lacked access to oxygen treatment. It was also stated that 40% of health facilities in these countries lacked a reliable oxygen supply. They also estimated that up to 320,000 cases of pneumonia fatalities could be prevented with oxygen therapy (“BRING O2 To Fill Oxygen Gap in Five Countries” n.d.). The article also mentions the need for investment into oxygen security, drawing cases when due to instances with power outages, facilities had no generators to maintain a constant supply. The Bring O2 initiative is designed to identify these gaps and then strengthen oxygen ecosystems in developing countries.

In a UNICEF bulletin, entitled “Oxygen Therapy” they describe the biggest gap in oxygen therapy as the provision of oxygen itself. This comes from a lack of sources of oxygen and oxygen providers. They go on to describe that oxygen availability in poor countries is near net zero outside of private facilities. Likewise, they also describe that other cheap diagnostic and monitoring equipment such as pulse oximeters were also in short supply in these low-resource settings (“Oxygen Therapy | UNICEF Office of Innovation” n.d.). UNICEF has also created the Oxygen System Planning Tool (OSPT), which was designed to plan oxygen ecosystem models to ensure oxygen delivery from the source to the patient (“Oxygen System Planning Tool | UNICEF Office of Innovation” n.d.). The tool utilizes input data from health facilities and systems to estimate the type and number of oxygen suppliers needed to meet demand. The tool also factors in and gives an estimate of costs related to each programme and can be extremely useful for health system planners. The output generated depends on the inputs into the system and, thus, various factors can be augmented to suit when designing oxygen ecosystems based on available resources. This was one component of UNICEF's Oxygen Therapy Project which collaborated with the Bill and Melinda Gates Foundation and the WHO in providing tools for developing governments to create oxygen ecosystems ("Oxygen Therapy | UNICEF Office of Innovation" n.d.). Other tools included an interagency technical specifications and guidance manual which provided information to decision-makers on the types of equipment needed to provide oxygen. The last tool was the UNICEF Supply Catalogue which was updated to include which products can be purchased and used as an alternative if appropriate equipment is not readily available in local markets.

3) Addressing Gaps in Oxygen Ecosystems

Addressing the pervasive gaps within oxygen ecosystems of developing countries requires a systematic and strategic approach. Insights from the WHO's South-East Asia Region (SEARO) panel seminar offer a roadmap that underscores the potential of such a model in driving improvements. The seminar recommends a series of pragmatic steps that countries can undertake to strengthen their oxygen ecosystems (World Health Organization South-East Asia Region - WHO SEARO 2022).

Needs-Gap Assessment: Conducting a comprehensive needs-gap assessment at the facility level serves as a foundational step. This assessment identifies specific gaps and requirements, enabling targeted interventions that optimize resource allocation and utilization.

Capacity Building: Investing in local capacity building is essential. This includes training biomedical engineers and technicians and equipping them with the necessary skills to ensure proper maintenance and upkeep of oxygen-related equipment.

Collaborations: Collaborations with key stakeholders, such as the private sector and international organizations, can bolster oxygen ecosystem capabilities. These collaborations facilitate knowledge sharing, resource pooling, and technology transfer.

Innovative Approaches: Exploring innovative solutions is crucial. These approaches can involve leveraging emerging technologies, novel supply chain strategies, and adaptive interventions to address unique challenges faced by developing countries.

Strategic Planning: Crafting strategic plans that encompass both vertical scaling (institutionalization) and horizontal scaling (expansion/replication) is vital. This approach ensures that oxygen ecosystem improvements are sustainable and adaptable to changing circumstances.

The UNICEF Oxygen System Planning Tool (OSPT) provides a practical application of a maturity model, offering a structured framework for health system planners to estimate oxygen supplier requirements and assess resource needs (“Oxygen Therapy | UNICEF Office of Innovation” n.d.). By utilizing this tool, governments and stakeholders can systematically identify gaps, allocate resources effectively, and ensure that oxygen ecosystems are fortified to deliver uninterrupted and high-quality oxygen therapy to patients in need.

By implementing the recommendations from the SEARO panel seminar and leveraging tools like the UNICEF OSPT, developing countries can navigate the complexities of oxygen ecosystem enhancement with a clear and strategic direction, leading to improved healthcare outcomes and enhanced patient well-being.

4) Utilizing a Maturity Model to Improve Existing Oxygen Ecosystems:

Leveraging a maturity model to enhance existing oxygen ecosystems represents a systematic and strategic approach to drive improvements and ensure the consistent delivery of high-quality oxygen therapy. The recommendations put forth by the WHO Executive Board's draft resolution on “Increasing Access to Medical Oxygen” offer a comprehensive framework for utilizing a maturity model effectively (Executive Board, WHO 2023).

Guidelines and Resources Development: Member States are encouraged to develop guidelines, technical specifications, and training materials. These resources facilitate standardized practices, enhance technical know-how, and promote the safe and efficient utilization of medical oxygen.

Innovation Sharing: Promoting the sharing of innovative solutions among Member States fosters the dissemination of best practices. By learning from successful initiatives and adapting them to local contexts, oxygen ecosystems can be optimized and modernized.

Non-State Actor Collaboration: Collaborations with non-state actors, such as private sector partners and non-governmental organizations, play a pivotal role. Engaging these stakeholders can bring about resource mobilization, technology transfer, and expertise sharing, amplifying the impact of oxygen ecosystem enhancements.

Infrastructure Integration: Integrating medical oxygen systems into the construction of healthcare infrastructure is a strategic step. This ensures that oxygen supply is an inherent part of healthcare facilities, minimizing bottlenecks and enhancing readiness for oxygen therapy delivery.

National and Subnational Oxygen Systems: Establishing dedicated oxygen systems at both national and subnational levels guarantees the uninterrupted provision of medical oxygen. These systems encompass comprehensive planning, infrastructure development, and efficient distribution networks.

By incorporating these recommendations, healthcare systems can harness the power of a maturity model to elevate existing oxygen ecosystems. The approach enables a systematic and structured enhancement process that ensures sustainable improvements, optimized resource allocation, and continuous quality assurance. The WHO's emphasis on the integration of medical oxygen into healthcare infrastructure aligns with a maturity model's holistic approach. This ensures that oxygen availability is deeply embedded within healthcare facilities, reducing reliance on external sources and minimizing potential disruptions. Therefore, the utilization of a maturity model to enhance existing oxygen ecosystems offers a robust framework to drive improvements systematically. By embracing the recommendations outlined by the WHO Executive Board, healthcare systems can elevate their oxygen delivery capabilities, improve patient outcomes, and strengthen overall healthcare resilience (Executive Board, WHO 2023).

Further contributions concerning the relevance of maturity models come from UNICEF ("UNICEF Supply Chain Maturity Model | UNICEF Supply Division" n.d.). According to UNICEF, the use of a Maturity Model encompasses three key objectives:

1. *Assessment and Prioritization:* The Maturity Model is utilized to assess and quantify strengths, gaps, and improvement priorities across all facets of public supply chains. These assessments establish performance baselines, serving as the foundation for continuous improvement planning and the development of supply chain strengthening strategies. The aim is to ensure equitable access to products and services, particularly for children.

2. *Coordination of Partners' Support:* The model informs and facilitates coordinated technical cooperation among partners in alignment with governments' identified objectives and targets. UNICEF offers specialized technical expertise, spanning areas such as enhancing domestic resource mobilization, utilizing innovative solutions for reaching remote areas, digitizing supply chains, and enhancing workforce professionalism.

3. *Efficiency and Impact Appraisal:* The Maturity Model functions as a comprehensive Monitoring and Evaluation framework. It enables governments and partners to gauge the efficiency and impact of their interventions along the maturity continuum. This assessment mechanism provides insights into the effectiveness of technical assistance efforts and guides decision-making for further enhancements.

In essence, the Maturity Model serves as a multifunctional tool that not only assesses and guides supply chain improvements but also supports effective coordination among partners and facilitates the evaluation of intervention outcomes, ultimately contributing to the advancement of equitable access to essential products and services. The adoption of a maturity model approach holds immense promise, as it offers a structured and holistic strategy to address the multifaceted challenges inherent in oxygen ecosystems.

