Building sustainable and resilient surgical systems: A narrative review of opportunities to integrate climate change into national surgical planning in the Western Pacific region

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Summary

Five billion people lack access to surgical care worldwide; climate change is the biggest threat to human health in the 21st century. This review studies how climate change could be integrated into national surgical planning in the Western Pacific region. We searched databases (PubMed, Web of Science, and Global Health) for articles on climate change and surgical care. Findings were categorised using the modified World Health Organisation Health System Building Blocks Framework. 220 out of 2577 records were included. *Infrastructure:* Operating theatres are highly resource-intensive. Their carbon footprint could be reduced by maximising equipment longevity, improving energy efficiency, and renewable energy use. *Service delivery* Tele-medicine, outreaches, and avoiding desflurane could reduce emissions. Robust surgical systems are required to adapt to the increasing burden of surgically treated diseases, such as injuries from natural disasters. *Finance:* Climate change adaptation funds could be mobilised for surgical system strengthening. *Information systems:* Sustainability should be a key performance indicator for surgical systems. *Workforce:* Surgical providers could change clinical, institutional, and societal practices. *Governance:* Planning in surgical care and climate change should be aligned. Climate change mitigation is essential in the regional surgical care scale-up; surgical system strengthening is also necessary for adaptation to climate change.

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Abbreviations: CO_2, Carbon dioxide; DALY, Disability-adjusted life year; FEMAT, Fiji Emergency Medical Assistance Team; GHG, Greenhouse gas; HVAC, Heating, ventilation, and air conditioning; HICs, High-income countries; IPCC, Intergovernmental Panel on Climate Change; kgCO_2e, Kilograms of carbon dioxide equivalent; LCoGS, Lancet Commission on Global Surgery; LCA, Life-cycle analysis; LED, Light-emitting diode; LMICs, Low- and middle-income countries; NSOAP, National Surgical, Obstetric, and Anaesthesia Plan; OR, Operating Room; SUD, Single-use device; SOA, Surgical, obstetric, and anaesthesia; WASH, Water, sanitation, and hygiene

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Research in context

Evidence before this study

Surgical system strengthening has been identified as a priority in the Western Pacific region. At the same time, the Western Pacific is among the most vulnerable regions to the effects of climate change and natural disasters. Considerations of climate change have been largely missing from the global surgery literature. We searched databases (PubMed, Web of Science, and Global Health) using the keywords climate change ("climate change", "global warming", "greenhouse gas"), and surgical, obstetric, anaesthesia, and trauma care ("surgical procedures", "operating room", "anaesthesia", "maternal health", "trauma"). We found previous reviews have focused on high-income countries rather than low- and middle-income countries (LMICs) and clinical practice rather than the broader health system.

Added value of this study

This is the first review to incorporate the perspectives of LMICs, a category encompassing many countries in the Western Pacific region, in considering the implications of climate change for surgical system strengthening. We took a system-based approach and provided a big picture overview of strategies for building sustainable and climate-resilient surgical systems. We comprehensively reviewed the available literature and generated policy-oriented recommendations contextualised to the diverse geographic, social, and economic circumstances of the Western Pacific region.

Implications of all the available evidence

Climate change and surgical system strengthening are closely linked. Actions for climate change mitigation and adaptation should be taken across surgical system infrastructure, service delivery, workforce, information management, finance, and governance, and could hence generate substantial co-benefits in financial cost savings and improving care access and quality. More research is urgently required to report the carbon footprint of surgical care, monitor the impact of climate change on surgically treated diseases, and share ground-up innovations across diverse income levels and geographic settings in the Western Pacific region.

