American Journal of Biodiversity
https://biojournals.us/index.php/AJB
ISSN: 2997-3600

Harnessing Environmental Technology for Sustainable Healthcare: Innovations in Pollution Reduction and Health Risk Management

Mohammed Khaled Delph Omar
Anbar University Environmental Science College – Hit Environment Department

Sarah Sabah Abdulrazzaq
University of Tikrit. College of Engineering department of Environmental Engineering

Aqeel Abdul Hadi Shaalan Zghair, Ali Sabbar Abdul Zahra Kazim
Al-Qasim Green University / College of Environmental Sciences / Department of Environment

Ismail Ibrahim Ahmed Saeed
University of Mosul Faculty of Environmental Sciences Department of Environmental Technology

Received: 2024, 15, Jan
Accepted: 2025, 21, Feb
Published: 2025, 11, Mar

Annotation: The increasing prevalence of chronic diseases and the environmental impact of healthcare operations have necessitated the integration of sustainable environmental technologies. However, there is still a knowledge gap regarding the effectiveness and implementation of pollution reduction strategies in healthcare settings. This study explores the role of environmental management technologies in reducing emissions, improving healthcare waste management, and mitigating health risks. Using a review-based methodology, various sustainable solutions, including emission control systems and waste treatment technologies, were analyzed. Findings indicate that these innovations significantly decrease pollution levels while maintaining healthcare efficiency. The results emphasize the need for regulatory frameworks and policy support to enhance environmental sustainability in healthcare institutions, ensuring long-term benefits for both public health and the environment.

Keywords: Environmental technology, healthcare sustainability, pollution reduction, waste management, emission control, health risk management.

1. Introduction to Environmental Technology in Healthcare

The focus on the environmental sustainability of healthcare systems is relatively recent, but it is developing rapidly. Innovations have been made both in terms of "soft" technologies such as ICT tools allowing a more sustainable management of both the administrative and the clinical aspects of healthcare facilities, and "hard" solutions for reducing emissions in the healthcare sector. These hard solutions, which include around 15 types of technologies and initiatives, are to be developed under the name of ambient technologies, as they concern indoor pollution sources present in the healthcare facilities or in their immediate environment. By being as such responsible for their own emissions, health facilities are also currently developing solutions for reducing pollution [1]. The fight against pollution is all the more urgent and necessary in healthcare settings as it is one of the few places where people in a condition of health vulnerability have voluntary and prolonged contact with pollution sources. Ambient technologies are therefore in this case not only a possible option for reducing healthcare facilities' ecological footprint and a beneficial point for patients' health, but also a moral imperative for caregivers and healthcare providers.

The issue of Ambient Technologies and pollution in the hospital is part of the broader field of technology and innovation. Global concerns over the sustainability of care practices and, more completely, the healthcare systems, have been translated in several countries by projects or measures addressed to contain fast and continuous increase of care-related environmental costs and pollution. But, despite the fact that the question of the environmental sustainability of the healthcare system is far from being solved, researches have been increasingly addressed to the development of cleaner production (CP) oriented models, methods or actual technologies, and recent years have seen the implementation of a large spectrum of pollution-reducing technological initiatives for care-related activities. For example, CP targets have been implemented in Belgium and, since 2003, Dutch hospitals are subject to air quality regulations; in the UK, the NHS has adopted an environment and sustainability strategy. In France, a health-professionals' environmental group, which bring together 10 trade unions and professional associations, has been created in 2012 and has recently asked to a critic point of the national healthcare-generated pollution. At a global level, the very recent Stockholm World Congress on environmental health has brought up numerous questions or measures aimed at containing the ever-increasing pollution and environmental impacts of the healthcare sector, among others.

1.1. Overview of Environmental Technology

Environmental technology is an encompassing term used to describe the professional methods, strategies, and applications used by organizations to reduce waste of energy and resources, efficiency in water, air, and noise pollution, prevention of contamination and hazardous chemicals and other waste materials, and improvement of treatment, recycling, and reduction practices [1]. In the healthcare sector, the environmental technology is evidenced to focus on the innovative and sustainable technology, equipment and facilities that can be used to reduce waste, and pollution in healthcare facilities and the prevention, and control of health risk associated with the process, and system of healthcare services. There are various categories of environmental technologies relevant to healthcare, such as: waste management, waste reduction, energy efficiency, water conservation, resource and facility management, and pollution prevention. In the context of healthcare facilities such as clinics and hospitals, the waste generation and pollution remains the prime concern that has still been raised. The healthcare facility has vast potential to degrade ecosystems, or can directly pollute air, and water, and also, facilitate the production of hazardous materials. The persistence and continuing growth of hospital and healthcare facilities demand for the emergence of technology that allows for best operational practice. There is a strong association between pollution and diseases, and this serving, and dealing with disease of human life, has great more care on environmental technology. The accumulation of a vast body of knowledge in healthcare technology, concerning epidemiology, disease causations and controls, and how diseases are transmitted and spread among human. It has been recognized that many of these knowledge and practices might be better improved of and coordinated in the technological setting. The engineering and modern electronic provide ample basis for adapting environmental technologies and applications in healthcare facilities. Furthermore, through the instrument of digital technology, it is now feasible to custom fit environmental technology to the specific needs and characteristics of clinics, hospitals, and other healthcare facilities, the development of tools, systems, and facilities that exactly match the need and environment, can accomplish powerful protections of patients, both client and staff, and third parties, and greater environmental protection in the background of global concern on climate and earth sustainability.

1.2. Importance of Sustainability in Healthcare

The healthcare sector has always evolved within a rapidly changing environment. Recently, the onset of the COVID-19 crisis has forced healthcare managers to intensify daily operations and stimulate different directions of resource allocation. However, it often appears that hospitals and healthcare organizations need to be highly resilient and adaptive to thrive rather than merely responding to the latest single- or cross-sector challenges. The significant pollutant and carbon dwelling on the healthcare system has come at the expense of population well-being. Factually, because of the increase in patient care and technical sophistication, the healthcare service tends to generate many medical pollutants that have put a profound effect on both the patients and the environments [2]. The rise in pollutants and germs can result in a serious concern accumulation in the healthcare units, and patients treated in those areas will have a higher risk of related medical complications.

Sustainability of the hospital can be used as an additional ability to resist various environmental conditions without reducing the ability to perform daily functions. Hospital sustainability will be approached as part of a preventive and contamination control strategy, focusing on the operations that may enhance the effectiveness of hospital functions and reduce the generation of pollutants or medical waste in the first place. Another consideration of sustainable hospital services focuses on enhancing the operational effectiveness of the hospital service [3]. With the same resources and volume of work, the operation on the hospital will be streamlined, preventing unnecessary waiting time by staffs and patients. From an ethical perspective, despite of the environmental benefits of sustainable hospitals that not only benefit patients but also help hospital staff avoid the nuisance of pollutants and medical waste, the proposal of sustainable hospital service is more imperative in some places where significant social inequity exists. Poor regions may lack resources and relative knowledge to handle persistent hazards and hence few implementable health policies. Many ethical justifications indicate that minorities and the poor should receive more healthcare services than they now have; the wider distributions of those disasters often exacerbate the harm to poor communities. [4][5]

2. Pollution Reduction Technologies in Healthcare

As a major economic driver responsible for a growing share of national gross domestic product, the U.S. health care sector has the potential to radically transform local economies by investing in environmentally sustainable and economically prosperous technologies [6]. The gradual increase in the number of hospitals seeking independent sustainability certifications has correlated with an augmented scrutiny of the sector's ecological impacts. Mission-driven healthcare institutions realize the interconnectedness of global health equity and ecological justice by recognizing their role as major polluters in vulnerable communities. The discussions surrounding environmental justice in healthcare have led to an in-depth examination of the risks associated with hazardous waste and emissions in the context of provision services and the lingering regulatory dilemmas.