Findings

Interviews

Interviewees selected for the study were:

ALEXANDER ROTHKOPF (SUPPLY CHAIN MANAGEMENT AND DATA SCIENCE ADVISOR AT PATH)

LAURA ALEJANDRA VELEZ RUIZ GAITAN (TECHNICAL FOCAL POINT OXYGEN ACCESS ACCESS SCALE UP WORLD HEALTH ORGANIZATION)

ERIC BUCKLEY (DIRECTOR OF OXYGEN ENGINEERING AT BUILD HEALTH INTERNATIONAL)

Research Question 1: What are the key elements/attributes of oxygen ecosystems through reviews of existing literature on oxygen ecosystems?

Figure 3 shows components of an oxygen ecosystem (WHO, 2023)

Interview Question 1: Do you agree with the framework for oxygen ecosystems proposed by the WHO? Do you believe there is a fundamental element that is missing from the layout?

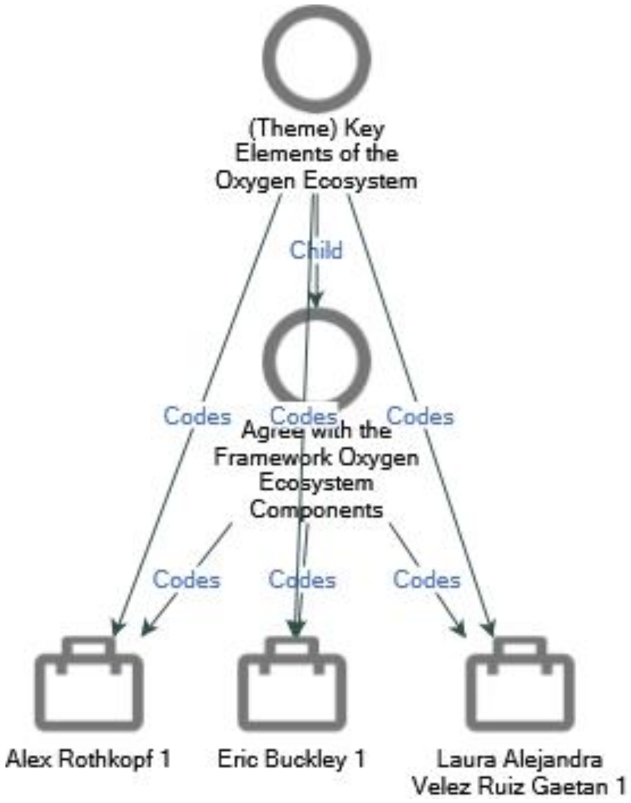


FIGURE 4 SHOWS THAT ALL INTERVIEWEES AGREED WITH THE WHO'S OXYGEN FRAMEWORK

"No, I think these six categories capture, I think everything all the challenges and all the obstacles that need to be overcome would fit into these six categories." – Eric Buckley

"In principle, yes, because I was involved in developing these, these foundations of medical oxygen systems. So we tried to group everything into it." – Laura Alejandra Velez Ruiz Gaitan

Research Question 2: What are the gaps in the oxygen ecosystems of developing countries?

Interview Question 2a: Based on your experience/knowledge, how capable are the oxygen systems in developing countries in meeting demand?

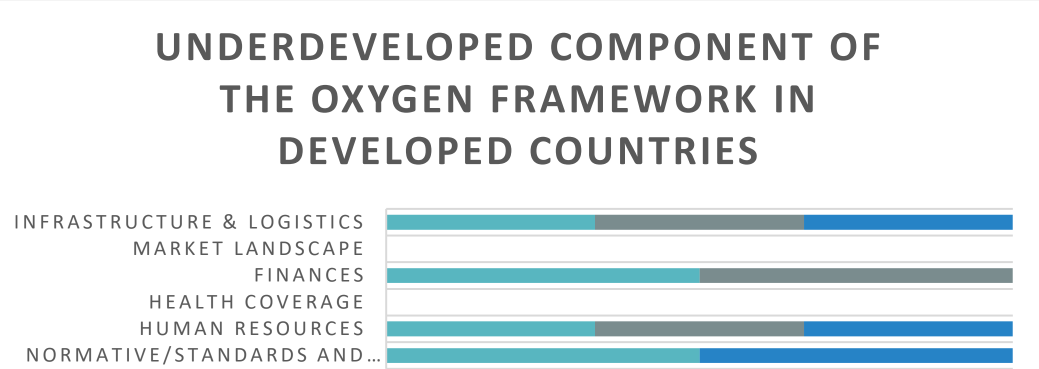
Have Oxygen Systems in Developing Countries (generally) been able to meet their demand	*Number of Responses*
Yes	*3*
No	*0*

Table 1 Showing Opinions of Interviewees on Whether Developing Countries' Oxygen Systems Meet Their Demand

“I would say to a location, everywhere that we've worked, there are challenges faced and shortcomings. Some of those are certainly more pronounced than others. But the challenges, at least in the environments in which we've been involved, are present everywhere.” – Eric Buckley

“I mean, there are countries that were already invested in providing oxygen. And having an established oxygen system even before the pandemic but also like were hit by Covid-19. And when the Covid numbers peaked, they were still backed up against the wall despite their capabilities… And then you have like countries that are like where there is almost nothing there… the point that I'd like to get across is that the picture is very diverse… however, most are not capable at this point” – Alexander Rothkopf

Interview Question 2b: Which component(s) of the oxygen ecosystem do you believe are most underdeveloped in developing countries?



	Normative/Standards and Regulations	Human Resources	Health Coverage	Finances	Market Landscape	Infrastructure & Logistics
Alex	1	1	0	1	0	1
Eric	0	1	0	1	0	1
Laura	1	1	0	0	0	1

Figure 5 Showing the Oxygen framework components the Interviewees Believed Were Underdeveloped in Developing Countries

“But I would say that infrastructure and human resources are the key to, to start with because. Yeah, because everything will be coming as a consequence of that.” - Laura Alejandra Velez Ruiz Gaitan

“And oftentimes it's the quality and the availability of power that limits access to oxygen, I would say, in that. And then that's probably the single biggest hurdle related to the infrastructure.”-Eric Burkley

Research Question 3: How can these gaps in Oxygen Systems be addressed/minimized?

Interview question 3a: What approach or key actions can health system managers take to improve the development of these underdeveloped components?

"One is that of temporary and facility ownership. I think a lot of this suffers from a global health illness. Global health institutions come in and try to help and try to solve a problem. The struggle is to involve the local organizations and particularly the ministry in the facilities and get them to own the problem and own the solution and said, let's try to implement a solution that they think will improve." – Alexander Rothkopf

"We saw during Covid, there were funds available. The problem is the way they're distributed and the problem they are used in different things. So, they were mostly used, for example, for procurement, but all the other factors were forgotten. And so, the balance between where you put the funds and how and the long-term sustainability should be something that we advocate with donors." – Laura Alejandra Velez Ruiz Gaitan

"But another problem is the task is at the facility level, but also the government level. They don't involve the technical part in their decision-making… I think that's something that should change everywhere. And because the technical teams are the ones understanding the context in terms of infrastructure." - Laura Alejandra Velez Ruiz Gaitan

"So, it comes down to the training and capacity building one to technically be able to operate and maintain the equipment effectively, but two to have the HR Systems and finance systems in place to ensure that the funding and the resources are there to do what needs to be done to maximize the capital investment of the initial purchase." – Eric Buckle

Interview question 3b: What are some success factors for creating a more efficient and reliable oxygen ecosystem?

"The prerequisite of having adequate infrastructure… We've seen many of these ad hospitals that have arrived and are just not installed are not running because the electrical infrastructure essentially is not there. So, there's no way to power it. So, there is a certain prerequisite and baseline infrastructure requirement that needs to be there" – Eric Buckley

"So, it's really about empowering and enabling the local technical staff to be able to operate the equipment, empowering and enabling the clinical staff to know how and when and the needs for use." – Eric Buckley

"I think the multidisciplinary approach. Yeah. If they are trying to cover the long-term sustainability, it needs to be factored in at least from the part of the usage of funds and maintenance." – Laura Alejandra Velez Ruiz Gaitan

Research Question 4: How can a maturity model be utilized to improve existing oxygen ecosystems?

Interview Question 4: Do you believe a maturity model using a whole-system approach be utilized in improving the efficiency of oxygen ecosystems in developing countries?