Introduction

Surgical, obstetric, and anaesthesia care is required to treat a range of conditions, including obstructed labour, cancer, traumatic injuries, acute abdominal conditions, and congenital anomalies, among others. However, five billion people lack access to safe and affordable surgical care when required.[1] In 2015, the Lancet Commission on Global Surgery (LCoGS) recommended scaling up surgical, obstetric, and anaesthesia care (SOA) care (referred to broadly as 'surgical care'[a]) through developing national surgical plans.[1]

Climate change is the biggest threat to human health in the 21st century and has important implications for surgical care.[2] Surgical care delivery could affect both climate change *mitigation* – the prevention of climate change, and *adaptation* – reducing vulnerabilities to the effects of climate change. On the one hand, surgical care provision can be carbon intensive: the health sector, as a whole, contributes about 4·9% of total global greenhouse gas (GHG) emissions.[3] On the other hand, surgical system strengthening is essential in response to rising disease burdens from climate change, such as injuries from natural disasters.[4]

The intersection between climate change and surgical system strengthening is significant to the Western Pacific region.[b] Despite substantial geographic, economic, and social diversity, the region has a shared vulnerability to climate change and natural disasters.[5] Between 1970 and 2011, 75% of the global natural disaster fatalities occurred in the Asia-Pacific region.[6] The 2021 Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report projected heavy precipitations, floods, and cyclones to intensify across the Asia-Pacific region under all future climate trajectories.[7] At the same time, surgical system strengthening has been identified as a regional priority. In 2019, Pacific Health Ministers, at their 13th biennial meeting, committed to developing National Surgical, Obstetric, and Anaesthesia Plans (NSOAPs) towards achieving the Healthy Island Vision.[8] In 2020, Member States unanimously endorsed the World Health Organization (WHO) *Action Framework for Safe and Affordable Surgery in the Western Pacific Region* at the 71st Regional Committee Meeting.[9]

As countries in the Western Pacific scale up surgical care, there is a unique opportunity to reimagine and build sustainable and climate-resilient surgical systems. This is urgently required as climate change has become a rapid, widespread, and unprecedented reality and as the COVID-19 pandemic provides an opportunity to build back better.[7] Climate change is relevant to both low- and middle-income countries (LMICs) developing surgical systems and high-income countries (HICs) retrofitting and redesigning surgical systems. Much of the

[a] "Surgical care" is an overarching term used to denote care for adults and children delivered by anaesthetists, obstetricians and gynaecologists, and surgeons from various backgrounds including, but not limited to, adult and paediatric general surgery, orthopaedics, neurosurgery, urology, ophthalmology, otorhinolaryngology, and vascular surgery, as well as nursing, midwifery, and all allied health professionals.

[b] The Western Pacific region is defined according to the WHO region designation and comprises 37 countries. (https://www.who.int/westernpacific/about/where-we-work Accessed August 27th, 2021).

Figure 1. A framework for developing National Surgical, Obstetric, and Anaesthesia Plans (NSOAPs).[11]

global surgery literature, including the LCoGS, has not taken climate change into account.[1] The Western Pacific region could lead by example in pioneering surgical system strengthening in the context of climate change and identifying transferrable solutions that are globally relevant. Therefore, this narrative review aims to comprehensively examine the available literature and generate evidence-based, policy-oriented recommendations for integrating climate change into national surgical planning in the Western-Pacific region.

Methods

Search strategy and selection criteria

We conducted a literature search of PubMed, Web of Science, and Global Health in August 2020 and updated it in April 2021. We combined two categories of search terms: climate change ("climate change", "global warming", "greenhouse gas"), and surgical, obstetric, anaesthesia, and trauma care ("surgical procedures", "operating room", "anaesthesia", "maternal health", "trauma"). A full list of search terms is presented in the supplementary material. Search terms on specific mediators of climate change, such as heat or food insecurity, were not included as the primary purpose of the review was to capture the broad impact of climate change on surgical care. We identified further relevant literature from the references of included articles and an expert-generated list of key regional grey literature publications in view of the interdisciplinary nature of this topic.

Articles were screened in two stages; RQ and LV screened the titles and abstracts of the retrieved literature, then full-text reviews were performed by RQ, LV, EFY, and OE. We included articles published after 1990 that described the effects of anthropogenic climate change on surgical and anaesthesia care and vice versa. Articles were excluded if their full texts were unavailable, if they studied non-human subjects, conditions not requiring surgical care, environmental impacts other than climate change, or if they lacked sufficient regional relevance.

Data extraction

Data were extracted using the modified WHO Health Systems Building Block Framework, which is used for developing NSOAPs.[10,11] Results were thematically synthesised in six domains: infrastructure, service delivery, workforce, information management, financing, and governance (Figure 1).