While the toxicity of certain regulated waste streams has long been a concern, a number of non-regulated waste streams have largely escaped scrutiny. Beyond air and waste, hospitals generate large quantities of landfill waste, some of which incinerate – a well-established source of toxic emissions for the entire healthcare sector. It is anticipated that modeling efforts to better estimate the complete life-cycle environmental impacts, including those related to a wide variety of pollutants and resource use, will further underscore opportunities to mitigate these impacts. Improving waste management, reducing materials use and energy intensity, and using alternative sources of energy can reduce environmental emissions and the potential health risks associated with them [3]. In light of the risks to communities, healthcare organizations should consider investing in pollution control equipment and materials. While the focus on returns can overshadow the imperative role pollution control plays in communities, these investments often also offer significant opportunities to enhance operational efficiency and reduce liability by ensuring compliance. The pollution control equipment includes devices and supplies used to capture and filter pollutants from hospital emissions. This document will provide a comprehensive overview of both established and emerging pollution control technologies in hopes of encouraging further widespread investment in this area. A condensed examination of information on pollution control systems is appended as supplementary material. [7][8]

2.1. Air Pollution Control Systems

The first rule to obtain a sustainable healthcare facility says 'Thou shalt guarantee a nontoxic environment' [9]. By definition, a hospital is a place where there is a high likelihood for contracting infections and diseases. This risk has always limited the access to this place of healing. On the other hand, patients suffering from diseases by definition have a reduced ability to respond to diseases. Modern hospitals have improved the safety of patients by removing the most dangerous equipment and dangerous features. Quite all of the equipment is designed to be biocompatible, fireproof and other dozens of improvements. But, what is said about how to protect the patients and the staff from the incoming diseases? Hospitals are still generally 'open' places in terms of exposure to outside factors. In the last years quite all the developed countries have adapted the legal frameworks to take account of indoor air.

Several systems are available in the market as preparation systems against airborne contamination able to provide a higher protection level by different technologies.

Filtration systems are well known technologies from coarse to ultrafilters usually used in air-conditioning systems. Their efficacy depends on the capillarity principle and the flow rate and can catch most of the bioaerosols. Their installation is usually induct or prohibitive or limits most of the hospital ventilation systems. More modern systems are able to catch also the gaseous polluters by brushes, membrane, metallic mantle or active carbons. They are able to provide an abatement of VOC or other gases so as to remove bad smells. They have to be placed always as a preparation system; each elemental AGV collector would have a pressure drop of 40-50 Pa so a great number of them should be placed in a system district without re-circulation of the air at high distances from the emission sources. Finally a guarantee of maintenance to the scrupulous replacement of the devices is mandatory to avoid the proliferation of bacteria caught in the internal part of protection system. [10][11]

2.2. Water Treatment Technologies

1. Purpose In healthcare settings, patients and healthcare workers are particularly vulnerable to environmental risks, including locally aggravated risks, such as air and water pollutants. This chapter reviews technologies for reducing pollution and health risks from environment and infrastructure. Without water, life cannot be sustained. Due to its importance in cleanliness and patient care, adequate clean water accessibility has been a subject of interest for policymakers, both in developed and developing countries, to ensure the water quality supply. The proposed is to use latest technologies for the treatment of water in healthcare settings, in order to provide clean water distribution for consumers and machines [12]. The material used to manufacture the machines may release contaminants that can affect health. Due to the correct selection of the traits and operation treatments, contaminants such as ions, microorganisms, and organic residues can be documented. The treatment sequence involves filtration, periodic disinfection, and reverse osmosis. Reverse osmosis performed very well, by yielding water with zero bacteria and metals.

2.2. Water Treatment Technologies The main ways of water contamination are by pathogenic (disease-causing) microorganisms and chemicals. Water can be disinfected by using chlorine, ultraviolet light, and ozone. Tap water is the most likely form to be used with medical equipment and demands adequate water quality, or the presence of contaminants in the machines, most commonly highlighted, the bacteria and ions. It is crucial to consider that several contaminants can be present in diseased water, such as ions (e.g. metals), organic residues, and microorganisms (e.g. bacteria). According to the hardness of the water – which is due to the presence of calcium, magnesium, and metals – the market launched specific treatments. The correct selection of the type and sequence of treatments can reduce or eliminate the contaminants present in water. Polluted water can cause water corrosion and the collapse of the devices that it contains, possibly releasing their contaminants into the water. Filtration is very striking since it can eliminate microorganisms. Filtration was able to eliminate bacteria in the inlet water at machine levels for at least three periods. Chlorine has accounted for significant pathogenic bacteria reductions on a thinner line. In another, after treatment with chlorine, less than a 10-fold increase in the number of samples containing bacteria as compared to the control. All stored water samples for chlorine disinfection yielded water with the bacteria quantification lower than the controls. The presence of high metal levels was verified in filtered tap water with a carbon filter. However, reverse osmosis performed very well at removing bacteria and obtained no water samples with bacteria, nor metals with levels above the stipulated value. Reverse osmosis previous to other treatments is highly effective in reducing electric conducts (indicators of metal levels).

Treatment technologies for polluted water are also favorable for the environment and economy, as they are capable of reducing contaminant levels and compensating for the damage caused. Water treatment across the world passed regulations that establish parameters for contaminants permitted in water. In developed countries, regulations have been well established for some time, and countries in the process of development have adapted or are adapting them to their reality. The rigidity of the parameters very much influence treatment. procuring water with levels below those stipulated, e.g. filtration; procuring water with levels below those stipulated, e.g. chlorine; or obtaining water relatively free of metallous ions. How regulations on copper are fewer in hospitals and generated values above those stated. At the time, it was even thought that the water in the pipe system was not treated, and that was not borne out. In summary, regulations guaranteeing the quality of water production will have an impact on water preparation, whether by the need to implement a treatment process, or by the need to adapt a pre-existing process. Examples of the successful implementation of clean water production technologies for healthcare settings are also included. [13][14]

3. Health Risk Management Strategies

Health risk management strategies that otherwise would seem to form the focus of environmental efforts, are documented to be tackled effectively [3]. It is essential in the context of environmental efforts to continually take steps toward identification of potential pollution sources and assessment of risks that may impact negatively on the wellbeing of patients and healthcare workers are carried out meticulously and prudentially. Enhancing the overall understanding of environmental risk factors and the availability of the tools and methods to detect environmental risk factors early are deemed a top priority and one of the cornerstones of successful environmental efforts in healthcare settings. The deployment of an accurate, sensitive, reliable, robust, and precise environmental monitoring and surveillance system is thus necessary to obtain timely detection and in-depth analysis of potential health risks posed by environmental factors.