FIGURE 6 SHOWING A WORD CLOUD WITH THE 15 MOST POPULAR WORD RESPONSES TO QUESTION 4

"Turn from available into accessible. That oxygen ecosystem around a hospital bed is so complex and is not part of the current discussion." – Alexander Rothkopf

"So, awareness, awareness. And so, because in the end, the people need to find their solutions also, right? Countries need to find their solutions. So that will be that's our work, like trying to share experience, to make advocacy and awareness for the issue." - Laura Alejandra Velez Ruiz Gaitan

"There is no easy answer to addressing it, but kind of a compilation of many solutions that are often brought together to provide, you know, as much access as possible." – Eric Buckley

"A lot of good equipment remains not used because of the lack of understanding of how to implement. So, I will say that the more we involve a multidisciplinary team in the decision-making, in the analysis of any gap assessment, that will also start making the whole team in think, okay, I need funds for this, not only for the procurement but maintenance, but policy development, training, development, etc. So, we are impacting on the ecosystem." - Laura Alejandra Velez Ruiz Gaitan

"It's not something of one moment, but it needs to be always, as I said, evolving and sustained for the long-term so that it doesn't break one of the other points." - Laura Alejandra Velez Ruiz Gaitan

"I think like ownership is a key problem. Nobody's responsible for operating and maintaining the entire oxygen ecosystem… I could also talk about like funding and resources and commitment and blah, blah, blah, right? And I think what if we create a sustainable environment, a holistic ecosystem that makes oxygen accessible? Would be interesting to get to." -Alexander Rothkopf

Results

Maturity Models

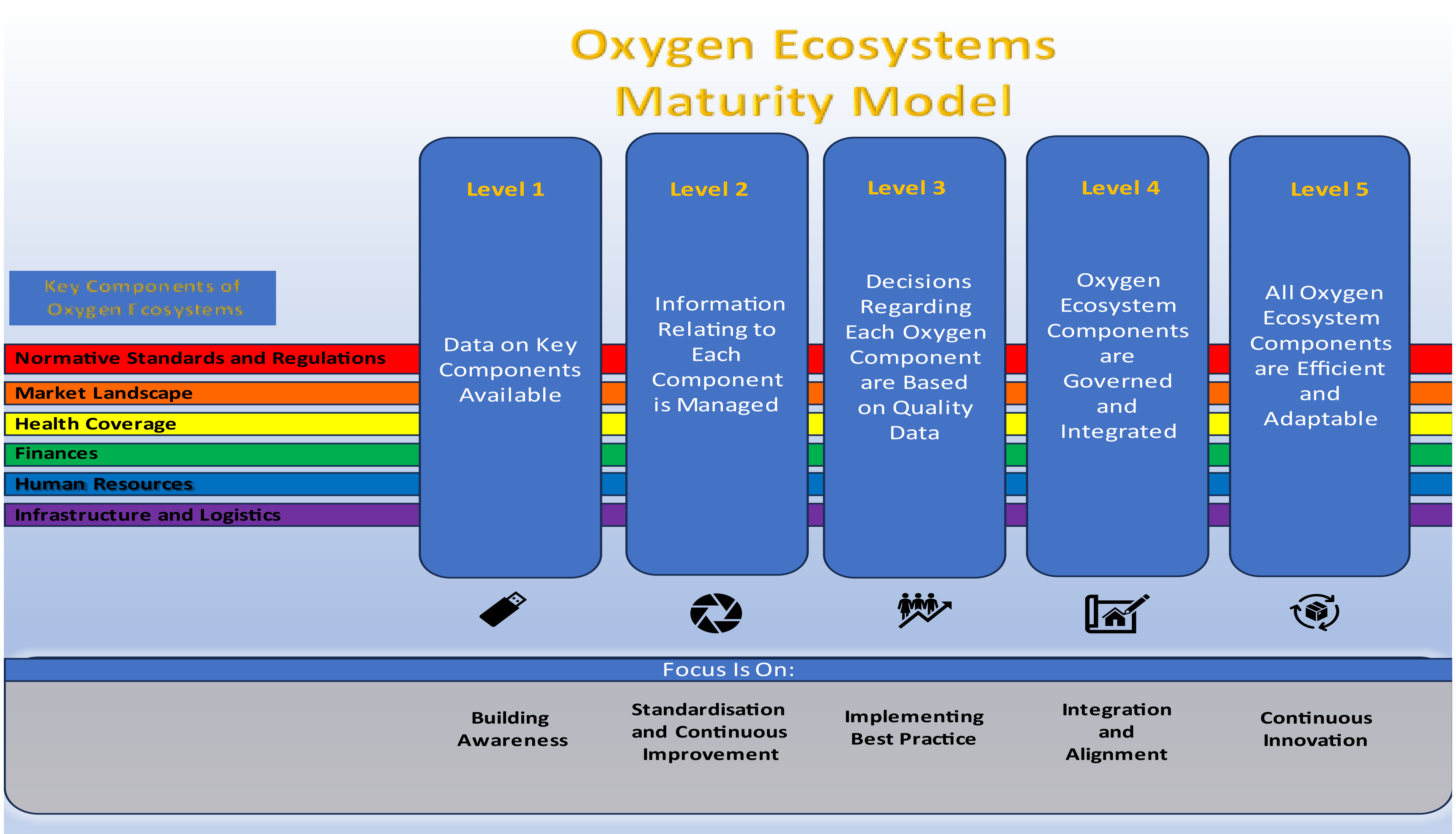


FIGURE 7 SHOWING OXYGEN ECOSYSTEM MATURITY MODEL (LEITE N.D.)

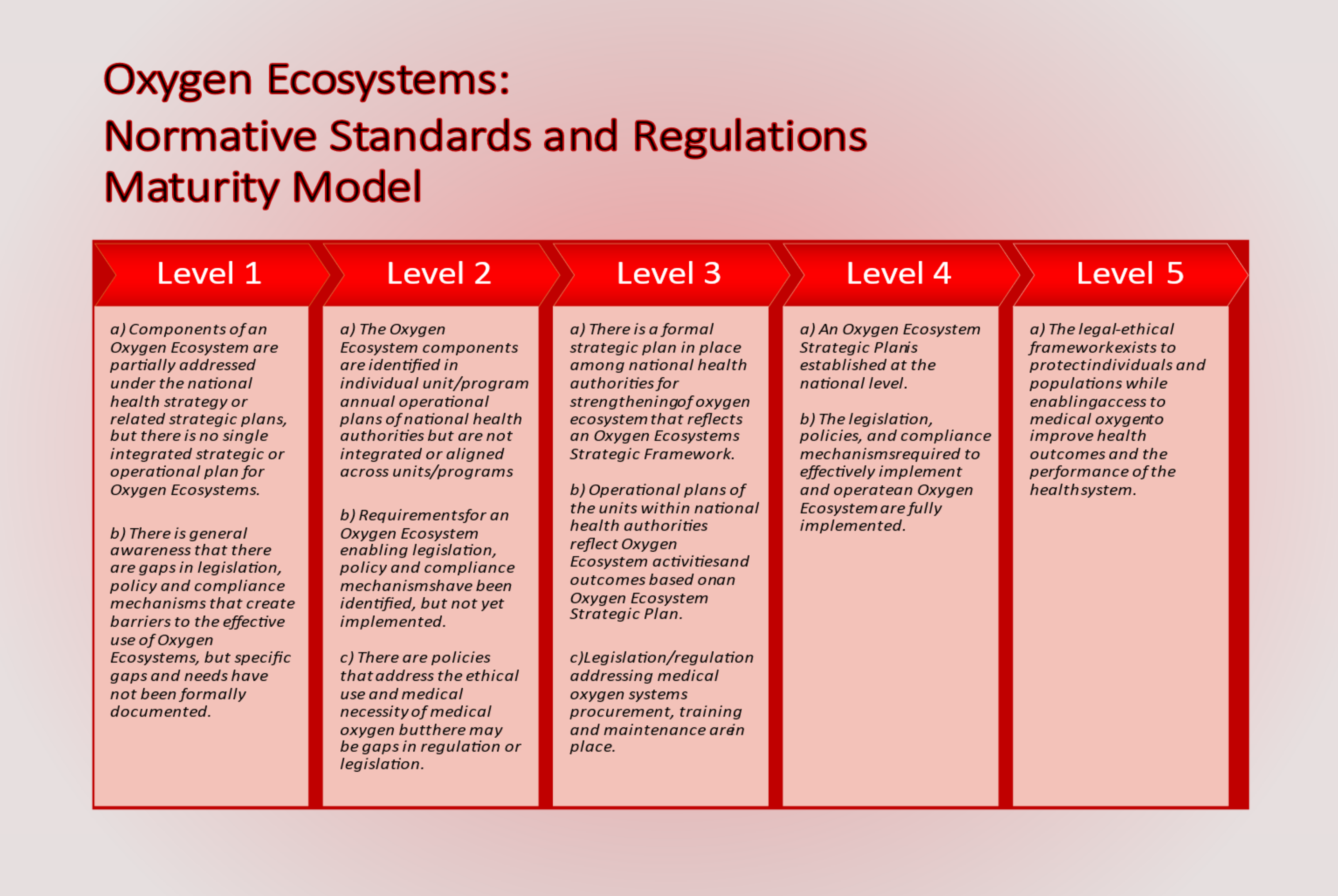


FIGURE 7.1 SHOWING OXYGEN ECOSYSTEMS: NORMATIVE STANDARDS AND REGULATIONS MATURITY MODEL (WHO AND PAHO 2019)