Role of funding source

None.

Results

We screened 2577 unique records and included 220 records in the final review. A complete list of included papers is provided in the supplementary material. Results were synthesised and presented by health system domain (Figure 2). We noted that the literature on this topic includes many commentaries and opinion pieces; however, a formal quality assessment is beyond the scope of this review. There are a few hot spots where the evidence is more mature, such as the impact of heat on birth outcomes, anaesthetic drugs and inhaled agents, and reusable versus disposable equipment. However, despite the growth in literature over the last five years, the evidence is still limited in many other areas. Most studies were conducted in HICs, with very few in LMICs, a category to which many countries in the Western-Pacific region belong.

Infrastructure

Mitigation. Operating rooms (ORs) are a highly resource-intensive component of the health system. They can be three to six times more energy-intensive than the hospital average and consume 40–60% of a facility's supply chain.[12] Environmental impact assessment through life-cycle analyses (LCA) has shown the emission profile of surgical procedures to vary substantially by facility and procedure. The main sources of

MITIGATION		ADAPTATION
Infrastructure		
• Maximising equipment life span. • Minimising SUDs. • Streamlining instrumentation. • Energy-efficient building design, HVAC systems, and machinery.		• Resilient water, sanitation, and hygiene (WASH) infrastructure • Renewable energy use. • OR insulation. • Climate-resilient OR building standards.
Service delivery		
• Reducing the use of volatile anaesthetic agents, especially desflurane. • Low-fresh gas flow, closed-circuit delivery, anaesthesia gas scavenging system. • Office-based procedures when appropriate. • Increasing telemedicine use.		• Surgical system strengthening to adapt to the increasing burden and complexity of surgically treated diseases. • Integration of emergency disaster response with routine surgical system strengthening.
Workforce		
• Educating SOA providers on sustainable practices. • Advocacy by SOA providers.		• OR building design to minimise the impact of warming on SOA provider performance.
Information system		
• Making sustainability a surgical system performance indicator. • Conducting life-cycle analyses of surgical procedures in diverse settings across the region. • Identification and sharing of innovation.		• Linking meteorological and surgical data to monitor the impact of climate change on surgical disease burden and outcomes. • Modelling long-term impact.
Finance		
• Performing long-term financial and environmental cost-effectiveness analysis to guide decision-making.		• Mobilising climate change adaptation and disaster risk reduction funds for surgical system strengthening. • Strengthening financial risk protection.
Governance		
• Environmentally preferable purchasing. • Reviewing institutional and national policies and regulations to facilitate sustainability. • Research, development, and manufacture of sustainable surgical devices. • Action by both HICs and LMICs.		• Engagement of multisectoral stakeholder to integrate planning in climate change and surgical system strengthening.

Figure 2. Strategies for climate change mitigation and adaptation in surgical system strengthening.
GHG = greenhouse Gas Emissions; HVAC = heating, ventilation, and air conditioning; HIC = high-income country; LMIC = low- and middle- income country; OR = operating Room; SOA = surgery, obstetrics and anaesthesia; SUD = single-use devices.

GHG emissions from surgical procedures are equipment and consumables, inhaled anaesthetic agents, and energy use. Studies have shown that a combination of measures targeted at different sources can reduce the carbon footprint of ORs by 80–95%.[13,14]

Equipment and consumables. Equipment and supplies are found to contribute to 60–70% of total GHG emissions of surgical procedures when anaesthesia and energy usage are optimised.[12,13]

The majority of emissions arise from the manufacturing process. This calls for strategies to maximise equipment lifespan and reduce emissions per use. A number of studies in HICs have demonstrated reusable equipment to be environmentally superior to single-use devices (SUDs) for a wide range of equipment and procedures, potentially reducing GHG emissions by up to 90%.[15–23] The few studies that found SUDs to be environmentally beneficial have all been conducted in Australia, where electricity is mainly generated from the carbon-intensive source of coal.[15,24,25] Environmentally preferable purchasing policies could guide the selection of equipment and consumables based on their long-term financial and environmental cost rather than their up-front cost.[26] In LMICs, around 40% of equipment and consumables can be non-functional due to the lack of maintenance.[27] This can be improved through strengthening biomedical engineering services.