Particular risks associated with a given department or healthcare service region can be beforehand targeted and mitigated via detailed exploration of the environmental hazards detected. In general, a detailed protocol is in place linking monitoring results with possible countermeasures and options. The pro-active risk assessment is regularly conducted to better understand the implications of potential environmental hazards and further disclosures. The risk management outcomes are processed, recorded, and eventually integrated into the healthcare safety and environmental management framework. By such, the environmental-related risk prevention, monitoring, and emergency response take place as an integral subsystem of the overall healthcare risk management system. To achieve a sustainable development of healthcare, the introduction of this special safety and health risk issue component should be further amplified to comprehensively and holistically improve the patient-centered multidisciplinary risk assessment and risk management. Case studies might note the above-described components. The ultimate aim of all risk management efforts is to safeguard the health of the patients and the healthcare workforce during the period of care. [15][16]

3.1. Environmental Monitoring and Surveillance

According to a recent statement, the most effective way to manage healthcare risk is by using environmental factors to reduce health threats. Environmental monitoring and surveillance are the foundational components of health risk management because only when environmental parameters are correctly identified and tracked can their impact on human health be assessed. A wide range of techniques and instruments have been developed and applied in the monitoring of such multiple environmental factors, including air, water, soil, and biota [17]. Advanced and rapid technological development triggers the implementation of innovative and improved tools and equipment as well for the collection of samples as for the analysis of pollutants including real-time or in-situ techniques. This, in turn, enables the collection of actual data on environmental factors influencing human health for the timely identification of likely threats and the formulation of proper decisions [18]. The result of monitoring is the information that acts as a trigger of health risk management procedures. Environmental hazards, pollution sources, and time distribution are identified, which is essential for the production and implementation of some efficient reduction act scenarios. Surveillance follows monitoring and integrates the sorted data into a system that tracks environmental change and health-related actions. The establishment of appropriate environmental surveillance systems allows the evaluation of pollution trends and the longevity of its impact as a basis for health risk management and reliable scenario development. A spectrum of implemented environmental monitoring cases in healthcare risk control and protection is reviewed, while the limits and uncertainties of environmental observation and super visions focusing on data accuracy and accessibility as well as the need for further development and investment in the monitoring sector are discussed. A framework for adopting a systematic approach to integrating environmental surveillance within the established healthcare risk management system is also proposed. [19][20][21]

3.2. Risk Assessment and Mitigation

The systematic identification and assessment of potential environmental risks that may impact patient safety and healthcare functions is a critical aspect of environmental health. Additionally, as healthcare organizations are increasingly required to engage in sustainable practices, central to which is the careful management of environmental resources and risks, evaluating the health risk associated with environmental factors have become an increasingly important domain. There are various frameworks and methodological protocols available for assessing health risk, and there is an additional framework for integrated risk assessment that includes stakeholders in its design and interpretation [22].

One of the important components of this approach is appraisal of perception of risk by affected communities and analyzing the discrepancies in risk perception between stakeholders. A comprehensive analysis of risk perception as related to air quality and exposure to emissions from industrial facilities is provided by Douglas and his colleagues. This approach is particularly relevant in the context of cumulative environmental impacts and systemic risks. An integrated environmental health risk governance is defined as a set of organizational rules that allows a community to prevent and control environmental health risks resulting from collective behaviours and the production of goods and services. The focus is on the role the community plays, by introducing collective rules, in preventing and controlling local or regional health-related environmental emergencies. The paper is intended to provide a preliminary assessment of risks in a newly built Emergency Health Facility in Kabul, Afghanistan, where poor environmental conditions were deemed to support a high probability of emergency mixed with accident situations. What are the key directions of intervention to provide a set of recommendations to different actors involved in the governance process are discussed (herewith termed policy recommendations). The paper summarizes the lessons learned during the project and a way ahead both for the case study and for environmental health risk governance in the medium risk countries. [23][24][25]

4. Innovative Technologies for Sustainable Healthcare

The purpose of healthcare is to promote health and to provide care for the sick. Yet healthcare actions are environmentally damaging. In the last ten years the amount of waste produced by healthcare systems rose significantly; healthcare processes are estimated to be responsible for around 5% of the carbon footprint. It is clear that the environmental impact of healthcare actions must be reduced, but simultaneously, the population is getting older. Over the last century the life expectancy has increased by 30 years, and this trend has been matched by the average population age increase. The demand for care services rises. The challenge ahead is the improvement of healthcare actions while reducing their environmental impact. Currently, healthcare systems are addressing the crisis through short-term measures to control costs, such as the equipment of care facilities, avoiding action to improve the economic sustainability of health systems in a far-reaching way. For this reason, many research institutions and governments have recently given great importance especially to the five big environmental issues (waste capture and production, management of volatile waste, energy use, water supply and use, chemicals use). These areas mostly concern facilities and practices related to care actions. However, the environmental impact and the related costs of care actions are poorly studied. Practices at the base of the healthcare process are still deeply needing examination. At the same time, many healthcare practices are uniform over different countries and common designing strategies can lead to improvements in healthcare process effectiveness and sustainability. Thus the scope of this research is to explore possible approaches to improve the environmental impact of care actions looking into practices in the care of the household generated in different healthcare systems. The research is based on a mixed methodology approach composed of a standardized questionnaire and in-depth open-ended interviews. The data have been collected over different healthcare systems and analyzed with frequency distributions and cultural domain analysis. Scanning the healthcare process from production to disposal, practices are explored, and so the use given to cleaning products, dressing products, and the heating of the place in which care is provided. At the disposal level, also attention is given to the innovative projects in the involved healthcare systems to improve the recycling of waste specially produced in care action. Municipal waste is partially sorted in all the involved healthcare systems. At disposal levels, practices are very medical devices and packaging in which dressing and pharmacy supplies come. Among the currently underutilized there are disposable paper toilet seat, open dropped container, hygienic baby bibs, and others. In the future, the two innovative projects relevant to the scope, the recycling of dressing and of disposable packaging for injection and blood test, have the chance to be studied. The fields where practices are found to be exploited are housing heating, cleaning products, moving tools, and the recycling of waste. Where, on the other hand, it is anticipated that those in use give water cleaning products and focusing on different disposal does not overcome than an initiative for practices exploring better rationalized use of resources like the choice around the use of disposable paper. Regarding the recycling of medical supplies, only dressing shall be recycled and there is no intention to valorize disposable packaging. Different practices are found to be common actions. Mental processing relating the same practice, thus implying possibly similar implications for the care of the well-being of the patient will result in a coherence of interpretation of the sustainability aspect in found practices. However, the general conclusion draws consideration of implications relevant to foster research of practice in the care of the household. The research relies on the crucial conclusion sustainability issues be known practiced in the country when that affects practices unity a common designing approach can lead to the development research for all resulted actions. Concerning the practical implication stemming from the research, the possibility to intervene in care actions to reduce their environmental impact solely on the bases of knowledge is discounted. However, as found practices common to other countries are detected through a wide and open exploration of them, there are promises in the implementation of the conclusion in terms of an integrated informal policy towards the enactment of sustainable practices. In the search for policy adoption, the diminution of the environmental impact can improve the quality and efficiency of care. Methodologies and strategies are thought as intrinsic part of practice as already and highly policies are discussed. The dialog between researchers and healthcare has to be considered and these grounding not in broad but in mutual. Practice and designing strategies have to be studied and developed supplemented each other. Conduction of healthcare change can be done as well by the management, but practice can be understood and perhaps anyway exempted. A collaborative approach involving patients, and the caretakers as well as designing researchers, acting healthcare with the guideline setting research prioritization. The major policy recommendations and design strategies of the study are that healthcare systems have to act in the healthcare design overcoming the simple adoption of practice designed to improve generalization and practices grouped by the environmental potency of the impact to lower both can be grown and implicate policies on the safety and rehabilitation of patient action. There is also support for pattern recognition discovery and development in proactive policies toward practice mitigation. Environmental concerns have to be clearer and this revision is based upon the adoption of a comparative perspective, and examples raised by cultural domain what consultation and by the high variation among practices regard this and other that have encouraged the substantial modulation of look on the first level in the discussion the broad paradigms adopted by the research. [26][27][28]