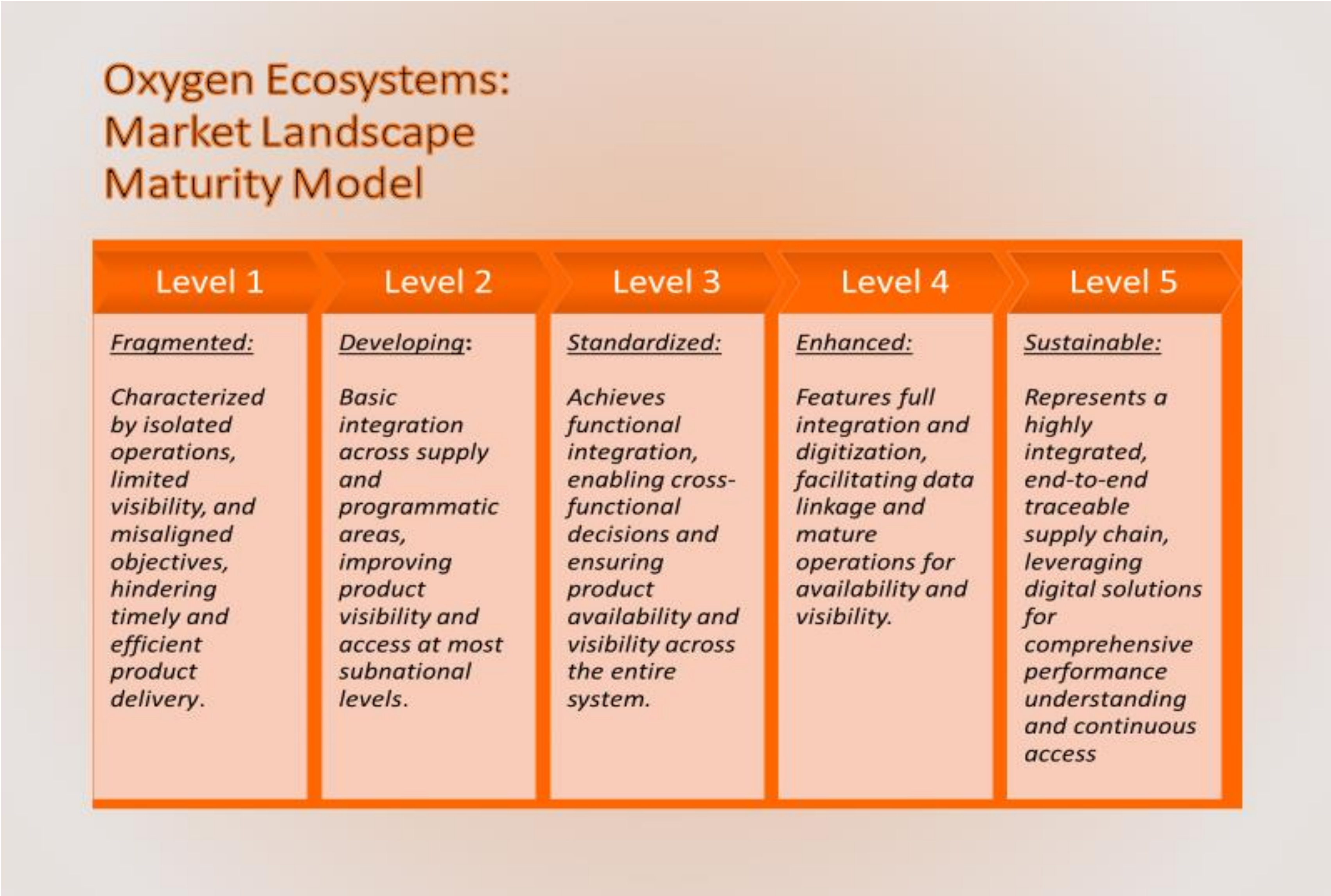


Figure 7.2 Showing Oxygen Ecosystems: Market Landscape Maturity Model ("UNICEF Supply Chain Maturity Model | UNICEF Supply Division" n.d.)

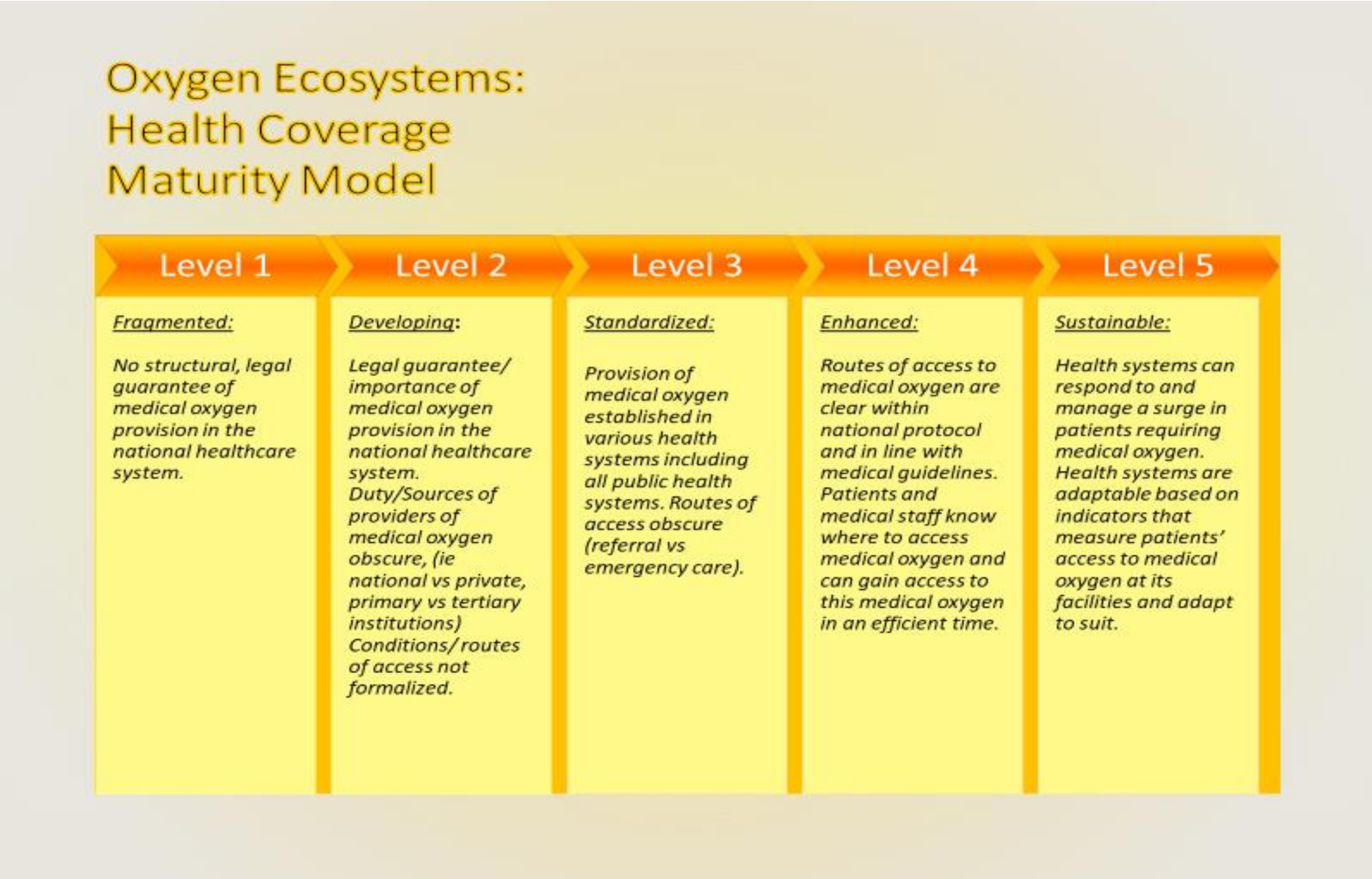


FIGURE 7.3 SHOWING OXYGEN ECOSYSTEMS: HEALTH COVERAGE MATURITY MODEL (SPIJKERS 2022; WORLD HEALTH ORGANIZATION 2023)