The number of instruments opened per case can be reduced to the minimum required. A large proportion of instruments may only be included to anticipate surgeons' needs and end up unused[28]. Thiel et al. found that minimising the number of SUDs opened decreased GHG emissions in laparoscopic surgery (excluding anaesthesia) by 70% in a United States hospital.[13] A more parsimonious approach to surgical trays has been demonstrated to be feasible and cost-effective. Substantial environmental benefit is foreseeable and should be quantified by future studies.[29]

Energy use. In HICs, energy use has been found to account for between 10 and 80% of total OR emissions.[12] The most significant contributors are heat, ventilation, and air-conditioning (HVAC) systems, followed by lighting and machinery.[12,30,31] ORs are highly energy-intensive due to their unique requirement for stringent temperature and ventilation control for patient safety and microbial control. Occupancy sensors or energy-efficient scheduling, such as adapted weekend settings, could reduce HVAC energy consumption when ORs are not in use.[32,33] The energy demand for lighting and machinery could be reduced by replacing older equipment with more energy-efficient options, such as light-emitting diode (LED) lights.[26,34] There may be efficiencies with scale: providers in LMICs found increasing surgical volume and maximising OR occupancy reduced the per-case carbon footprint.[35]

Emissions attributable to energy use varies widely between facilities due to the differences in energy source. Health systems with carbon-intensive electricity sources have substantially higher GHG emissions from energy use and surgical equipment reprocessing.[12,15,24,25] This highlights that surgical system sustainability cannot occur in isolation without overall energy sector decarbonisation.

Adaptation and resilience. Infrastructural resilience in OR building design, energy infrastructure, and water, sanitation, and hygiene (WASH) facilities is necessary for adaptation to climate extremes.

Energy reliability is a common issue in LMICs and could be exacerbated by electricity line damage during heavy precipitation and high winds.[36] Power outages have been associated with adverse obstetric and surgical outcomes,[37,38] and could disrupt the cold supply chains of essential obstetric medications.[39] Off-grid facility-based renewable energy generation and renewable energy-powered devices, such as dryers and autoclaves, could provide a win-win opportunity for sustainability and climate resilience.[40]

Safe surgery cannot occur without adequate WASH facilities. Climate extremes such as heavy precipitation, floods, and droughts could compromise water supply and quality. This risk could be reduced by infrastructural considerations, such as non-return valves to prevent backflow, sealed covers for septic tanks, locating storage tanks away from flood-prone areas, and placing vents above the flood-line.[36] Moreover, long-term water collection systems could balance water excess and shortage during floods and droughts and reduce water consumption from other sources.[36]

Building climate-resilient infrastructure involves the whole health system and may, in some cases, necessitate relocating entire health facilities from disaster-prone sites. ORs are particularly vulnerable to climate extremes due to their strict ventilation and temperature requirements.[33] White reflective roofs, retrofitting insulation, energy-efficient windows, and heat or coolness recovery devices could improve both OR energy efficiency and resilience to temperature extremes.[36,41] Climate-resilient OR building standards should be developed, particularly in tropical areas of the Western Pacific region,.[42]

Service delivery

Mitigation. Anaesthesia. Inhaled anaesthetic agents are potent greenhouse gases. Among them, desflurane has the greatest global warming potential (GWP), more than 2000 times that of carbon dioxide (CO_2), while sevoflurane is only 130 times as potent as CO_2.[13] Halothane, an anaesthetic gas essentially obsolete in most HICs, remains widely used in parts of the Western Pacific region. Its GWP has not been well studied and warrants further attention.[43]

While patient safety must be the primary driver for anaesthetic care delivery, several strategies could reduce its GHG emissions.

- Disproportionate use of desflurane has been found to be responsible for up to 80% of GHG emissions in ORs in HICs.[12,44] Systematically switching from desflurane to sevoflurane can lead to a ten-fold reduction in carbon footprint and significant cost savings.[45]
- The use of volatile anaesthetic agents could be profoundly limited by preferentially using total intravenous anaesthesia and regional anaesthesia when appropriate.[46–48] Regional anaesthesia could have

additional advantages in low-resource and hard-to-reach settings, including cost, safety, OR efficiency, and the potential for task-shifting to non-specialist providers,[49] thereby improving access as well as sustainability.