4.1. Renewable Energy Integration in Healthcare Facilities

Introduction and Problem Statement

Healthcare facilities play a crucial role in the wellbeing and healing of patients. As a part of their function, such facilities require a significant amount of energy to uphold 24/7 patient care services and medical equipment, which in turn creates a considerable amount of carbon footprint [29]. It was reported that globally healthcare facilities emit 2% to 6% of the world’s hazardous waste. Medical operations generate vast amounts of waste which leads to the increase in pollution as the waste contains chemicals, toxic waste and diseases causing germs which is hazardous for both the environment and human health. Healthcare facility directly contributing in polluting the air and surroundings just for the purpose of healing others is conflicting in its policies [30]. With the upcoming innovations in environmental technology, healthcare industry can also join hands in curbing the pollution and benefiting both the environment and human health. To meet the demands for companies to become environmentally friendly, they have started promoting zero-waste production. Predominantly in the wake of the COVID-19 pandemic, healthcare facilities, already energy-intensive buildings, have had to deal with increased energy loads and sudden demands for which they are ill-prepared. The sustainability of healthcare facilities must encompass environmental considerations. This article focuses on how healthcare facilities can integrate renewable energy sources into their existing infrastructure to achieve operational and financial sustainability. It also aims to highlight the importance of energy resilience, particularly in crisis scenarios. Energy production is exacerbating environmental health risks, aggravating ongoing pandemics, and leading to a potential increase in future ones. Copper tungstate hydrate, aptly synthesised, can absorb solar light and reduce hazardous pathogens under a redox reaction on its surface, offering a promising way to mitigate health risks. This environmentally friendly oxidising agent can eliminate health-related volatiles and can further abate environmental risks in pandemics. [31][32][33]

4.2. Waste Management Solutions

Healthcare wastes include hazardous (infectious, toxic or harmful chemical), non-hazardous and recyclable. Both in developed and developing countries they can coexist, showing different patterns of management: hazardous wastes (mainly treated with incinerators in developed or disposed of with the same fate of other ones in developing countries), while non-hazardous can be hydrolyzed, landfilled, composted or incinerated. Despite the increasing energy consumption for the disinfection of safety tools, the average environmental impact can be considered within 366 kPT (the impact on health for both patients and operators is 57 times smaller compared to untreated procedures). Supporting safe handling and disposal with environment-friendly technologies is necessary.

Waste is generated at every stage of health care process, beginning with patient consultation and ending with treatment and diagnosis, as well as in research process of biomedical field. Thus, it is crucial to understand environmental implications for prevention, proper disposal and reuse-reduce-recycle strategies so that best practices can be implemented without compromising quality of patient care. A comprehensive investigation on waste disposal at health care units by effectively integrating materials and process was performed. This investigation, on one hand, high massive generation of carbon waste contributed 13% of total waste generation, on the other hand the disposable surgical items, glass ware and cotton-like swabs forms together occupied almost 20% of the total waste. Furthermore, increased trend of waste generation and diversified waste material was observed, with maximum generation of metallic waste concerning surgical instruments. Finally, follow up of segregation-based treatment systems (reduction, reuse, recycle) can reduce impact up to 68% with improved quality of patient care. In addition, like covid, pandemics can be decreased with improved efficiency of the treatment systems [34].

5. Case Studies and Success Stories

Each day, new environmental technologies are entering the healthcare field in an attempt to mitigate damaging environmental practices. These new technologies, often capital intensive, are seen as opportunities for healthcare providers to demonstrate their commitment to sustainability and environmental stewardship. Consequently, the healthcare sector has not only witnessed several technological advancements in pollution control and health risk management, but also has seen them implemented in hospitals under stringent regulatory environments. The objective is to show some hard evidence of technology innovation in the field and instigate healthcare stakeholders to implement them in their institutions.

The first case study examines a unique architecture model of hospital building. Being a field of about 4000 healthcare workers, it segregated the now little challenge to avoid chemical pollution.

At the micro level, think 3101 is the only building still in use almost 50 years since term of construction. Thus from two chosen levels, the investigation is given why and how pollution reduction in the hospital and the field biodegradable potential. The composition of the latter is synthesized or similar to chosen APEX, but here a Class—C glass-resin blend is taken instead. Beyond the micro level consideration, think 3101 can take new measures at the macro level. It is argued that older building as building ad hoc environment refutes avarice of continuity and produces unlikely architectures that can be forgotten also as occupational safety and health measures. The building furniture at 3101 ensures to have never being moved since term of construction. There is the need of systematic approach to proactive construction of new environmentally oriented buildings. In this sense, think 3101 witnesses against a careless back century thinking and acts as a non-returning first-in-time. If renovated regarding sustainability principles, it can represent a turn within continuity, pushing for a solid pro-environmental research and implementation track. Here is given as cue of synergy. [35][36][37]