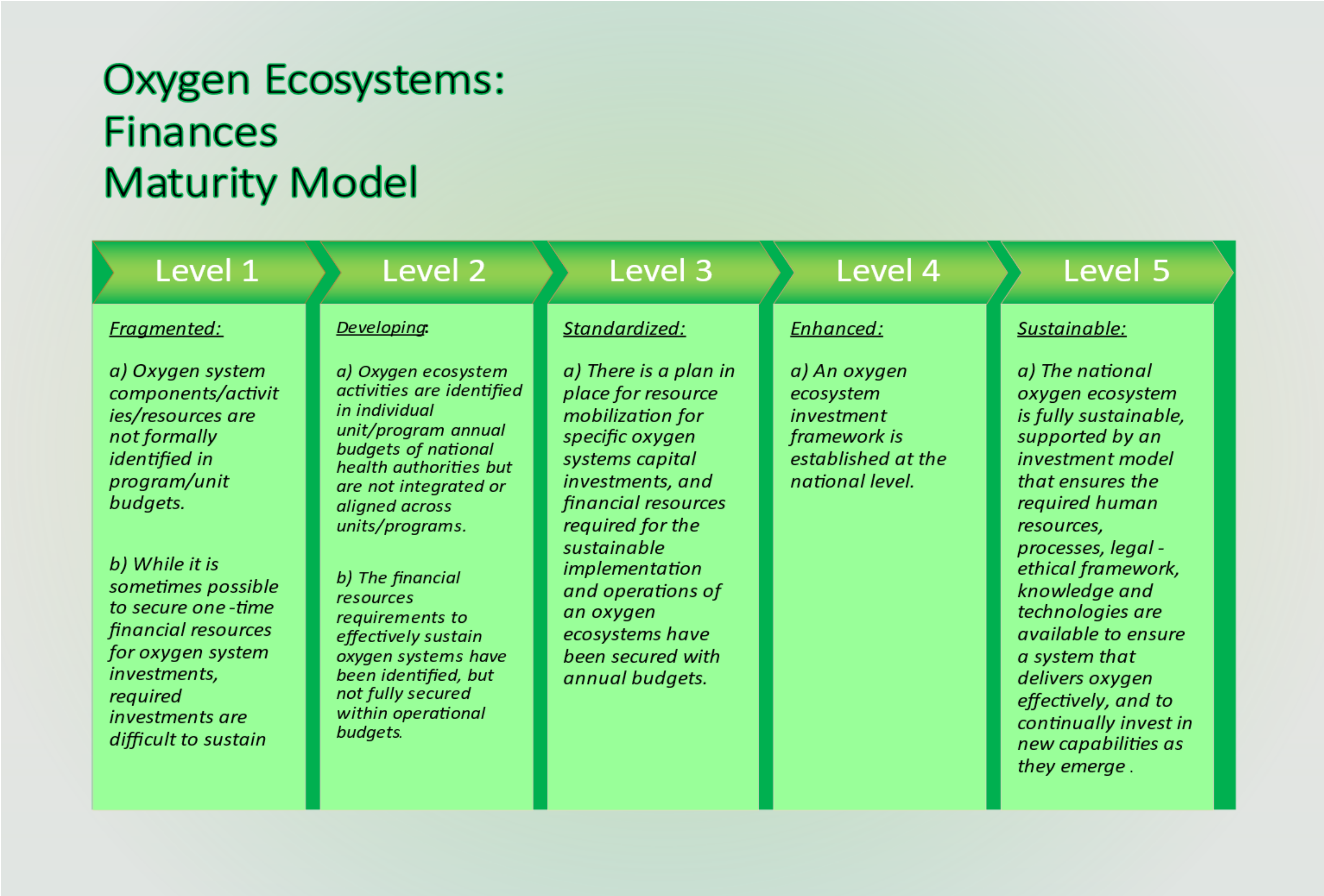


FIGURE 7.4 SHOWING OXYGEN ECOSYSTEMS COMPONENT: FINANCES MATURITY MODEL (WHO AND PAHO 2019)

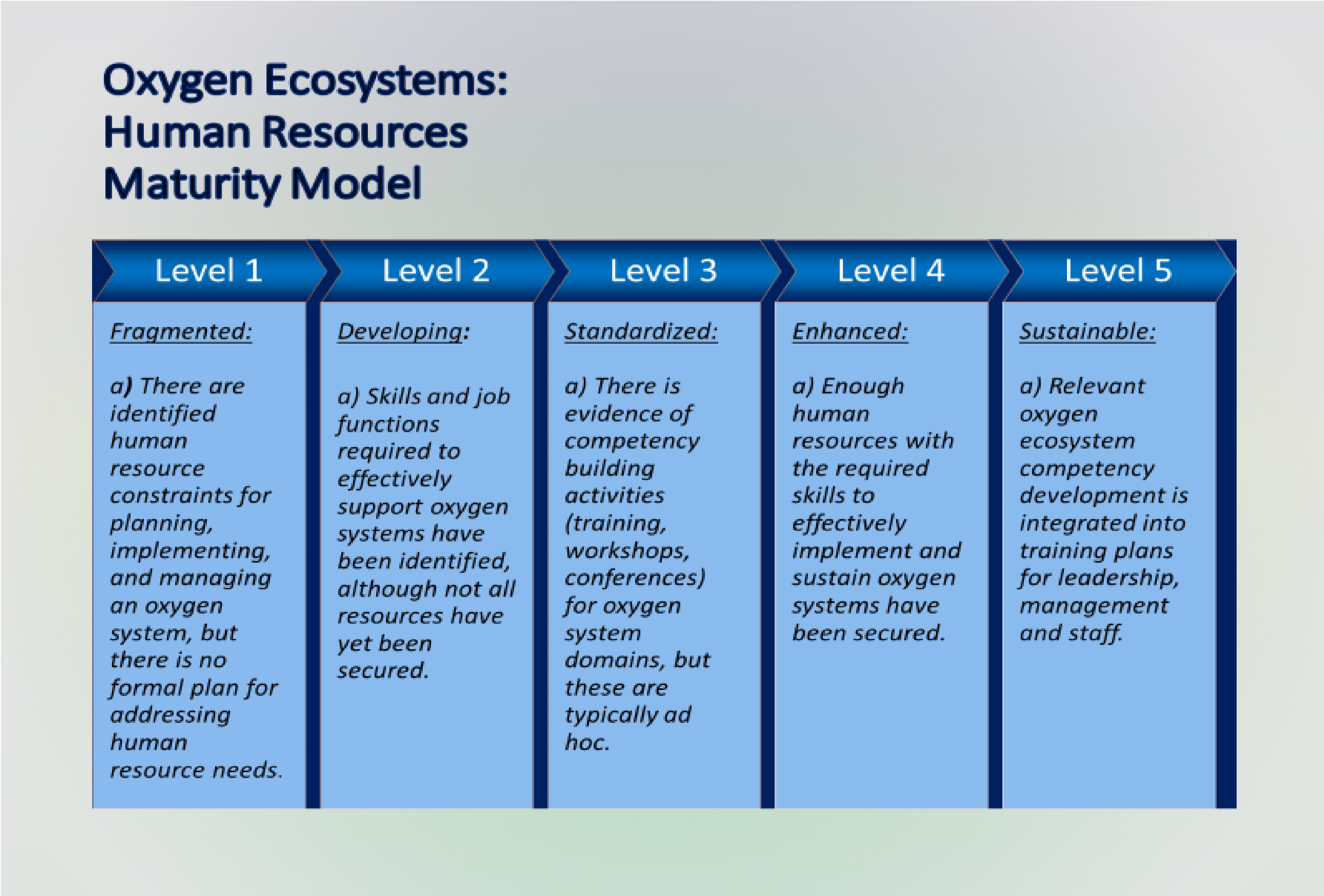


FIGURE 7.5 SHOWING OXYGEN ECOSYSTEM COMPONENT: HUMAN RESOURCES MATURITY MODEL (WHO AND PAHO 2019; THE GLOBAL FUND 2023)