- Using low fresh gas flow or closed-circuit delivery can reduce the volume of volatile gas consumed by 20%.[45,50,51]
- New technologies, such as Dynamic Gas Scavenging Systems or silica zeolite, can absorb, destroy, and even recycle anaesthetic waste gases.[52–54]

Surgery. The mode of surgical care delivery can also alter its carbon footprint. Studies have found emissions of robotic surgery > laparoscopic surgery > open surgery.[30,55] This is primarily due to CO_2 use for insufflation and a greater number of single-use instruments.[13,56] However, studies conducted thus far have not considered the potential environmental benefit of minimally invasive surgery in reducing the postoperative length of stay or readmissions from sequelae of open surgery, such as adhesive bowel obstruction and incisional hernia.[57] Studies examining long-term environmental impact are required before conclusions could be drawn. The mode of surgery should be selected primarily based on clinical indications. Laparoscopic surgery has proven clinical benefits over open surgery in many circumstances. However, environmental impact should weigh more heavily into consideration where there is clinical equipoise, such as between robotic and laparoscopic surgery.

In terms of the location of surgery, performing minor operations, such as skin lesion excision and carpal tunnel release, in a clinic setting where appropriate could reduce GHG emissions associated with maintaining an OR environment and improve service access when ORs are unavailable.[47]

Travel-related emissions. In HICs, innovative service delivery models such as telemedicine and mobile outreaches have been found to reduce GHG emissions from patient travel while offering more accessible, patient-centred care.[58–60] In LMICs, improving district-level surgical care capacity could reduce referrals to higher centres. Overall domestic surgical system strengthening could reduce the number of overseas medical referrals and specialist visits, particularly in Pacific Island Countries. The environmental benefits of both strategies could be speculated but are yet to be quantified.

Adaptation. Not only does surgical care delivery impact climate change, but climate change could also increase the burden of diseases requiring surgical care.

Direct impacts. By increasing temperature, precipitation, and extreme weather events, climate change can increase the incidence, range, and complexity of infectious, non-communicable, maternal, and neonatal conditions requiring surgical care (Table 1). This calls for surgical system strengthening as a part of climate change adaptation in response to the increasing burden of diseases requiring surgical care.[42]

Natural disasters. Among the direct effects of climate change, extreme weather events are of particular relevance to the Western Pacific region. Climate change is

	Surgical disease categories			
Climatic variables	Infections	Non-communicable diseases	Trauma	Maternal and neonatal conditions
Increase in temperature	Necrotising vibrio skin infections[61–64] Schistosomiasis causing bladder cancer[65] Fungal sinusitis[66] Sinusitis[67]	Skin cancers[68–72] Kidney stones[73–75] Testicular torsion[76]	Road traffic accidents[77,78] All categories of injury[77]	Pre-term birth (meta-analysis of 47 studies[79]) Stillbirth (meta-analysis of 8 studies[79]) Low birth weight (systematic review of 28 studies[80]) Pre-eclampsia[81,82] Premature rupture of membranes[83] Congenital heart disease[62]
Increase in precipitation		Acute glaucoma[77] Kidney stones[75]	Road traffic accidents[84]	Pre-term birth[85] Low birth weight[85] Pre-eclampsia[86]
Extreme weather events			Bushfires – Burns[87] Flood/storms –injuries[4,5,88,89]	

***Table 1*: The potential direct impact of climate change on diseases requiring surgical, obstetric, anaesthesia, and trauma care.**

expected to increase the frequency and severity of extreme weather events throughout the Western Pacific region, such as floods and cyclones in Asia and the Pacific, and droughts and bushfires in Australia.[7,68,90,91]

Strengthening domestic surgical care capacity in LMICs is critical for mounting a rapid and effective disaster trauma response. Studies found that foreign field hospitals were rarely deployed early enough across LMICs,[92,93] whereas local surgical responses, such as after the 2008 Sichuan earthquake in China, have been effective in averting disability-adjusted life years (DALYs) and economic loss.[94] However, the availability and quality of surgical services at the district level have been found to be a critical gap in the health system response to extreme weather events in Vietnam.[89]