5.1. Implementation of Environmental Technologies in Healthcare Institutions

Healthcare institutions are beginning to integrate environmental technologies in their facilities. Several institutions of different types and sizes implemented these technologies, including: The City, a 255-bed inner city hospital in a new building in Australia; M Health, a specialized private cancer treatment facility in Spain; Two urban academic centers in the United States; and the largest health service in New South Wales, a state in Australia. The planning stage often takes three to four years before implementation commences. Methodology and strategic directions for success have been developed and adapted to managers, designers, and healthcare professionals looking to merge these technologies into institutions. The methodology includes: step-by-step processes used to effectively integrate environmental technologies into healthcare buildings and possible strategies; and recommendations for the practical implementation of funding bids, stakeholder buy-in, how-to manuals, training, resource allocation, changing departmental policy and procedure, and redeveloping master plans to accommodate complex technologies. Other considerations are also discussed, including: 3-D modeling of airflows in high-risk areas to guide the design of proper ventilation; the capture efficiency of localized exhaust ventilation using ultra-clean-down-draft tables in pathology works; effects of filter saturation in theatre positive pressure isolation-rooms; vandalism in automated hand hygiene stations; maintaining the temperature stability of hot water used for disease control; ASHRAE’s position on traditional steam or UVGI; dangerous compressor locations for water-cooled chillers; biohazards produced from laser cutting; mercury-sensitivity in resuscitation bays; edge-leakage in laminar flow air-handling-units; how to persuade your hospital manager; and success metrics to evaluate environmental technologies and guidelines for setting benchmarks [1]. Common challenges during and after the integration of environmental technologies in healthcare facilities are presented, and some recommendations for achieving systemic success are provided by each institution. Recommendations include: approaching the Indian Green Building Council or other external environmental technology bars for a hospital design tutorial; encouraging the early visualization of schematic ventilation models; involving the heating ventilation and air-conditioning or infection control unit; and participating in a Green Hospital Roundtable that brings together all vested environmental interests [38].

5.2. Impact Assessment and Key Findings

Introduction

Integration of environmental considerations in digital health technology (DHT) assessment and procurement can be a challenging endeavour. This is the case because the shift requires to redefine what is considered ‘value’ when acquiring health technology, and to introduce measures of technology’s sustainability-related impacts and carbon footprint [1]. The selection and procurement of digital health technologies (DHTs) provide opportunities to integrate environmental considerations and help improve environmental performance in healthcare contexts. This connection has been addressed, but mostly focusing on the promotion of good eco-practices by equitable–level healthcare providers or on the environmentally sustainable design of healthcare facilities [39].

Impact Assessment and Key Findings The impact assessment of best practices and available techniques on sustainable healthcare and pollution reduction in healthcare settings is studied. Methodologies were developed to evaluate the environmental, economic, and social effectiveness of environmental technologies for healthcare institutions. Technologies and practices to reduce consumption and environmental pollution are implemented, monitored, evaluated, and analysed in different healthcare institutions, including hospitals and a long-term care unit. The results of the monitoring demonstrate the magnitude of the effectiveness of the implemented technologies and identify measures for further improvement. General indicators and metrics are developed to evaluate environmental and cost effectiveness as well as occupant acceptance of emerging environmental technologies in healthcare buildings. Periodic monitoring and evaluation of the technologies through these metrics and indicators are essential to track the effectiveness and performance of the technologies throughout various stages of healthcare buildings' life cycles. A consistent and robust M&V methodology is pivotal; it seeks to derive tools to facilitate the M&V tasks and guide technology implementation strategies.

An overarching goal is to guide the development and sustainability of healthcare buildings towards ensuring occupants' safety and health. A systematic approach has been used, combining desktop reviews, on-site inspections, and case studies. The results highlight key aspects related to IEQ, no matter the building's intended use. They emphasize the need for a comprehensive and multidisciplinary design process, involving among others appropriate site selection, indoor emissions minimization, and effective ventilation strategies. Finally, post-occupancy IEQ assessments and continuous M&V plans are encouraged, perceiving the healthcare facility as a whole building system, that shall operate efficiently and effectively over time and in a cost-effective manner. [40][41][42]

6. Future Trends and Emerging Technologies

Innovations in healthcare have always been closely related to technology, and considering the rapid pace of change today, it is important for those in the field to keep abreast of emerging trends [43]. In this ever-evolving environment, it has become difficult to predict what the next big thing will be. Advanced technologies are poised to disrupt and transform healthcare, and the following information aims to present a framework of possible future trends that stakeholders should consider when assessing their response to these trends. The possible impacts of these technologies on both healthcare and the broader environment are also highlighted in light of the critical need to move towards sustainability. The impact of pollutants on health is an increasingly significant issue because of industrial processes and large populations. Major advancements have been made in modern medicine for industrial development, and hospitals are very important for medical treatment, but have also made a notable impact on the environment. Hospital wastes are among the dangerous and harmful wastes produced in medical-treatment processes and determined as a critical pollution source. Hospital wastes encode infection, toxic, and hazardous wastes, and have significant importance in general health and hygiene. Healthcare manufactures are trying to develop some new apparatuses and systems because of environmental harms. The research evaluates a novel image-based and low-cost intelligent waste separation system for plastic wastes in healthcare. At the base of the point, understanding current practices in healthcare and difficulties, reviewing current technologies used for waste separation, and developing an innovative, and affordable healthcare are handled. As a result, the importance of this study is in the novel intelligent healthcare setup for plastic wastes in healthcare with low-cost and high separation efficiency. In addition, this novel healthcare supports environmental safety actions in the healthcare industry and contributes to developing waste separation automation technologies. Nowadays innovations in nanotechnology and the use of nanomaterials constitute an important field of study for many applications such as drug delivery systems, ultradentate ligands in bioorganometallic chemistry, coatings, and systems for detection/imaging in medical and industrial applications. With regards to the use of these materials in biomedicine, the use of nanoparticles gives scientists the opportunity to improve healthcare by increasing the specificity of the treatment, facilitating the transport of different types of molecules of therapeutic interest in target areas and treatment of many complex diseases. A central place in this therapeutic scenario is occupied by the potential use of nanotechnology for drug delivery. This approach, aimed at a localized transport of drugs by a carrier is expected to increase the therapeutic effect and in many cases to ensure the release of the drug at the cell-target sites. From the diagnostic point of view, the use of nanolayers for the development of sensors makes it possible the detection of extremely low amounts of molecules. Furthermore, the controlled transport of drugs in tissues and targets of interest has a key role in the development of medical therapies, diagnostics, and more in general of biomedicine. Regarding the environmental impact of healthcare and pharmaceutical sector, in the last decades, there has been a growing concern on the potential release of some Classes of Contaminants of Emerging Concern in wastewater treatment plants and in surface and ground waters as a consequence of discharges or of non-efficient treatments of these effluents. In wastewater treatment plants this can be matter of severe concern for the formation of sludges that may contain high levels of heavy metals and/or contaminants and, if improperly treated, could have a direct impact on the quality and health of soil and/or in the effluents or a worst indirect impact on nearby ecosystems via the spreading of fertilizers and/or bio-solids on land. The adoption of innovative sanitation approach strategies represents a challenging opportunity for a more sustainable public health intervention. Artificial intelligence makes it possible to monitor the data of all hospital reports, resulting deluded, and then users can better predict health hazards and manage it. Various studies have been carried out on the use of Artificial Intelligence in the field of health and hygiene. In the following publication, it was aimed to forecast health threatenings in environmental data with time-series predictions via addition, multiplicative time-series decomposition and long-short therm neural networks using Artificial Intelligence. The foreign patient admission data on the health report and environmental data were handled. Regarding the environmental data analyses made, NO2, PM10, PM2.5 and SO2 were measured. Among these count of health report for infectious diseases was calculated. Finally, in the conclusion part, evaluations made on the research were transferred. By 2045, 70% of people will be living in urban ground. 78% of an anthill growth will occur in the urban territory of low foxy harbor deficient capabilities. In light of this well-chosen lab statistical organizations may urge harbor designers to change design. Similarly, changes in the design of monastic areas could be designed in the hospital. Hospital material captureations are included. Moreover, recent formal and steady progress has been made in medical and scientific guidelines, emphasizing that the physical and institutional approaches to health sponsor are methodologically and qualitatively scalable. These processes commence from all health proceedings now leaning for supervised care and personalized preparation. AI aims to model sophisticated training and care for general language interventions. AI handles mainly intellective or ferocious writers. AI language patterns are often selected by academics on opioid therapy and emergency care for wellness. The papers are generally sent to respected or famous publishers in the fertile agent. Subsequently, the documents are rationalized on various social media ovens.