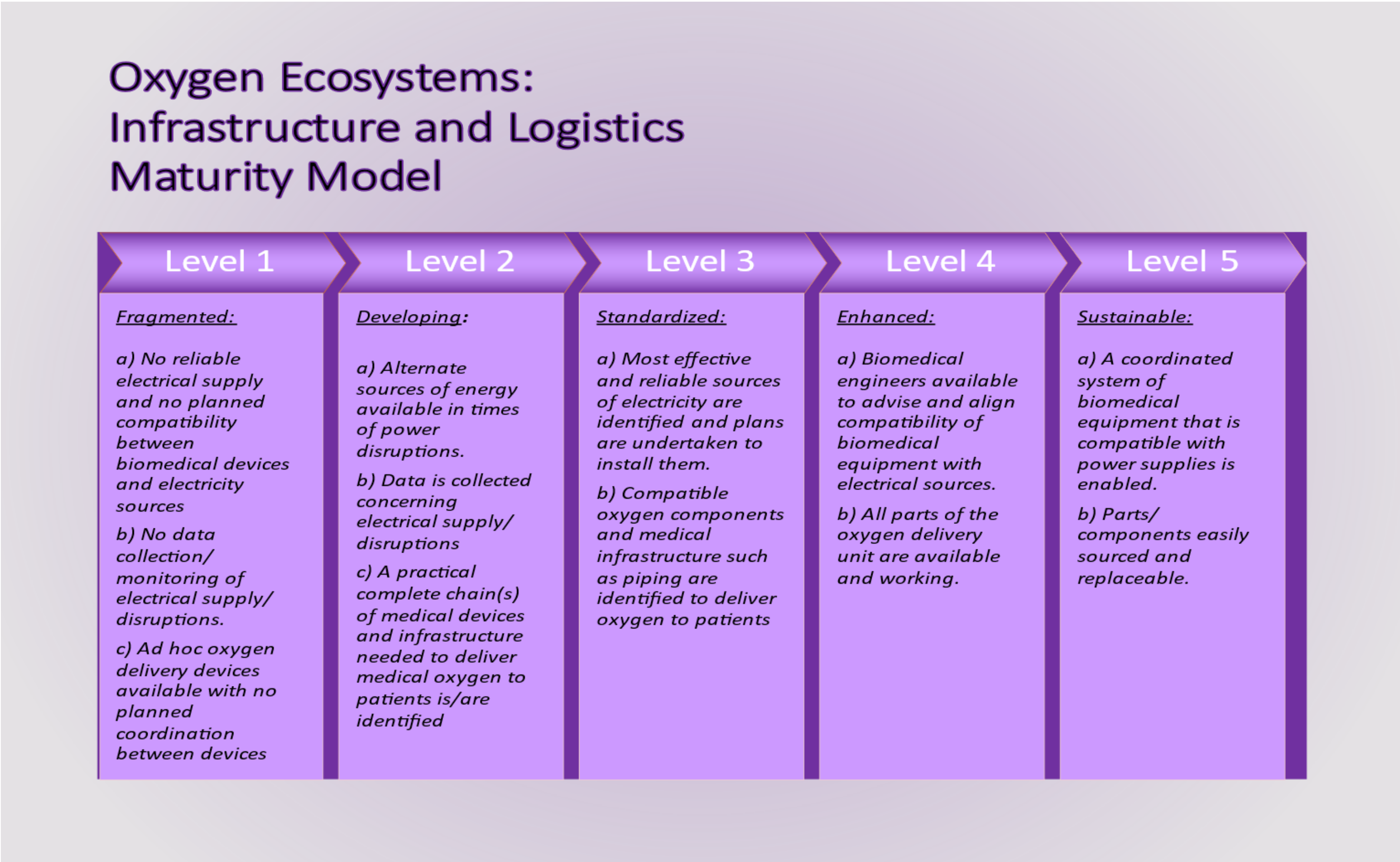


FIGURE 7.6 SHOWING OXYGEN ECOSYSTEMS COMPONENT: INFRASTRUCTURE AND LOGISTICS MATURITY MODEL (PATH 2020B; 2020A)

Discussion

1. Key elements/attributes of oxygen ecosystems

The foundational principles outlined by the World Health Organization (WHO) in its "Foundations of Medical Oxygen Systems" (World Health Organization 2023) serve as a comprehensive framework for understanding the key attributes of oxygen ecosystems within healthcare facilities. These attributes are instrumental in ensuring the continuous availability, effective utilization, and safe administration of medical-grade oxygen.

1. **Normative Standards and Regulations**:
   - The WHO's framework emphasizes the importance of regulatory standards and norms that govern the entire oxygen ecosystem, from production to dispensation. These standards are critical for ensuring the safety and quality of medical oxygen.
2. **Market Landscape**:
   - Understanding the market dynamics for oxygen production equipment and supplies is a fundamental aspect of the WHO's approach. It guides policymakers and healthcare facilities in making informed decisions about procurement and resource allocation.
3. **Health Coverage**:
   - The WHO underscores the need for oxygen ecosystems to align with broader healthcare policies and strategies to ensure equitable access to oxygen therapy for all individuals in need.
4. **Finance**:
   - Adequate financial planning and resource allocation are at the core of the WHO's foundation. Securing the necessary funds for the establishment and maintenance of oxygen ecosystems is vital for their sustainability.
5. **Human Resources**:

- The WHO emphasizes the importance of building and maintaining a skilled workforce capable of managing all aspects of the oxygen ecosystem. This includes training programs and workforce development.

6. **Infrastructure and Logistics**:

    - The framework highlights infrastructure assessment and logistics optimization as central elements. This ensures that oxygen can be reliably produced, stored, and distributed within healthcare facilities.

These foundational elements collectively constitute the backbone of oxygen ecosystems in healthcare facilities, as guided by the WHO. It's important to note that the context in which these ecosystems operate can vary, leading to different strategies and considerations. The Lancet article by Nakkazi (Nakkazi 2023) further underscores the specific challenges and strategies in the African context, emphasizing themes like infrastructure, governance, human resources, advocacy, and funding as crucial for creating sustainable oxygen ecosystems.

Incorporating these foundational principles into the structure of an oxygen ecosystem is pivotal for delivering high-quality healthcare services, especially in resource-constrained settings. The intricate interplay of planning, market dynamics, health coverage, finance, human resources, and infrastructure ensures the availability of medical-grade oxygen, enabling healthcare systems to effectively meet patient demands, optimize resource allocation, and ultimately enhance patient outcomes.

The validation of the World Health Organization's "Foundations of Medical Oxygen Systems" (2023) by experts in the field of medical oxygen further strengthens the significance and credibility of the foundational principles outlined by the WHO. Expert endorsements from prominent figures such as Eric Buckley from Build Health International, Alexander Rothkopf from PATH, and Laura Alejandra Velez Ruiz Gaitan from the WHO provide valuable accreditation to the framework.

Eric Buckley, renowned for his work in healthcare infrastructure development through Build Health International, has highlighted the WHO's foundational principles as a crucial guide for healthcare facilities globally. He underscores the importance of aligning oxygen ecosystem planning with infrastructure development to ensure a reliable supply of medical-grade oxygen. Eric's endorsement reinforces the practicality and real-world applicability of the WHO's framework.

Alexander Rothkopf, a respected expert associated with PATH, acknowledges the WHO's framework as a pivotal tool for navigating the complex landscape of medical oxygen systems. His endorsement emphasizes the significance of understanding market dynamics and financial considerations in procuring and sustaining oxygen ecosystems. Alexander's expertise underscores the alignment between the WHO's principles and real-world challenges in oxygen procurement.

Laura Alejandra Velez Ruiz Gaitan, a prominent figure within the World Health Organization, recognizes the WHO's foundational framework as a cornerstone for global health efforts. Her endorsement reaffirms the importance of harmonizing healthcare policies and strategies with oxygen ecosystem planning. Laura's expertise highlights the relevance of the WHO's framework on a global scale, emphasizing its potential to improve healthcare infrastructure and patient care worldwide.