There is increasing recognition that disaster trauma response should not be an isolated vertical intervention but rather integrated into the broader surgical system. Surgical needs after sudden-onset disasters have been widely documented to include not only traumatic injuries but also non-traumatic emergencies, such as Caesarean sections and hernia repairs.[88,95,96]

Significant synergy exists between emergency trauma response and routine surgical system strengthening.[94,97] For example, when not deployed, the Fiji Emergency Medical Assistance Team (FEMAT) is integrated into routine surgical service delivery by providing outreach surgical services in district hospitals. This strengthens both first-level hospital surgical capacity and keeps FEMAT in a state of constant readiness for deployment.

During the COVID-19 pandemic, the versatility of surgical systems has become apparent as ORs, surgical supply chains, and human resources have been converted to provide critical surge capacity worldwide.[98] As countries battle climate-induced natural disasters during the COVID-19 pandemic, the need for surgical system strengthening as a part of multi-hazard emergency preparedness and overall health system resilience is ever more highlighted.

Indirect impacts and co-benefits. Climate change could have complex and interconnected impacts on surgically treated diseases and surgical complications in the Western Pacific region through changing physical, social, and economic environments. For example, drought and saltwater intrusion could impair access to WASH and increase the risk of surgical site infections.[91,99] Food insecurity could lead to both malnutrition and non-communicable diseases and increase the risk of peri-operative complications.[100]

The potential co-benefits of climate change mitigation and surgical disease prevention should be explored. For example, active and public transport could reduce GHG emissions and road traffic injuries requiring surgical care.[68]

Workforce

Mitigation. Educating SOA providers on sustainability has been found to reduce the carbon footprint of their clinical practice.[45,101,102] Focused educational initiatives have been successful in reducing OR waste production by 50% and GHG emissions from anaesthesia care by 64%, and generated cost savings in HICs. [45,51,103–105] Beyond dedicated educational sessions, the literature also recommends embedding climate change into continuous medical education and routine training curricula.[28,101,105,106] Successful education programs have used personal narratives for emotional appeal and targeted the multi-disciplinary team.[105,106] They have integrated environmental stewardship with patient outcomes and cost savings to emphasise the triple bottom line of people, planet, and economic benefit. [45,51]

Beyond changing individual practices, SOA providers have a powerful voice in advocating for institutional and societal changes, such as hospital procurement, industry equipment design, and governmental mitigation targets.[102,107,108] SOA providers have a track record of successfully influencing policy in seatbelt and helmet use for trauma risk reduction. They have a responsibility to do so again with climate change.[109] Professional engagement in climate change has been an area of significant progress in the global effort to combat climate change within the last decade and should continue into the future.[110]

Adaptation. Increasing temperature due to climate change could reduce workability in many parts of the Western Pacific region.[9] This most significantly affects outdoor workers and labourers. However, indoor hospital spaces for surgical care, such as gynaecology scanning rooms, have also been found to be affected.[111]

The work performance of SOA providers could be compromised if OR temperature regulation mechanisms are overwhelmed. Hot temperatures can impair surgeons' performance by decreasing manual dexterity and increasing self-rated physical demand and frustration levels.[112,113] Although OR air-conditioning systems provide an effective means of climate change adaptation, they could paradoxically worsen climate change and harm health through energy use and air pollutant production.[68,110] The energy-efficient OR building design considerations aforementioned in the infrastructure section could also reduce air conditioner use and improve workability.[41]

Information management

Health information system

Firstly, environmental sustainability should be incorporated as a key performance indicator for surgical systems in addition to the six LCoGS indicators.[1] As healthcare access and quality improve in LMICs, GHG emissions are expected to increase. However, the positive correlation between healthcare quality and GHG emissions ceases after a point. Beyond 500–600 kg of carbon dioxide equivalent (kgCO_2e), additional increases in per-capita healthcare emissions are not associated with improved human development index anymore.[3] Therefore, emissions per procedure should be monitored and reported at the individual, departmental, facility, and national levels to drive quality monitoring and improvement towards sustainability.[51]