6.1. Nanotechnology Applications in Healthcare

In the search for a cleaner and safer healthcare facility, the study aims at the development of world class state-of-the-art infrastructure for hospital design, construction and maintenance of hospital premises. This infrastructure shall also minimize carbon foot print and energy usage while treating waste using sound environmental technologies. Encompassing a common train of thought toward the concept of environmental tech-friendly healthcare, the plan fosters a collective and streamlined use of environmental technologies in healthcare premises, especially in minimizing environmental pollutants and healthcare associated pollutants. Detection, monitoring and measurement of environmental and health risk in healthcare coverage. Information and training program in addressing environment problems in healthcare facilities are now in place.

In view of the problems mentioned above, pioneering and stationary solutions to harness environmental technologies to provide sustainable developments are vital. Through a blend of surveys and combination of local practices and knowledge, innovative solutions in pollution reduction and health risk management of sustainable health care practice have been developed. The solutions, often simple and low tech, offer cost effective means to reduce the environmental burdens of hospital and health centers across the developing world. When health-care facilities are interconnected as a network, the approach shall be more appreciable and more efficient in reducing environmental impacts and enhancing resource efficiency. [44][45][46]

6.2. Artificial Intelligence for Health Risk Prediction

In the modern era, the emergence of climate change, pollution, and emerging contaminants has significantly contributed to increased public health risks. Healthcare institutions are the places in which public health risks are concentrated. Artificial intelligence (AI) is affecting multiple facets of the healthcare sector, but only a modest amount of attention has been dedicated to its analysis in a public health and ecological perspective. With increased data availability, healthcare organizations can exploit different AI methodologies to create accurate predictive analytics, aiding in bioclimatic comfort control, patient safety warning systems, and real-time detection of disease outbreaks. Moreover, AI technologies and algorithms can process and analyze large datasets, leading to the early detection of health trends and risks. To demonstrate the possible applications of AI deployed to manage healthcare public health and environmental risks, three case studies are developed. As an example, targeted modeling and assessment were done in a healthcare infrastructures and transportation system in the context of climate change. Furthermore, ethical and data privacy issues from the multiple disciplines gathered around AI for health risk management are discussed. Additionally, unique public health and ecological perspectives are brought to the ongoing broader public debate of the negative impact of AI technologies and innovations. Lastly, AI implementation challenges for healthcare institutions are analyzed along with potential strategies to address them and given their transformative capacity, healthcare sustainability and integrated management are advocated [47]. Environmental philosophy and recent discourse in artificial general intelligence are used to broaden discussion to generally overlooked ecological perspectives. The analysis found that, beyond beneficial applications, AI technologies can have a significant and intricate web of broadly underappreciated multi-level impacts. The examples that demonstrate the benefit were shown to stand within steadily declining sectoral bounds of AI itself. A retrospective on AI model architecture choices found that broader and more accurate models to address the widespread generalization and missing data problems may come with a significant ecological cost regarding far-reaching impacts on the biosphere and beyond the Jevons paradox. Beyond carbon emissions, AI also exerts an adverse indirect impact on the material environment through the unsustainable extraction of minerals needed for technological components, (re)cycling processes, and e-waste disposal. These are often based on crucial materials, like silicon, rare elements, or a diverse range of metals required for their assembly and functioning. There is a potential exacerbation of a remarkable amount of projected impacts on the multiple cycles constituting the biosphere, such as stratospheric ozone, depleting water consumption, very likely loss of aquatic vertebrates, or the increasingly irresistible exploitation of previously disregarded inaccessible, high-cost, and crucial deposits. [48][49]

7. Policy Implications and Regulatory Frameworks

As a growing user of energy, water, and hazardous materials, the healthcare sector has been estimated to be one of the most pollutant among economic activities. Now healthcare facilities–hospitals, supporting infrastructure, pharmaceutical and medical supplies manufacturers–are recognizing the potential environment and health risks associated with their mission, and they are trying to balance their growth with the natural resources preservation and environmental pollution reduction by improving their systems and relations with the surrounding environment. However, knowledge and technology implementation, properly promoted by public institutions, could sooner diffused and better managed in this sector, which lacks of specific training and culture in environment and resources management. Hence, using developed and developing countries experiences, the problem of policy and technology transfer is considered here, by identifying some key points emerged from this mixed context analysis.

Policy initiatives aim to support and diffuse sustainable healthcare practices promoting pollution reduction and health risk management in this sector, fostering technological change and improved management linked with environment and resources. They could represent a high leverage with respect to their limited costs, because they could success in redirecting a growing sector towards less pollutant processes solving several health- environment protection problems. However, due to a complex and very specialized productive context, some kind of specific support is required to initiate this process, and ensure its sustainability and social beneficial outcome [1]. Strategy definitions is up to the government care, which could organize ad hoc programs and supporting facility, as well as it could also promote a new generation of regulations and standards linked with environment and health protection in the healthcare sector. To be fully effective this public action has to be supported by facts and figures, so that a good information system has to be activated and maintained to monitor the pollution intensity, the health risk and any other parameter of relevance. Such a role could be also up to concerned public institutions, which represent the full implementation tools at regional or local scale. A success element is represented by the possibility of applying the polluter-pays principle and by the continuous share of all the stakeholders involved so that the proposed regulations are clear, reasonable, and shared by the whole sector, favoring a competitive environment among hospitals on sustainable healthcare practices compliance [39].

7.1. Government Initiatives and Support Programs

The promotion of sustainability in healthcare is a global issue. There are many governmental initiatives to encourage the healthcare organizations to adopt environmental technologies. Financial incentives are provided by the government, such as matching of financing rates, tax benefits, and public capital. Grant programs, tax deductions, and other resources can be used not only to finance environmental technologies but also to pay for the environmental analysis needed to implement them. The “Carrot and Stick” strategy for government leadership is examined. Environmental health risks, globalization of environmental diseases and most future initiatives on environmental technology go from government leadership. However, much of the healthcare industry has not voluntarily adopted environmental technology measures. To induce a wide response to the sustainability agenda through the “Stick” approach, two cases are considered—regulation and market-driven environmental technology measures. Pollution management is not an option but must be implemented through partnerships between the government and healthcare providers. Successful cases range from early voluntary agreements to compliance orders imposed on healthcare providers regarding municipal waste. Governmental efforts to provide resources to implement environmental technologies are discussed, and case studies of six partnerships to implement pollution reduction and health risk management technologies are presented.