The collective endorsement of the WHO's "Foundations of Medical Oxygen Systems" by experts like Eric Buckley, Alexander Rothkopf, and Laura Alejandra Velez Ruiz Gaitan underlines its significance in the field of medical oxygen. Their accreditation serves as a testament to the framework's practicality, relevance, and potential to enhance healthcare systems' resilience and efficiency, ultimately leading to improved patient outcomes. By combining expert insights with the WHO's foundational principles, healthcare facilities can further optimize their oxygen ecosystems and ensure the continuous availability of high-quality medical-grade oxygen.

2. The gaps in the oxygen ecosystems of developing countries

The gaps in oxygen ecosystems in developing countries, as identified by experts Alexander Rothkopf, Laura Alejandra Velez Ruiz Gaitan, and Eric Buckley, revolve around three key areas: normative standards and regulations, human resources, and logistics and infrastructure, with a particular emphasis on electricity supply. These gaps significantly impact the functionality and effectiveness of oxygen ecosystems, hindering their ability to provide consistent access to medical-grade oxygen.

Normative Standards and Regulations:

- *Expert Insights:* According to Alexander Rothkopf, there is a substantial need for improved logistics and operations in many countries. This deficiency extends to the regulatory and normative aspects of oxygen ecosystems. He suggests that while infrastructure may have improved, the regulatory and normative frameworks governing oxygen systems need more attention.
- *Discussion:* In developing countries, the absence of robust regulatory standards and norms can lead to issues such as suboptimal oxygen production, inadequate quality control, and insufficient safety measures. The lack of clear guidelines can hinder the establishment of reliable oxygen systems.

Human Resources:

- *Expert Insights:* All three experts, Alexander Rothkopf, Laura Alejandra Velez Ruiz Gaitan, and Eric Buckley, emphasize the critical role of human resources in addressing gaps within oxygen ecosystems. They highlight a shortage of skilled personnel, particularly in clinical and biomedical engineering roles.
- *Discussion*: The shortage of qualified healthcare professionals and biomedical engineers capable of operating and maintaining oxygen equipment is a significant challenge. This shortage leads to reduced system efficiency, inadequate training, and a lack of expertise in oxygen system management.

Logistics and Infrastructure, especially Electricity Supply:

- *Expert Insights:* Eric Buckley and Alexander Rothkopf point out that one of the most significant infrastructure challenges related to oxygen access is the reliability and quality of the electrical infrastructure, particularly the power grid. Eric Buckley also underscores the importance of hospital piping networks to deliver oxygen to patient bedsides. Poor infrastructure and lack of power quality and availability present substantial barriers.
- *Discussion:* In many developing countries, inadequate infrastructure, especially unreliable electricity supply, can disrupt oxygen production and delivery. Oxygen concentrators, for instance, depend on a stable power source. Without it, they may fail to meet the demand for medical oxygen. Additionally, outdated or insufficient piping networks within hospitals hinder the efficient delivery of oxygen to patients.

Finances:

- *Expert Insights:* Eric Buckley and Alexander Rothkopf both touch upon the financial challenges associated with oxygen ecosystems. They emphasize the importance of adequate funding and the allocation of resources to support these systems.
    - Eric Buckley: He mentions that the reliability and availability of power can significantly affect access to oxygen. Often, funding constraints limit the necessary infrastructure upgrades that could improve power supply reliability. This highlights the financial barrier that countries face in ensuring consistent access to medical-grade oxygen.
    - Alexander Rothkopf: Alexander underscores that logistics and operations on the financial side pose substantial challenges. The procurement of equipment and supplies requires financial resources, and the lack of funding can hinder the functionality of the oxygen ecosystem.
- *Discussion:*

  Resource Allocation: Oxygen ecosystems require substantial investments in equipment, infrastructure, training, and maintenance. These investments may compete with other healthcare priorities for limited resources. In many developing countries, healthcare budgets are constrained, and oxygen systems may not receive the necessary financial allocation.

  Capital Investment: Eric Buckley's insights highlight the capital-intensive nature of oxygen systems. The initial purchase of equipment, along with ongoing maintenance and operational costs, can strain healthcare budgets. Without adequate financial planning, these systems may become underfunded, leading to breakdowns and disruptions in oxygen supply.

  Cost-Benefit Considerations: While the financial challenges are evident, it's crucial to assess the cost-effectiveness and long-term benefits of investing in oxygen ecosystems. Adequate financing can lead to improved patient outcomes, reduced hospital admissions, and healthcare cost savings in the long run.

The WHO's foundational principles acknowledge the financial dimension of oxygen ecosystems. They emphasize the need for health financing as one of the structural actions required for optimal and sustainable implementation. This includes allocating funds for infrastructure development, equipment procurement, training programs, and ongoing maintenance.

Incorporating Laura Alejandra Velez Ruiz Gaitan's insights regarding systematic issues related to policy and governance, it becomes evident that addressing these gaps requires comprehensive solutions at multiple levels. These issues often originate from a lack of understanding and capacity within governments and facilities.

Moreover, the experts collectively highlight the need for better training and capacity building at the facility and Ministry of Health levels. Adequate training ensures that healthcare professionals and technicians can effectively operate and maintain oxygen equipment, enhancing system reliability and safety.

Thus, addressing the gaps in oxygen ecosystems in developing countries, as identified by experts and supported by the WHO's "Foundations of Medical Oxygen Systems," requires a multifaceted approach. This approach should encompass the development of robust regulatory standards, investment in human resources development, and substantial improvements in logistics and infrastructure, particularly reliable electricity supply. By bridging these gaps, countries can ensure that their oxygen ecosystems function optimally, ultimately saving lives and improving healthcare outcomes.

3. Addressing the gaps within Oxygen Ecosystems?

Addressing and minimizing the gaps in oxygen ecosystems in developing countries requires a multifaceted approach, drawing upon the insights provided by experts Alexander Rothkopf, Laura Alejandra Velez Ruiz Gaitan, and Eric Buckley. These experts offer valuable perspectives on the key actions and success factors that can help improve and sustain underdeveloped components of oxygen ecosystems.

1. Involvement of Local Organizations and Ministries:

- *Expert Insights*: Alexander Rothkopf emphasizes the importance of involving local organizations and ministries in addressing the challenges within oxygen ecosystems. He suggests that temporary and facility ownership should be prioritized. This approach ensures that the local stakeholders take ownership of the problem and actively participate in finding solutions.

- *Action:* Health system managers should collaborate closely with local healthcare organizations and government ministries to co-create and implement solutions. This collaborative approach ensures that solutions are tailored to the specific needs and context of the region.

2. Efficient Allocation and Sustainability of Funds:

- *Expert Insights:* Laura Alejandra Velez Ruiz Gaitan highlights the importance of efficient fund allocation and long-term sustainability. She notes that during the COVID-19 pandemic, funds were available but not always effectively distributed or utilized for long-term sustainability.
- *Action:* Health system managers should advocate for donors and funding agencies to prioritize the balanced allocation of funds. Emphasis should be placed on both procurement and long-term sustainability efforts, including training, maintenance, and infrastructure development.

3. Technical Involvement in Decision-Making:

- *Expert Insights:* Laura Alejandra Velez Ruiz Gaitan underscores the need to involve technical teams in decision-making processes at both the facility and government levels. Technical teams possess an understanding of infrastructure and equipment requirements, which is crucial for informed decision-making.
- *Action:* Health system managers should ensure that technical experts are actively engaged in decision-making processes. This involves consulting with biomedical engineers and other technical professionals to make informed choices regarding equipment, infrastructure upgrades, and overall system design.

4. Training and Capacity Building:

- *Expert Insights:* Eric Buckley highlights the importance of training and capacity building, both technically and in terms of human resources and finance systems. He notes that adequate training is essential for the effective operation and maintenance of equipment.
- *Action:* Health system managers should invest in comprehensive training programs for healthcare professionals and technical staff. These programs should cover equipment operation, maintenance,

and system management. Additionally, finance systems should be established to ensure the availability of funding for ongoing maintenance and resource optimization.

5. Infrastructure Development:

- *Expert Insights:* Eric Buckley emphasizes the prerequisite of having adequate infrastructure, particularly stable electrical infrastructure, for the reliable functioning of oxygen systems.
- *Action:* Health system managers should prioritize infrastructure development to ensure that the necessary electrical and piping infrastructure is in place. This includes upgrading electrical grids and creating proper piping networks within healthcare facilities.