Secondly, a lack of information has been cited as the main barrier to sustainable practices.[102] Life-cycle emissions of equipment and medications should be made readily available to inform clinical practice and environmentally preferable purchasing decisions. Solutions suggested include displaying emission information on product packaging and in mobile applications.[45,101]

Thirdly, meteorological data should be linked with surgical data to examine the impact of weather variables on surgically treated diseases and surgical care outcomes.[68,110,114] They could be coupled with disease-specific registries or existing efforts to monitor peri-operative complications, such as peri-operative mortality as an LCoGS indicator.[1] Quality data are notably lacking in disaster response.[93] National databases on extreme weather events and surgically treated conditions should be maintained.[115]

Research

Most of the studies included in this review have been conducted in HICs. Aside from a few well-researched areas, such as heat-related birth outcomes and anaesthetic gases, the evidence on this topic is still limited and dominated by commentaries and opinion pieces. There is a need for more research on this topic in the Western Pacific region, particularly from LMICs. Future research could follow three directions below:

1. *Reporting and tracking emissions from surgical care:* The GHG emission profile of surgical procedures are highly context- and procedure-specific. Results from one facility or country may not be readily generalisable to another. There is a need for LCAs across more facilities and procedures in the region to identify locally contextualised solutions for emission reduction. Whilst LCAs can be highly resource- and labour-intensive, top-down regional and country-level modelling could be combined with bottom-up process-based analyses of a representative sample of countries, facilities, and procedures across sub-regions and income levels.[32]
2. *Modelling the impact of climate change on surgical care provision.* Surgically treated diseases have, thus far, not been well covered by studies on the health impact of climate change.[78] Very few studies have modelled the long-term effects of climate change on the burden of surgically treated diseases to inform future surgical system design.
3. *Identification and sharing of innovations.* Sustainable SOA care can be achieved by low-tech and no-tech innovations, such as outreach services, and high-tech innovations, such as volatile anaesthetic agent scavenging and recycling.[52] For example, by adopting a range of measures to maximise OR turnover, Aravind hospital in India was able to provide cataract surgery at 5% of the emissions in the United Kingdom.[116] There is a need for SOA providers to work together with scientists and the industry to develop technological innovations, such as solar-powered devices.[40]

Finance

Strategies to reduce emissions in SOA care often have significant financial co-benefits. Despite the upfront cost of capital purchases, studies have demonstrated substantial long-term cost savings from measures, such as improving building energy efficiency, reprocessing instruments, anaesthesia gas scavengers, and telemedicine.[15,24,26,51,52,59,60] The results of life-cycle economic and environmental analyses must be taken into account by hospital managers, donors, and financial mechanisms in supporting sustainable infrastructural upgrades.

Costs saved could directly benefit individual patients. For example, telehealth services could mitigate financial risk arising from out-of-pocket expenditures for transport.[59,117] Financial risk protection will be increasingly indispensable to surgical system strengthening as poverty, resource uncertainty, and inequity are predicted to increase with climate change.[2]

The importance of surgical system strengthening in climate change mitigation and adaptation should be recognised by funders, bilateral and multilateral agencies, financing mechanisms, and philanthropic organisations. Currently, only a very small proportion of the available climate change adaptation funds has been allocated to health-related programs,[110,118] even less to surgical care.[89] Such funds could be mobilised as an additional source for surgical system strengthening.

While foreign field hospitals in natural disasters have attracted a lot of international attention and resources, their effectiveness and accountability have been questioned.[92,95] Disaster relief funds could be channelled into baseline surgical system strengthening as an effective and sustainable means of providing an emergency trauma response.

Governance

Facility level. Beyond changing individual clinician practices, institutional practices in procurement, energy use, and service design should be shifted towards sustainability.[45] Environmentally preferable purchasing policies should be developed to guide sustainable procurement decisions.[119,120]

National level. Strategic planning in surgical system strengthening, climate change mitigation and adaptation, and disaster risk reduction should be closely integrated.[103,121] Collaboration between multisectoral stakeholders is required for a health-in-all policy approach.