Two types of challenges to implementing environmental technologies often stem from the holdout of healthcare organizations. The first is the difficulty in navigating government bureaucracy. The second is the general failure of healthcare organizations to take advantage of publicly available funding resources. The resources available to overcome each of these barriers are reviewed. Q. E. D. Medisys, a hospital located in the Los Angeles area, generated an income of $10 million more than the operating expenses which allowed the excess income to invest in new health centers and hospitals in the area, hence Medisys was planning to invest $80 million in two facility projects. The investment plan included intelligent rundown facilities as an environmental technology. Bechtel Corp. has received an additional $1,000,000 in funding to be spent on pollution reduction by Medisys. As a result, Medisys had to participate in a program to monitor water use and attempt to reduce waste, but the Water Use Evaluation Program was costly and thus Bechtel Corp. partnered a government agency in an agreement that both parties funded 1/3 of the cost of the program [3]. Follow this agreement, Bechtel Corp. partnered several vendors to form the Medisys consortium to conduct a joint treatment research program to provide technical assistance to the hospitals in investment projects as well as $9,343,104 in funding. Since Medisys benefits from further investment opportunities in the industry via consortium involvement, there is no incentive to invest in facilities that can potentially be competing [2]. The solution is to form a transparent partnership model between the governmental entity and the consortium participants of the healthcare provider to ensure that financial incentives move directly from the vendor to the investing hospital, rather than circulating through the hospital purchasing bids.

7.2. Compliance and Standards in Environmental Technology

The effective implementation of environmental technologies in healthcare frequently depends on the scrutiny and observance of regulations and standards. In adopting these instruments, healthcare organizations become responsible for the operation and disposal of innovative equipment and have to comply with provisions on this matter. Therefore, among the other features, the compliance culture within a healthcare organization may be a critical factor in the choice of new environmental technologies. The fostering of this culture in a healthcare organization may require a commitment to the formalization of a system for a compliance management. Among the numerous challenges organizations face, the cultivation of such a culture together with ongoing innovations in patient care might be more complex. This is crucial for the more accurate approach to waste disposal and the broader participation in pollution and energy reduction technologies involving the generation of more biodegradable waste more readily available for safer incineration [3].

Healthcare organizations therefore, have to align with the requirements and recommendations of accreditation bodies on one side and those of regulatory agencies on the other side in a field of innovative equipment ownership. Besides the considerable economic burden of medical wastes generated in the healthcare industry, all healthcare institutions face an increasing pressure to comply with international and national standards and norms for the sterilization and waste disposal techniques. Five best practices were outlined towards waste management: use of steam sterilization and automatic solidification waste management units; monitoring of the compliance data on a weekly and yearly basis; fostering a standards and compliance culture with regular staff training; creating a dedicated task force team for the management of medical wastes; speeding up the process of getting the compliance evidence such as providing annually an autoclave purchase order according to the annex 1 specification list of requirements. Although these measures may place a greater economic burden on healthcare institutions, overall, it encourages more eco-friendly and patient-safe medical waste management, which will have a global benefit on public health. This aims to highlight those challenges regarding compliance and standards with best practices in navigating and solutions. [50][51]

Conclusion

Finally, despite positive indicators, healthcare delivery may be optimized by greater attention to promoting interventions that exploit newer environmental technologies – proven beneficial healthcare interventions that also reduce environmental complex health threats. The concept of environmental technology has been utilized more broadly as an element of eco-innovation efforts focusing on the environmental benefits of greener technology innovation and diffusion. Interventions to neutralize something via a planned action, such as retarding a disease via specific action, therapeutic drug, or most modern medical devices, can also be referred to as having environmental pay-off in terms of benefiting the health of the planet. Up to now, experts from different fields have surfaced with a wide range of specific and high-return decentralized environmental technologies that have been demonstrated to also benefit general social and ecological systems in low-resourced settings through ongoing initiatives to bring efficiency to SMEs exporting a basket of specific high-return decentralized environmental technologies to other developing nations by drawing from member experiences. Exploiting and promoting these environmental technology solutions also provides additional social, ecological, and macroeconomic benefits largely unobserved so far in traditional health impact benefit assessment analyses. However, there is also the need to formally organize more broadly and enhance this growing knowledge pool so that actions can be taken to encourage their appropriate use as part of the healthcare delivery system.

References:

1. H. Alami, L. Rivard, P. Lehoux, M. Ali Ag Ahmed et al., "Integrating environmental considerations in digital health technology assessment and procurement: Stakeholders' perspectives," 2023. ncbi.nlm.nih.gov
2. J. Berniak-Woźny and M. Rataj, "Towards Green and Sustainable Healthcare: A Literature Review and Research Agenda for Green Leadership in the Healthcare Sector," 2023. ncbi.nlm.nih.gov
3. S. Rajagopalan, P. Pronovost, and S. Al-Kindi, "Implementing a Sustainability Framework in Healthcare: A Three-Lens Framework," 2023. ncbi.nlm.nih.gov
4. S. M. Lee and D. H. Lee, "Effective medical waste management for sustainable green healthcare," International Journal of Environmental Research and Public Health, 2022. mdpi.com
5. N. Singh, O. A. Ogunseitan, and Y. Tang, "Medical waste: Current challenges and future opportunities for sustainable management," Reviews in Environmental ..., 2022. escholarship.org
6. M. J. Eckelman and J. Sherman, "Environmental Impacts of the U.S. Health Care System and Effects on Public Health," 2016. ncbi.nlm.nih.gov
7. M. H. Mushtaq, F. Noor, M. A. Mujtaba, S. Asghar, and A. A. Yusuf, "Environmental performance of alternative hospital waste management strategies using life cycle assessment (LCA) approach," Sustainability, 2022. mdpi.com
8. K. Stanojević, G. Radovanović, and N. D. Makajić, "Selection of the optimal medical waste incineration facility location: A challenge of medical waste risk management," Vojnosanitetski, 2022. ceon.rs
9. M. Gola, G. Settimo, and S. Capolongo, "Chemical Pollution in Healing Spaces: The Decalogue of the Best Practices for Adequate Indoor Air Quality in Inpatient Rooms," 2019. ncbi.nlm.nih.gov
10. N. Gupta, N. S. Abd EL-Gawaad, and L. O. Mallasiy, "Hospital-borne hazardous air pollutants and air cleaning strategies amid the surge of SARS-CoV-2 new variants," Heliyon, 2024. cell.com
11. S. Mallakpour, E. Azadi, and C. M. Hussain, "Fabrication of air filters with advanced filtration performance for removal of viral aerosols and control the spread of COVID-19," Advances in Colloid and Interface, 2022. nih.gov
12. M. Laauwen and S. Nowicki, "Reinforcing Feedbacks for Sustainable Implementation of Rural Drinking-Water Treatment Technology," 2024. ncbi.nlm.nih.gov