6. Multidisciplinary Approach:

- *Expert Insights:* Laura Alejandra Velez Ruiz Gaitan stresses the importance of a multidisciplinary approach for long-term sustainability, covering factors such as fund usage and maintenance.
- *Action:* Health system managers should adopt a multidisciplinary approach that involves collaboration between clinical staff, technical experts, financial teams, and policymakers. This ensures that all aspects of the oxygen ecosystem are considered, leading to more efficient and reliable systems.

Therefore, addressing and minimizing the gaps in oxygen ecosystems in developing countries requires a holistic and collaborative approach. Health system managers should engage local stakeholders, prioritize sustainable fund allocation, involve technical experts in decision-making, invest in training and capacity building, and ensure adequate infrastructure development. By implementing these actions and considering the success factors highlighted by experts, healthcare systems can create more efficient and reliable oxygen ecosystems, ultimately improving patient care and outcomes.

4. Using Maturity Models to improve existing oxygen ecosystems

Utilizing a maturity model to enhance existing oxygen ecosystems offers a structured and systematic approach to identify areas of improvement and advance the quality and efficiency of these systems. Drawing upon expert insights and best practices, we can outline key actions for applying a maturity model effectively. A maturity model provides a structured pathway for healthcare systems to evolve from merely having oxygen resources available to ensuring that they are accessible and optimally utilized. It enables a shift from a fragmented and complex ecosystem to a more streamlined and accessible one, ultimately benefiting patients by ensuring consistent access to life-saving oxygen. Maturity models not only serve as a practical tool but also as an advocacy platform. By implementing and documenting the maturity model's progress, healthcare organizations can raise awareness about the complexities and challenges within oxygen ecosystems. This increased awareness can drive advocacy efforts and support for sustainable solutions at both local and global levels.

A maturity model also encourages the involvement of diverse teams encompassing clinical staff, technical experts, financial specialists, and policymakers. This collaborative approach ensures that all aspects of the ecosystem are considered comprehensively. It promotes a holistic understanding of the challenges and solutions required to improve oxygen access, fostering a more integrated and effective healthcare system. Maturity models are inherently designed for continuous improvement. It serves as a framework for ongoing assessment, adaptation, and advancement. By adopting this approach, healthcare systems can ensure that improvements are not short-lived but are sustained for the long term, reducing the risk of setbacks and system failures. A maturity model addresses the issue of ownership by promoting shared responsibility among stakeholders. When different components of the ecosystem are integrated into a maturity model, it fosters a sense of collective ownership and accountability, reducing fragmentation and ensuring consistent progress toward improved oxygen access.

The maturity model for oxygen ecosystems and its subcomponents (as shown in the results section) was created after considerable revision of existing literature and examining the inputs of the experts interviewed. This maturity model uses the foundations of medical oxygen systems created by the WHO (World Health Organization 2023) as the pillars through which oxygen (eco)system managers can optimize the various oxygen ecosystems. The maturity models created gives generally the key steps/criteria oxygen systems need to take to fulfil this optimization. Notably and of crucial importance, is that these individual components should be developed in tandem with each other and not in isolation. The steps mentioned in the maturity models of each component were again based on the existing literature and the inputs of the experts. An example of this is the focus on electrical supply in the infrastructure and logistics model. This issue was recurring and mentioned many times in the literature and interviews. Health (eco)system managers can modify various elements of the maturity model sub-components to fit their individualized contexts. These maturity models offer an exclusive opportunity to guide oxygen system managers on the significance of this intertwined development and not repeat the common mistake of focusing on oxygen procurement.

In summary, these maturity models offer a structured and adaptable approach to tackle the complex challenges within oxygen ecosystems. It helps transform availability into accessibility, raises awareness and advocacy, encourages multidisciplinary collaboration, promotes sustainability, and addresses issues of ownership. By leveraging these benefits, healthcare systems can make significant strides in ensuring that medical-grade oxygen is readily accessible to patients, ultimately saving lives and improving healthcare outcomes.

Limitations

1) This study was limited by the number of published data and information currently available regarding oxygen systems. Given the aftermath of the COVID-19 pandemic, numerous studies and information regarding medical oxygen and oxygen systems are currently being undertaken which can potentially impact the findings shown in this study.

2) A wider panel of experts, including those within the government/public officials would have contributed more to the insights into the oxygen system components used for the creation of maturity models.

Recommendations

1) In addition to this maturity model, health system managers should use other related tools such as the UNICEF's Oxygen System Planning tool and the WHO's Harmonized Health Facility Assessment (HFFA) which provide users with easily accessible information regarding where they can source oxygen components, the idealized amount of equipment and facility resources and the expected cost that would be needed to operate oxygen systems based on contextualized data managers can input into the tool

2) Data should be collected on health systems which implement the maturity model in upgrading their oxygen (eco)systems to compare effectiveness pre and post-implementation. This data could then be used to update the maturity models as needed.

Conclusion

In conclusion, the critical importance of a reliable and sustainable oxygen supply in healthcare settings cannot be overstated. Oxygen is fundamental to sustaining human life, and its availability plays a pivotal role in the treatment of various medical conditions, particularly those involving hypoxia. While the use of medicinal oxygen in healthcare dates back centuries, there is a pressing need to enhance the existing oxygen ecosystems in developing countries to meet the demands of modern healthcare.

The World Health Organization (WHO) recognizes the significance of a well-functioning oxygen ecosystem and has highlighted its key components, encompassing infrastructure, policies, health financing, multidisciplinary guidelines, and qualified teams. This comprehensive definition underscores the interconnected nature of the oxygen supply chain, extending from production to patient delivery.

To address the challenges in existing oxygen ecosystems and drive improvements, the concept of a maturity model is introduced. A maturity model serves as a structured framework for assessing the current state of an oxygen ecosystem and defining a roadmap for advancement. By progressing through levels of effectiveness, healthcare facilities can systematically enhance their oxygen ecosystems to meet the ever-evolving demands of patient care.

The impact of this maturity model on oxygen ecosystems is poised to be profound. Providing healthcare system managers and oxygen administrators with a clear path for development empowers them to make data-driven decisions, allocate resources more efficiently, and ensure that their facilities operate at the highest level of efficiency. This, in turn, will result in better patient outcomes, reduced mortality rates, and an overall enhancement of healthcare delivery in developing countries.

Moving forward, the maturity model for oxygen ecosystems will serve as a valuable tool for healthcare systems worldwide. It will not only help bridge the gap in oxygen access but also contribute to strengthening healthcare infrastructure and improving the quality of care. As the model is applied and refined, it has the potential to save countless lives and serve as a testament to the transformative power of structured, evidence-based approaches in healthcare management.

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Appendix

Appendix 1: Interview Questions

Project: Development of a Maturity Model for Oxygen Ecosystems in Developing Countries

Partner Organization: The Global Health

Student Researcher: Dr Ryan Abraham (The Graduate Institute (IHEID) – MINT Global Health)

By agreeing to be interviewed, you hereby consent for the content discussed during the interview to be included in the findings of this research which may result in publication. You also agree that for your position and expertise in the matter, you agree that your name and job title be included in the research conducted. Thank you in advance for your consideration in partaking in this meaningful study.

The World Health Organization has identified 6 components as being essential to the creation of a reliable medical oxygen ecosystem. These include:

1) **Normative Standards and Regulations**
2) **Market Landscape**
3) **Health Coverage**
4) **Finance**
5) **Human Resources**
6) **Infrastructure and Logistics**

Figure 7 Components of an Oxygen Ecosystem (WHO 2023)

(Leading) Interview Questions:

Research Question 1
1) Do you agree with the framework for oxygen ecosystems proposed by the WHO? Do you believe there is a fundamental element that is missing from the layout?

Research Question 2
2a) Based on your experience/knowledge, how capable are the oxygen systems in developing countries in meeting demand?
2b) Which component(s) of the oxygen ecosystem do you believe are most underdeveloped in developing countries?

Research Question 3
3a) What approach or key actions can health system managers take to improve the development of these underdeveloped components?
3b) What are some success factors for creating a more efficient and reliable oxygen ecosystem?

Research Question 4
4) Do you believe a maturity model using a whole-system approach be utilized in improving the efficiency of oxygen ecosystems in developing countries?

Appendix 2: NVIVO Themes and Coding Used