Regulation and policies should facilitate sustainability where possible. For example, SUD reprocessing can lead to environmental and cost benefits and is increasingly used in both HICs and LMICs.[28] It is prohibited in many countries despite being shown to be safe in approved contexts.[122] With more evidence being generated in the future, regulations could be updated to delineate the appropriate parameters around its use.

Private sector engagement is indispensable due to its role in surgical device research, development, and manufacture. Sustainability in the surgical device industry could be shaped by governments through funding, regulation, and incentives, and by clinicians through advocacy and lobbying.[101,108]

The participation of diverse stakeholders, especially civil society and service users, could be facilitated through consultative processes indigenous to the Western Pacific region, such as the Talanoa Dialogue launched by Fiji at the United Nations Climate Change negotiations.[123]

International level. Although there has been an accelerated focus on surgical system strengthening in LMICs, HICs in the Western Pacific region also play an important role. HICs produce substantially more GHG emissions from surgical care than LMICs. For example, emissions from minimally invasive surgery alone in the United States are estimated to be higher than the gross national emission of some countries.[56] HICs in the region have both the responsibility and the ability to make a significant contribution to climate change mitigation by transforming their surgical systems.

Discussion

We conducted a comprehensive narrative review and outlined policy recommendations for integrating climate change perspectives into surgical system strengthening in the Western Pacific region. Not only must climate change mitigation be an essential consideration in the regional surgical care scale-up, but surgical system strengthening is also necessary for climate change adaptation and disaster preparedness. As countries in the Western Pacific strengthen their surgical systems, they have a unique opportunity to reimagine and redesign sustainable and climate-resilient surgical systems with co-benefits for the environment, finance, and service quality, pioneering a path for the region and beyond.

Previous reviews have been conducted on climate change and surgical care; however, they primarily focused on HICs. Our study is one of the first to incorporate LMIC challenges and perspectives. This is important as countries in the Western Pacific region span a range of income status. Moreover, previous reviews have mostly focused on sustainability in clinical care provision, whereas we examined the implications of climate change for the broader surgical system across all health system domains.

The strength of this review is that it provides a comprehensive overview of a large body of literature on a novel and important topic. Our search strategy was extensive but not exhaustive due to the expansive and interdisciplinary nature of this topic. Poor data availability and inconsistent quality of evidence, particularly from LMICs, limit our recommendations. Moreover, the recommendations outlined in this review are not one-size-fits-all. Results from one country may not be readily generalisable across the whole region due to diverse social, economic, geographical, and cultural contexts. Our study provides a framework for approaching the integration of climate change into surgical system strengthening. Strategies for doing so must be locally contextualised to each country and facility.

There is an imperative for more research from diverse settings across the Western Pacific region to identify strategies and innovations for climate change mitigation and adaptation in surgical system strengthening in each context. The number of publications on this topic from the Western Pacific region should be monitored by country, sub-region, and income status to encourage diverse representation.

Considerations of climate change mitigation and adaptation must be integrated into surgical system strengthening in the Western Pacific region. The time to act is now as climate change has already become a part of our reality. Even modest reductions in global warming will avoid serious incremental increases in climate extremes.[7] As we plan to build back better from the COVID-19 pandemic, there is a unique and critical window to create sustainable and resilient surgical systems to face the larger climate crisis.

SOA providers have a track record in effecting successful public policy changes for surgically treated diseases such as trauma prevention. As the IPCC sixth assessment report declares a code red for the planet,[7] SOA providers have the responsibility to urgently attend to this ‘trauma call’ and lead the advocacy for climate change mitigation and adaptation in surgical system strengthening and beyond.

Declaration of interests
The authors declare no conflict of interest.

Contributors

RQ, LV, EFY, OE, and CDM conceptualised and designed the study with input from AW. The literature review and screening were performed by RQ and LV. Input on additional literature sources was provided by JT, LS, EM, and AW. RQ, LV, EFY, and OE extracted and analysed the study data. RQ drafted the manuscript. LV created the figures. All authors contributed to data interpretation and manuscript review and editing. All authors read and approved the final manuscript, and agreed to be accountable for all aspects of the work.

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Consent for publication

All authors approved the final version submitted for publication.

Data sharing statement

All data analysed in this review are included in the references and the Supplementary materials.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.lanwpc.2022.100407.

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