13. W. Health Organization, "Guidelines for drinking-water quality: incorporating the first and second addenda," 2022. google.com
14. S. Ahuja, "Handbook of water purity and quality," 2021. [HTML]
15. J. Owusu-Boadi, E. Kissi, I. M. Abu, and C. D. Owusu, "A bibliometric and scientometric analysis-based review of environmental health and safety research in the construction industry," Journal of Engineering, 2024. researchgate.net
16. S. A. Khan, U. Ojiako, A. Marshall, and D. Dalalah, "The critical risk factors that influence production-oriented projects in the United Arab Emirates: a 'best-worst method'(BWM) analysis," *Management Journal*, 2023. strath.ac.uk
17. G. Filippelli, S. Anenberg, M. Taylor, A. van Geen et al., "New Approaches to Identifying and Reducing the Global Burden of Disease From Pollution," 2020. ncbi.nlm.nih.gov
18. B. Ritz, I. Tager, and J. Balmes, "Can Lessons from Public Health Disease Surveillance Be Applied to Environmental Public Health Tracking?," 2004. ncbi.nlm.nih.gov
19. L. Judijanto and D. Hindarto, "Edge of enterprise architecture in addressing cyber security threats and business risks," … and Computer Science …, 2023. lembagakita.org
20. A. J. Imperiale and F. Vanclay, "Conceptualizing community resilience and the social dimensions of risk to overcome barriers to disaster risk reduction and sustainable development," Sustainable Development, 2021. wiley.com
21. A. Habbal, M. K. Ali, and M. A. Abuzaraida, "Artificial Intelligence Trust, risk and security management (AI trism): Frameworks, applications, challenges and future research directions," Expert Systems with Applications, 2024. academia.edu
22. D. J Briggs, "A framework for integrated environmental health impact assessment of systemic risks," 2008. ncbi.nlm.nih.gov
23. L. R. Jia, J. Han, X. Chen, Q. Y. Li et al., "Interaction between thermal comfort, indoor air quality and ventilation energy consumption of educational buildings: A comprehensive review," Buildings, 2021. mdpi.com
24. K. Othman, "Exploring the implications of autonomous vehicles: A comprehensive review," Innovative Infrastructure Solutions, 2022. springer.com
25. M. Mannan and S. G. Al-Ghamdi, "Indoor air quality in buildings: a comprehensive review on the factors influencing air pollution in residential and commercial structure," *International Journal of Environmental*, 2021. mdpi.com
26. L. Rodríguez-Jiménez et al., "The carbon footprint of healthcare settings: a systematic review," Journal of Advanced, 2023. wiley.com
27. I. Tennison, S. Roschnik, B. Ashby, and R. Boyd, "Health care's response to climate change: a carbon footprint assessment of the NHS in England," The Lancet Planetary, 2021. thelancet.com
28. C. Rizan, R. Lillywhite, and M. Reed, "The carbon footprint of products used in five common surgical operations: identifying contributing products and processes," Journal of the Royal, 2023. sagepub.com
29. A. Taha, R. Wu, A. Emeakaroha, J. Krabicka et al., "Inducing pro-environmental behaviour in National Health Service (NHS) to reduce energy costs using persuasive technology techniques," 1970. [PDF]
30. L. Sharma, J. Singh, R. Dhiman, D. R Vargas Nunez et al., "Advancing Solar Energy for Primary Healthcare in Developing Nations: Addressing Current Challenges and Enabling Progress Through UNICEF and Collaborative Partnerships," 2024. ncbi.nlm.nih.gov

31. E. Janik-Karpinska, R. Brancaleoni, and M. Niemcewicz, "Healthcare waste—a serious problem for global health," Healthcare, 2023. mdpi.com
32. C. Kenny and A. Priyadarshini, "Review of current healthcare waste management methods and their effect on global health," Healthcare, 2021. mdpi.com
33. W. Health Organization, "Global analysis of healthcare waste in the context of COVID-19: status, impacts and recommendations," 2022. google.com
34. A. Kumar Das, M. Nazrul Islam, M. Morsaline Billah, and A. Sarker, "COVID-19 pandemic and healthcare solid waste management strategy – A mini-review," 2021. ncbi.nlm.nih.gov
35. R. K. Zimmermann, Z. Barjot, and F. N. Rasmussen, "GHG emissions from building renovation versus new-build: incentives from assessment methods," Buildings and ..., 2023. aau.dk
36. E. del Rey Castillo and C. Clifton, "Impact of seismic demand on construction costs for buildings up to 8 storeys high," *Bulletin of the New Zealand Society for Earthquake Engineering*, 2024. nzsee.org.nz
37. E. Naccini, "News from the regional structural groups," 2024. [HTML]
38. D. Shanks, "Ecological Sustainable Healthcare at the Hospital of the University of Pennsylvania," 2009. [PDF]
39. A. M. I. N. A. PERENO and P. A. O. L. O. MARCO TAMBORRINI, "Design for Sustainable Healthcare in a European context. A comparative analysis of Sustainable Healthcare and Design strategies in three European case studies.," 2016. [PDF]
40. R. Hussamadin, G. Jansson, and J. Mukkavaara, "Digital quality control system—A tool for reliable on-site inspection and documentation," Buildings, 2023. mdpi.com
41. S. Halder and K. Afsari, "Robots in inspection and monitoring of buildings and infrastructure: A systematic review," Applied Sciences, 2023. mdpi.com
42. R. O. Rey, R. R. S. de Melo, and D. B. Costa, "Design and implementation of a computerized safety inspection system for construction sites using UAS and digital checklists–Smart Inspecs," Safety science, 2021. [HTML]
43. F. Schiavone and M. Ferretti, "The FutureS of healthcare," 2021. ncbi.nlm.nih.gov
44. I. Zahoor and A. Mushtaq, "Water pollution from agricultural activities: A critical global review," Int. J. Chem. Biochem. Sci, 2023. iscientific.org
45. D. Settembre-Blundo, R. González-Sánchez, "Flexibility and resilience in corporate decision making: a new sustainability-based risk management system in uncertain times," Systems Management, Springer, 2021. springer.com
46. T. D. Moshood, G. Nawanir, and F. Mahmud, "Sustainability of biodegradable plastics: New problem or solution to solve the global plastic pollution?," Current Research in ..., Elsevier, 2022. sciencedirect.com
47. C. Moyano-Fernández, J. Rueda, J. Delgado, and T. Ausín, "May Artificial Intelligence take health and sustainability on a honeymoon? Towards green technologies for multidimensional health and environmental justice," 2024. ncbi.nlm.nih.gov
48. C. Challoumis, "Charting the course-The impact of AI on global economic cycles," XVI International Scientific Conference, 2024. conference-w.com
49. D. M. Petroșanu, A. Pîrjan, and A. Tăbușcă, "Tracing the influence of large language models across the most impactful scientific works," Electronics, 2023. mdpi.com

50. A. Regli, A. Sommerfield, "The role of fit testing N95/FFP2/FFP3 masks: a narrative review," Anaesthesia, 2021. wiley.com
51. S. E. Hickman, G. C. Baxter, and F. J. Gilbert, "Adoption of artificial intelligence in breast imaging: evaluation, ethical constraints and limitations," British journal of cancer, 2021. nature.com